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PECHORA RIVERBASIN
INTEGRATED SYSTEM MANAGEMENT

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Pechora River basin Integrated System Management

Towards sustainable forestry in the Pechora Basin: Results of a simulation study.

M.J. Schelhaas, A.L. Fedorkov, I.T.M. Jorritsma,
T. van der Sluis, P. Slim, A. B. Zlotnitskiy

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Acknowledgement

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Summary

The Pechora River basin Integrated System Management (PRISM) project focuses on sustainable management of natural resources in the Pechora river basin. An important aim of the project is to produce a decision support system for the wise use of the ecosystems of the Pechora basin. This system is called the Pechora Knowledge System (PKS). The aim of the PKS is to integrate available knowledge in one platform, to make this information available for policy makers and other interested parties, and to give insight in the future consequences of different decisions that are made now. Simulation models are a useful and effective tool to develop and evaluate different scenarios. Within the PRISM project, a hydrological model, a forestry model and a biodiversity model will be developed and integrated into to the PKS. This report gives an overview of the activities undertaken for the forestry modelling part, the linkage with biodiversity and economy, and the integration of the results in the PKS.

The total forested area in Komi is about 28.6 million hectares, the main part being virgin forest, with very high values for nature conservation and biodiversity. At the same time, more than 30% of the population of the Komi Republic is economically dependent on the forest. Forests are crucial for economic and social development, and a balanced economical development is crucial to maintain biodiversity for the future. Within this project, we explored the possibilities of using the ForGra forestry model to evaluate different forest management strategies in the Pechora Basin and use the outcomes in subsequent analyses of biodiversity and economics.

The five most important tree species in the Pechora basin were parameterised and calibrated against local growth and yield tables. Based on a very broad classification according to vegetation zone, altitude and dominant tree species, and availability of field data, a selection of eight forest types was made that were studied further. Each forest type was subjected to three different forest management regimes: no management, clearcut and selection felling. For the latter management option, some modifications were made to the ForGra model.

The simulation outcomes generally reflected succession patterns as observed in the field and as reported in existing literature. However, some aspects of parameterisation and calibration would need further investigation, particularly the competition between overstory and seedlings/understory trees.

The simulation outcomes were then classified in the same way as the MODIS classification in the PKS and combined with the biodiversity assessment. In this way, we were able to give an indication of the development of the potential number of red list species that could be expected under the different management scenarios. Further, a tool was developed to integrate the simulation results into the PKS. This tool can generate maps of forest type and potential number of tree species for a 100 year period, based on initial forest type, forest age and management regime. In a way similar to the biodiversity assessment, the outcomes of the simulations were analysed in economic terms.

This study demonstrates that it is very well possible to model the development of individual forest types and use the results for subsequent analyses, as demonstrated by the biodiversity and economic assessments. However, the forest model is sensitive to uncertainties in the parameterisation and calibration of the model and thus results should be interpreted with care. Recommendations for further work in this field are included in the report. The link with biodiversity is implemented in a very rough way,

because a detailed analysis of dependencies of species on specific forest characteristics was lacking. However, we demonstrated that this link can be made in a much more sophisticated way, which seems a promising way to continue this kind of work. Also the link with the PKS could be improved, with more options for the user to edit the management maps and with a better classification.

1. Introduction

At the eastern border of Europe, just west of the Ural mountains, the Pechora river flows. With a length of 1809 km and a catchment basin of 288,000 km^2, the dimensions of the Pechora river are somewhat larger as the river Rhine: the length is about 1.5 times of that of the Rhine and the size of the catchment area two times. In contrast to the Rhine, the Pechora is still largely untouched by human influences. The Pechora river is said to be the last virgin river in Europe. All European salmonids are present in the river; the delta is an important breeding area for bird species; the forests and shrublands of this river basin are for a considerable part virgin forest and represent reserves for boreal forests, peat bogs and mountain ecosystems.

The Pechora river flows through the Komi Republic and the Nenets. As in near future strong industrial developments are foreseen, the Committees of Natural Resources in Komi and Nenets have indicated that there is an urgent need for a strategy of the development of the area, at the same time safeguarding the natural wealth which is still present.

In this scope the PRISM (Pechora River Integrated System Management) project was formulated. PRISM is a collaboration project between several Russian and Dutch institutes and focuses on the production of a decision support system for the wise use of the ecosystems of the Pechora basin. This system is called the Pechora Knowledge System (PKS). The aim of the PKS is to integrate available knowledge in one platform, to make this information available for policy makers and other interested parties, and to give insight in the future consequences of different decisions that are made now. Simulation models are a useful and effective tool to develop and evaluate different scenarios. Within the PRISM project, a hydrological model, a forestry model and a biodiversity model will be developed and integrated into to the PKS.

PRISM is divided in 5 clusters, each divided in sub-projects. Cluster B is the ecological cluster, focussing on biodiversity, land use and forestry modelling. It aims at integrating basic knowledge towards interpretation on ecological functioning and processes, with a strong focus on biodiversity. Activities within the cluster aim at increasing the understanding of the inter-dependencies of ecosystem components as well as consequences of human interference for natural ecosystems. The current report gives an overview of the activities undertaken for the forestry modelling part in cluster B.

Forests are an important ecosystem in the Komi Republic. The total forested area in Komi is about 28.6 million hectares, the main part being virgin forest, with very high values for nature conservation and biodiversity. At the same time, more than 30% of the population of the Komi Republic is economically dependent on the forest (Buryan, 2002). Komi already protected 15% of its area, but this is concentrated in the Ural mountains and important forests remain unprotected. Forests are crucial for economic and social development, and a balanced economical development is crucial to maintain biodiversity for the future. Current management will influence the forest for a very long time in future and thus careful planning is needed. Within the current project, we explored the possibilities of using the ForGra forestry model (Jorritsma et al. 1999) to evaluate different forest management strategies in the Pechora Basin. The output of this model can be used to make predictions on forest production, regeneration, changes in biodiversity and economic analysis. The results should give indications for managing the forests in a more sustainable way, but also help in understanding natural processes in undisturbed forests in general. Due to the limitations of time and budget, this study has the character of a pilot study.

Chapter 2 gives a general outline of the forests in the Pechora basin. Chapter 3 focuses on the ForGra model, the parameterisation and calibration process, the selection of input types and the results of the forestry modelling itself. Chapter 4 deals with the integration of the simulation results into the PKS, and how the link with biodiversity is dealt with in the PKS. Chapter 5 gives an economic analysis of the simulation outcomes. The results are discussed in Chapter 6 and Chapter 7 gives recommendations for future work in this area.

2 The Pechora River Basin

2.1 General

The Pechora River Basin is situated in Russia at the eastern border of Europe, just west of the Ural Mountains (Figure 2.1). The Pechora River Basin is situated in the Komi Republic and Nenets Autonomous District. The Pechora River is, with a length of 1809 km, one and half time as long and with a catchment basin of 288,000 km2, twice as large as the river Rhine. The river itself is almost in its natural state, with only one bridge crossing the river and no major river improvement works established (Van Eerden 2000). Only one railway line connects the northern industrial town of Vorkuta with the southern part of the Komi Republic and the Russian hinterland. No roads are present in the north outside the few urban areas.

Figure 2.1. Location of the Pechora River Basin, Russia

The total population is some 632,700 people of which 65 % are of Russian origin (1-1-2001: Buryan 2002). The average population density is low with 1.4 person per km^2 compared to the Russian average of 8.5 person per km^2. The population is concentrated in small towns like Pechora, Ukhta, Vorkuta and Inta. Most of the area however is not inhabited, with occasionally small settlements and villages.

The local population makes a living in forestry, mining, agriculture, fisheries, and the oil industry. Due to recent economic changes many people are unemployed, and resort to illegal fishing and poaching, as only option to acquire some food. Some minor environmental problems are related to exploration of oil, gas, mineral resources, timber, and poaching. Forestry and mineral exploitation (oil, gas, minerals) are important economical activities in Komi. Several processing industries related to these are present in the region, in particular Neusiedler-Syktyvkar, one of the largest pulp and paper factory of Europe. Small scale farming activities, hunting, fishing and haymaking take place, concentrated around existing settlements and villages. Production is mainly for subsistence, since the infrastructure is very limited.

The climate is continental, with extremely low temperatures in winter of 45 - 50° C below zero, in summer on average 17 degrees, with a maximum up to 30 degrees. Rainfall depends very much on the location, varying from 500-550 mm in the tundra zone, 650-750 mm in the taiga zone, to over 1200 mm in the highest parts of the Ural Mountains (Bratsev 2002). One of the characteristic features of the climate in the Pechora basin is irregular changes of wind directions and intensity of winds from different origins. Atlantic cyclones of western directions are very common in this area, especially in the wintertime.

2.2 Forestry in the Pechora Basin

Forest resources
The Pechora Basin is covered with tundra in the north, and taiga in the south (Figure 2.2), forming part of the West-Siberian and North European taiga. The total forest area of the Pechora basin is about 17 million hectares, located in the sub-tundra zone (35.3%), the northern taiga zone (34.1%) and in the central taiga zone (30.6%). Part of these forests have once been harvested, but still large areas can be regarded as pristine forests. The largest world heritage site is located in this territory, with a total area of 3.28 million ha (They can be considered among the most important boreal forests that still exist (http://www.wcmc.org.uk/protected_areas/data/wh/komi.html).

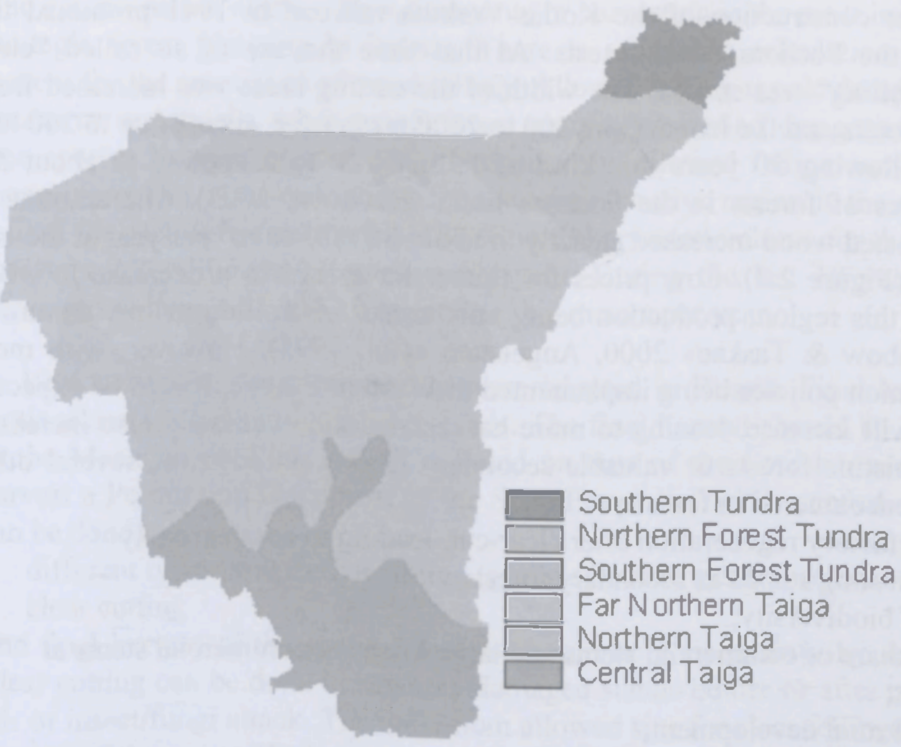


Figure 2.2. Main vegetation zones in the Pechora basin.

Coniferous stands are most common with 85.3%, mostly covered by Siberian spruce (*Picea obovata* Ledeb.) and Scots pine (*Pinus sylvestris* L.) (Table 2.1). Deciduous stands occupy 2.46 million hectares (14.7%), mostly consisting of birch (*Betula pubescens* Ehrh. and *B. pendula* Roth.). The share of overmature and mature forest is high, about 80% and 44% for coniferous and deciduous stands, respectively. Old forests are mainly conifer forests and are located further from transportation facilities and inside protected areas. The share of deciduous species is higher in young stands located in old felling sites. The total volume of exploitable forests in Pechora basin today is 685.9 million cubic meters (Forestry and forest resources of the Komi Republic, 2000).

Table 2.1. Distribution of stands according to tree species in the Pechora basin (% of total forest area) (Bobkova, 2003).

Common name	Scientific name	% of area	Common name	Scientific name	% of area
Siberian spruce	*Picea obovata* Ledeb.	63.9	birch	*Betula pubescens* Ehrh. and *B. pendula* Roth.	13.9
Scots pine	*Pinus sylvestris* L.	18.9	aspen	*Populus tremula* L.	0.3
Siberian fir	*Abies sibirica* Ledeb.	1.4	willow	*Salix* ssp.	0.4
Siberian larch	*Larix sibirica* Ledeb.	1	alder	*Alnus incana* (L.) Moench.	0.1
Siberian pine	*Pinus sibirica* Du Tour	0.1			
Total conifers		**85.3**	**Total broadleaves**		**14.7**

Forest exploitation

Komi Republic is one of the most forested areas of Russian Federation. Small-scale industrial exploitation of forest in Komi Republic started already at the end of the 17th century (Larin and Pautov, 1989). Substantial forest exploitation started during the 20th century. For example, the British company "Stella Polare" exported during 1903-1915 every year about 50 thousand cubic meters of sawn timber from the Pechora basin. Also the construction of the Kotlas-Vorkuta railroad in 1941 promoted the harvesting in the Pechora basin forests. At that time the use of so called "clear concentrated felling" was started. The width of the cutting areas was increased from 100 to 1000 meters and the length from 200 to 2000 meters (i.e. sizes of up to 200 ha). During the following 50 years this kind of felling has been applied to about 3.2 million hectares of forests in the Pechora basin (Bobkova, 2003). The amount of annually harvested wood increased steadily to about 26 million m^3 per year at the end of the 1980s (Figure 2.3). Low prices for timber have lead to a decrease in wood demand from this region, production being only some 5.5 million m^3 per annum at present (Kozubow & Taskaev 2000, Angelstam et al. 1995). However, with more strict conservation policies being implemented in Western Europe, it is to be expected that demand will increase, leading to more harvesting, and eventually also increased pressure on pristine forests or valuable secondary forests. In addition, several other problems are encountered in forestry:

- unsatisfactory regeneration after clear-cut, leading to commercially uninteresting stands as secondary forests;
- loss of biodiversity;
- small share of commercial stems and large losses of commercial stems at harvest;
- limited rural development;
- illegal logging

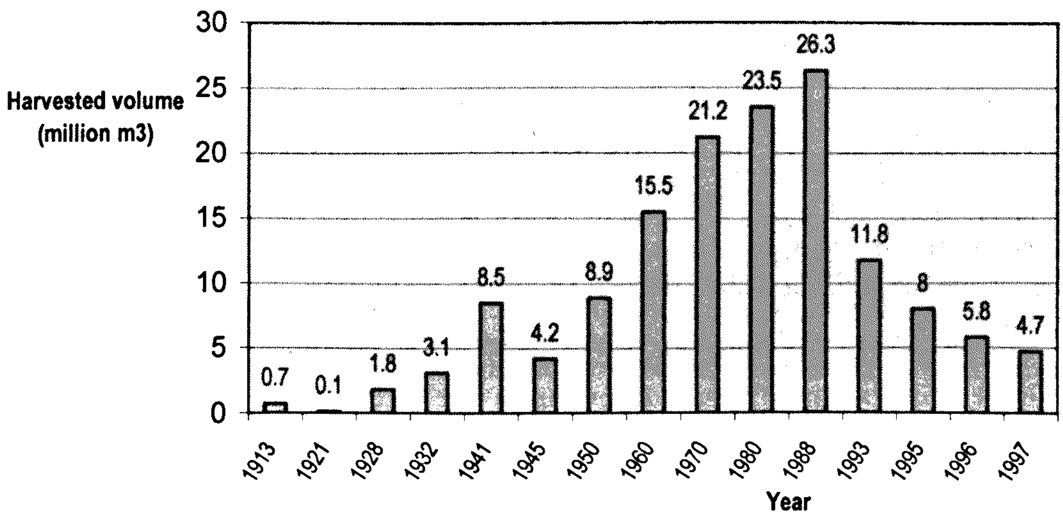


Figure 2.3. Harvested timber volume in the Komi Republic (Kozubow & Taskaev 2000)

Management of forest resources

According to the Russian administration system forests are divided in so called management groups. Group I includes protected forests such as pre-tundra forests, forests along spawning rivers and national parks and occupies about 57% of forested area. The forest in the group III are so called exploitable forests and occupy about 33% of forested area. The main function of group III forests is wood production, but part of the group III forests is also under the special protection. This part consists of genetic reserves, water protection belts etc. The allowable felling applies only to forests in group III.

The determination of the allowed amounts of harvesting is the most important issue of strategic forest planning in Russia. There is a specific calculation and evaluation system for the amount of allowed felling. Allowed felling is calculated for each forest enterprise separately, whereby all forest groups, protection categories and dominant tree species have to be taken into account. The allowed felling can not exceed the mean increment. Allowed felling for the administrative region is the sum of allowed felling for each forest enterprise. The allowed harvested volume for the Pechora basin forest is 7.2 million cubic meters per year. During the last 10 years the actually harvested volume was 0.8-2.0 millions cubic meters per year.

In 1994 new rules for clear cutting were adopted in Russia. Final harvests or main cuttings are carried out in mature stands. The final harvest should be done according to the Management Plan, which is based on data of the Forest Inventory. For final harvest a Permission Document of the State Forest Service is needed. A final harvest can be done by:

- different types of selective cutting (group selection system, selection felling etc.)
- clear cutting

The final harvest of the group I forests should be done **mainly** by selective felling. Clear cutting can be done in severely damaged stands before or after mortality due to fair or insect/fungi attack. The maximum allowed size for clear fellings is 10 ha. Final harvest of the group III forests can be done both by clear and selective cutting. The maximum size of clear fellings for this group is 50 ha. To promote (natural) regeneration of clear felled areas there are different operations such as:

- young trees should be left
- seed trees should be left
- soil scarification
- fencing
- supplementary planting

Forest protection

There are several large protected areas within the Pechora River Basin: in total 6 million hectares or about 14 % or of the Komi territory is protected area. The largest reserves are situated in the Pechora basin: the Yugyd Va National park 1.9 million ha, established in 1993, and recently approved as a UNESCO Man & Biosphere Reserve, and the Pechora-Ilyich Zapovednik, which was established in 1930 and measures, with buffer zone, over 1 million ha (Degteva 2002). In addition, the riparian zone of all rivers is protected up to 1 km from the main river or 500 m for smaller tributaries. This means that in principle no human activities such as building, industry and forestry are allowed in this zone. In practice however, this is not entirely implemented, although no large-scale forestry is found. The Siberian pine trees is under special protection of the regional government and harvesting trees of this species is restricted.

3 Modelling of forest development

3.1 FORGRA

Introduction

The FORGRA model has been developed to study the impact of large ungulate grazing on forest development. An application of the model to an area in The Netherlands is described in Jorritsma et al. (1999). For the current project, only the forest development module of the model was used, excluding the effects of grazing. Some small modifications were made to the model to adapt it to the purposes of the current study. Parts of the following text is taken from Jorritsma et al. (1999).

The main principles of FORGRA are similar to other forest succession models and follow the JABOWA/FORET approach (Botkin et al., 1972; Shugart, 1984). In such models, individual trees are placed in small plots and forest succession dynamics is estimated by averaging data of several plots of varying stages of development. The plot size is usually derived from the smallest regeneration unit, namely the crown size of a single mature tree. The name `gap model' for this type of models refers to this unit. Tree dynamics are described by regeneration, growth and mortality of individual trees and cohorts of seedlings. In FORGRA, it is assumed that light is the main driving force in the processes of growth, regeneration and mortality.

The simulation model presents results on forest development expressed in time scales of decades to centuries. Based on data relating to growth, reproduction and mortality of individual trees in plots, the sequence of replacement of species is, in the long run, described by the average dynamics of several plots. Earlier gap models proved to predict forest succession in a sufficient way (Dyer and Shugart, 1992).

Growth

In FORGRA, individual trees are modelled, located in plots of 20*20m. The maximum amount of trees per plot was increased from 300 to 1000 for this study. For each tree several characteristics are followed over time, such as species, height, diameter, crown radius and height and biomass weight of different parts of the tree. The crown biomass of all trees in a plot is distributed over layers of 1 meter. The monthly incoming radiation is distributed over the individuals according to their biomass share in each layer. Part of the incoming radiation is absorbed and part is passed through to the next layer. In the version of FORGA as used by Jorritsma et al. (1999), all plots were independent from each other. The consequence of this approach was that shading effects of surrounding plots were not taken into account. A clearcut of 1 ha would yield the same (light) conditions as a gap of 20*20m, while in reality the small gap would receive less light. Therefore, in the current version, a weighted average is taken over all surrounding plots, where the relative weights of each plot can be set by the user. The amount of incoming radiation is averaged with the surrounding plots at the height of the highest leaf layer in the plot. If the trees in the plot are taller than in the surrounding plots, the amount of available radiation will be unchanged. If the surrounding plots have taller trees, part of the radiation is already absorbed in those plots, and the averaged amount of radiation will be reduced, thus simulating shading effects from neighbouring plots.

Biomass increase of a single tree is obtained by calculating the amount of light absorbed, multiplied by a species-specific radiation-use efficiency (RUE, Monteith, 1977), thereby implicitly accounting for limitations in water and nutrient supply. Newly formed biomass is partitioned to the different plant organs according to a seasonal species-specific pattern, derived from observed biomass distributions. The partitioning of biomass to the roots, however, is also depending on site conditions. Height increment is imposed, its maximum depending on the tree species, site conditions and actual tree height. Height increment is reduced when too little biomass is partitioned to the stem to meet the imposed height increment. Increment of diameter is derived from stem biomass and tree height, assuming a cone-shaped stem form.

Regeneration

Seed production is calculated for each individual tree, the amount depending on species, age and mast year. Incoming seeds mainly come from trees in the plots although seeds can immigrate from elsewhere (the `blue jay effect').

The number of newly incoming trees results from the number of sound seeds in a plot and the light availability at the forest floor. Seedling growth is depending on a species-specific relative growth rate, which is reduced when light availability decreases. As with adult trees, newly formed biomass of the seedlings is partitioned to the plant organs according to a species-specific pattern and height increment is imposed. Initially, new seedlings are not described as individuals, but as cohorts. When height or age of a cohort exceeds a critical value (respectively 1 meter and 2 years), new individuals are added to the plot. Mortality of seedlings, caused by competition for light and space, is related to total seedling biomass in a plot.

Mortality

Mortality of an individual tree may result from various causes, such as from competition, aging or from large-scale disturbances as windthrow, fire, or prolonged drought. These processes can be modelled by relating the probability of a tree dying from one of these causes to some tree characteristics as growth rate, or the height-to-diameter ratio. In gap models, such as those described by Shugart (1984), these relationships are typically taken from silvicultural literature. In the model application as described in this report, three types of mortality are taken into account: competition, aging and instability. Competition for resources leads to reduced growth. Therefore, mortality due to competition is in the model related to the diameter growth rate. The minimum required growth rate can change with the actual tree diameter. A tree will die when the minimum required growth rate has not been reached for a certain number of successive years, as defined by the user. In this way, it is implicitly assumed that when growth rate is below a certain threshold level, maintenance cost exceeds the amount of sugar produced by the foliage, and the tree dies. All trees are assigned each year a mortality probability due to age, according to a function as set by the user. The shape of this function will generally increase with age, to a value of 1 when the maximum age is reached. Instability of a tree is judged by the ratio between height and diameter. If the height (in meters)/diameter (in cm) ratio exceeds 1, the tree will be assigned a mortality probability, which increases to 1 when approaching the maximum H/D ratio possible.

Harvest

For this application of the FORGRA model, an extra harvest option was built in. Each plot can be harvested once, where the exact year can be defined by the user. Also a minimum harvest diameter can be defined. All trees lower than this diameter will be untouched. This diameter limit is valid for all tree species. Additionally, the user can specify the fraction of seedlings present on the plot that will be destroyed due to the harvest activities.

3.2. Parameterisation, calibration and testing

3.2.1. Initial datasets

In this pilot study, only the three most important tree species are parameterised individually: Scots pine (*Pinus sylvestris* L.), Siberian spruce (*Picea obovata)* and birch (*Betula pubescens* Ehrh. and *B. pendula* Roth.). The parameterisations of Jorritsma et al. (1999) were taken as a basis, where Douglas fir (*Pseudotsuga menziesii)* was taken as a basis for Picea obovata. For all species, values were replaced by (local) literature data whenever available. In the final simulations, Siberian fir (*Abies sibirica)* was assigned the same parameter set as Picea obovata and Siberian larch (*Larix sibirica*) the same parameter set as Pinus sylvestris, except for the turnover of foliage. All parameter values that are used in the final simulations are listed in Annex 1.

3.2.2. Calibration of individual species

Values for the radiation use efficiency (RUE) and diameter-dependent mortality are calibrated manually against growth and yield data (Northern Forest Research Institute, 1986). For Pinus sylvestris, site class 4 is taken as reference, for birch site class 3 and for Picea obovata site class 4. For Abies sibirica no yield tables were present, so the same values as Picea obovota are used. The calibration was done species-wise by initialising the area with monocultures of various ages. Simulations were done for 100 years, without the possibility of regeneration. The performance of the parameter set was tested against the development of volume, basal area and stem number per hectare over time. Since the FORGRA model works with gross increment and the yield tables show net increment, we set the RUE at such a level that the increment was about 20-25% higher as in the yield tables. Then, we adjusted the diameter-dependent mortality so that a fit as good as possible was obtained for all simulations starting at different ages. In reality, increment will decrease at higher tree ages. However, in the current model, no such process is present, which could lead to deviations (overestimates) at higher ages. Therefore, it is almost impossible to obtain a good fit for all variables over time. The variable growing stock is given the highest priority for goodness of fit. In Figures 3.1 to 3.3, the results of the calibrations are shown for Scots pine, Siberian spruce and birch. For Scots pine, the development of growing stock and basal area until an age of about 150 years is more or less satisfactorily. At higher ages, the model overestimates the development of both variables. The simulated number of trees is comparable to the yield table, only the simulations starting with seedlings and at age 30 show a too high number of trees per hectare. The simulations for Siberian spruce are satisfactorily for all three examined variables. However, starting with seedlings or at age 30 yield the largest deviations as compared to the yield table. For birch, the development of all variables seems to be more or less satisfactorily at initial ages of 50 and higher. At lower initial ages the model overestimates the amount of trees and underestimates the growing stock volume and basal area. In general, the model seems to have difficulties to follow the patterns from the yield table when starting at low ages or with seedlings. Especially the increment seems to be too low, which leads to a too low growing stock and a too low basal area. This is partly compensated by a too high number of trees that stay alive.

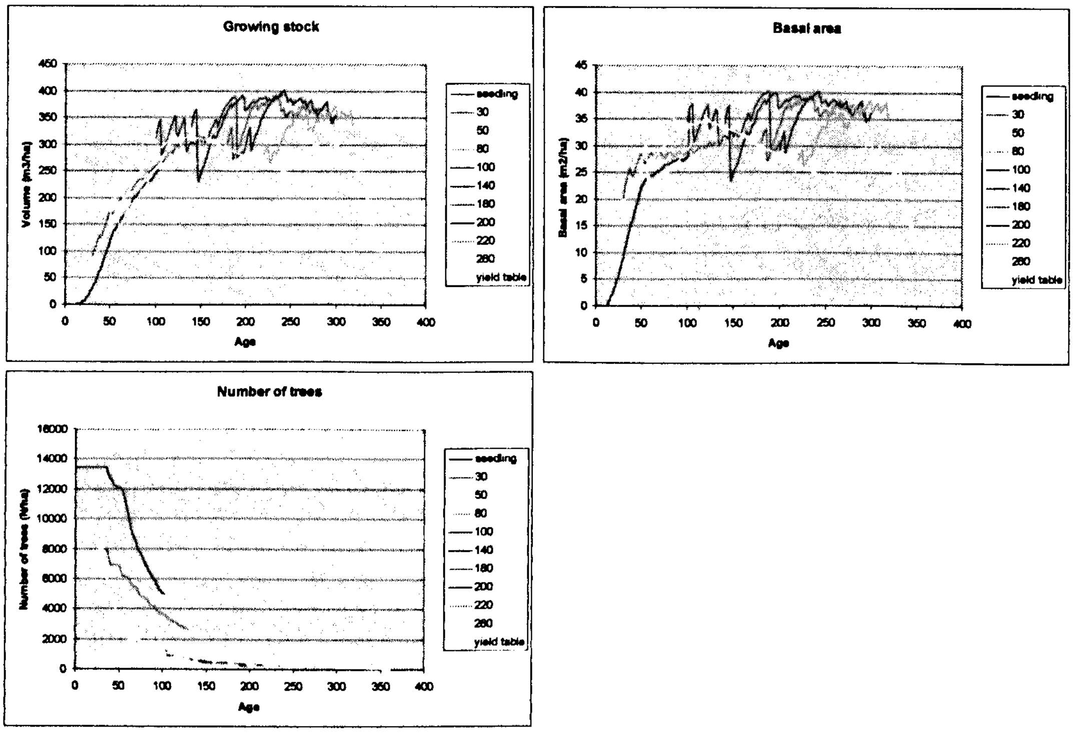


Figure 3.1. Calibration results for Scots pine against the yield table. Each line represents the development over time of a monoculture with a different initial age.

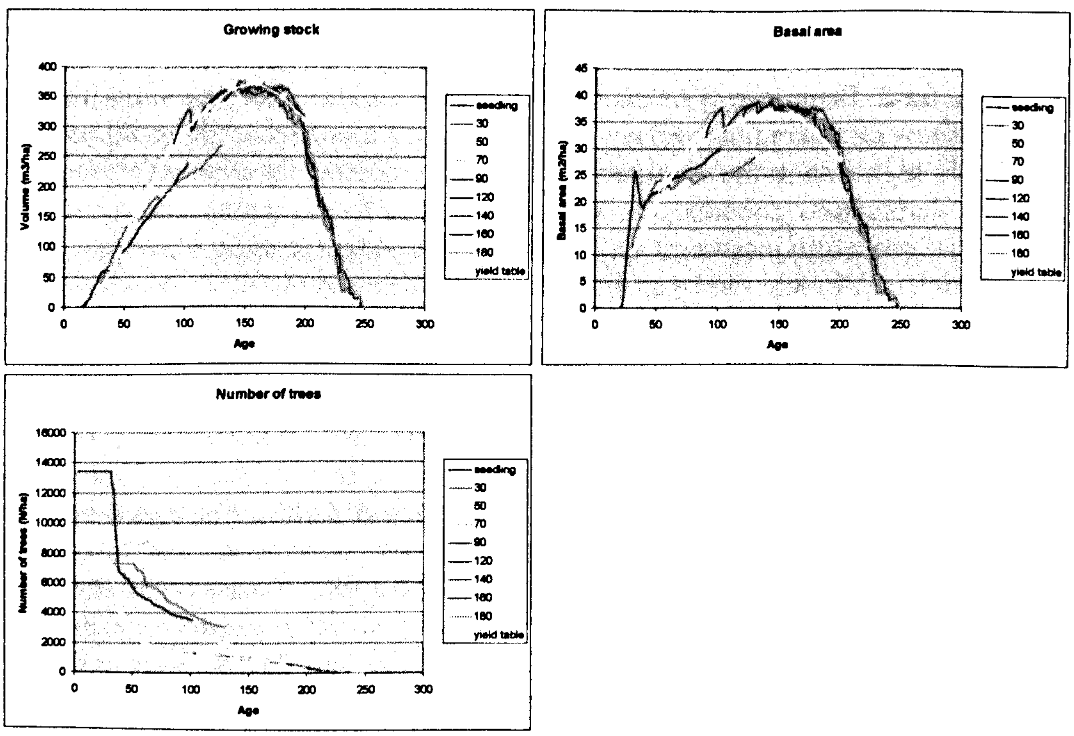


Figure 3.2. Calibration results for Siberian spruce against the yield table. Each line represents the development over time of a monoculture with a different initial age.

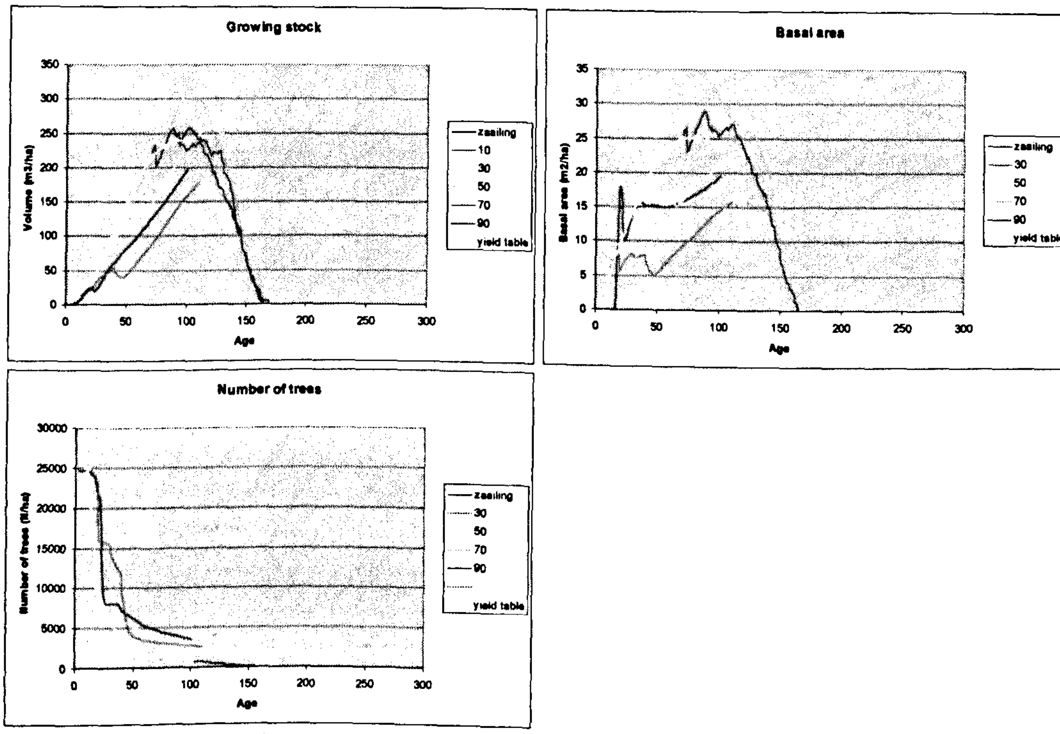


Figure 3.3. Calibration results for birch against the yield table. Each line represents the development over time of a monoculture with a different initial age.

3.2.3. Testing competition of combinations of two species

As a next step, combinations of species are simulated to test mutual competition. For this purpose, the same starting situations as for the calibration are taken. The only addition is a dense seedling layer of another species. Further, regeneration of both species is made possible, to be able to test if seedlings of the overstorey species will outcompete the established seedlings. It also facilitates the establishment of seedlings from seeds from outside, to replace the seedlings that die. These situations were also simulated for 100 years. Development patterns with regard to growing stock volume are evaluated against expectations/observed behaviour in the field.

3.2.3.1. Combinations of seedlings

The first situation for all test combinations is the situation with seedlings of two different species. Figure 3.4 shows the development of the growing stock for each possible combination. The combination of pine and birch seedlings yields a plausible result. Both species survive and grow up together. However, the share of pine in the stand tends to decrease after 70 years, which might not be realistic. The combinations of spruce with pine or birch do not give results that might be expected. In both cases, the spruce cannot compete and birch or pine dominates the stand. In reality, pine and birch will probably be able to grow ahead of the spruce for a certain time span, but eventually the spruce would dominate the stand.

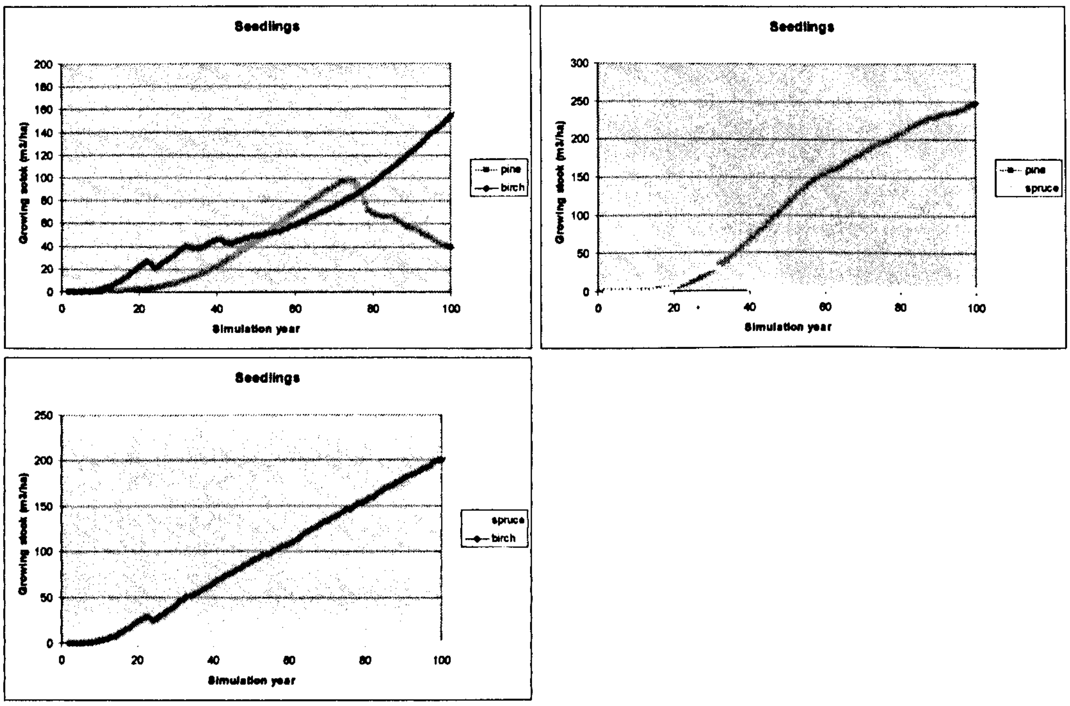


Figure 3.4. Development of growing stock when combining seedlings of different tree species.

3.2.3.2. Birch overstorey

Generally, birch is a species that transmits a lot of light. Therefore, we would expect the other tree species to be able to grow under an overstorey of birch, at least for spruce. This is confirmed by the growth and yield tables, which show an example of a birch stand which is gradually invaded by spruce. However, if we look at the results of the simulations (Figure 3.5), we see that until an age of about 110 years, spruce is not able to get a share in the stand's growing stock. Only when the birch stand starts to degenerate the spruce is able to invade the birch stand and eventually takes over the dominance. Pine shows the same pattern as spruce (Figure 3.6), but starts some 20 year later. This is consistent with the fact that spruce is a shadow-tolerant species. However, we would have expected the spruce to start growing already much earlier. Part of the explanation might be found in the very high number of birch trees per hectare. This was derived from the yield tables, but in the field plots such a high number per hectare was never encountered. Therefore we also did some tests with lower birch densities, which gave more satisfactorily results. The observed patterns for the understorey species were the same as in Figure 3.5 and 3.6, but the onset of the increase was 20 to 40 years earlier.

and to a lesser extent birch would be able to grow under a pine canopy is not met. Also here the high density of pines might play a role.

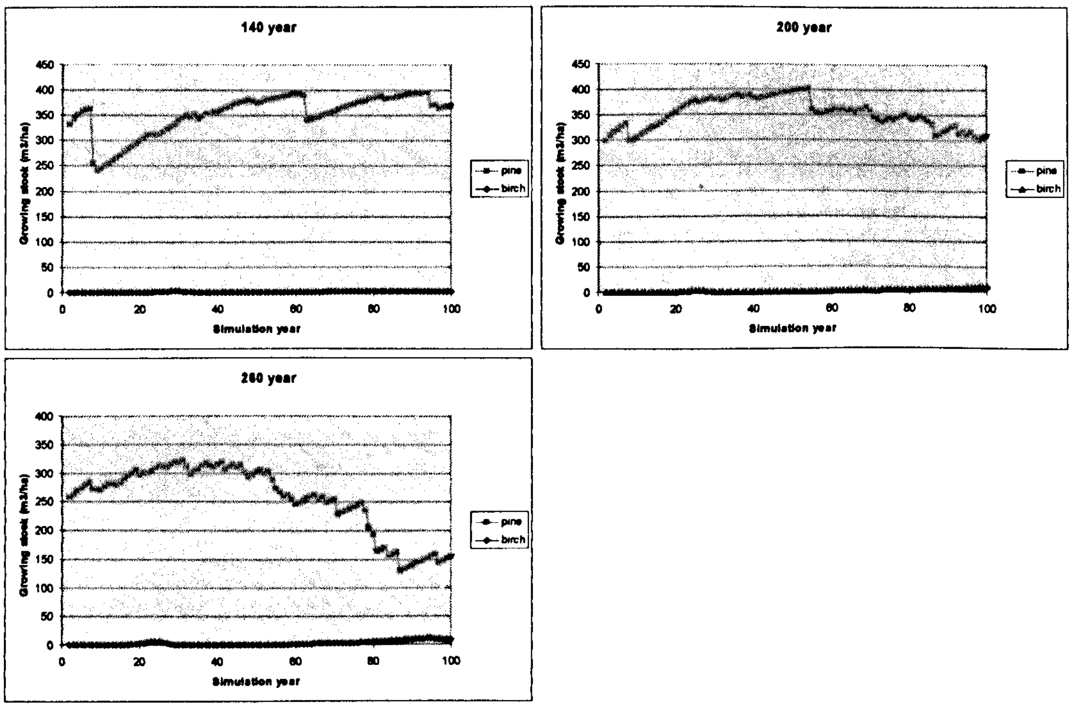


Figure 3.7. Simulation of pine stands with various initial ages and a seedling layer of birch.

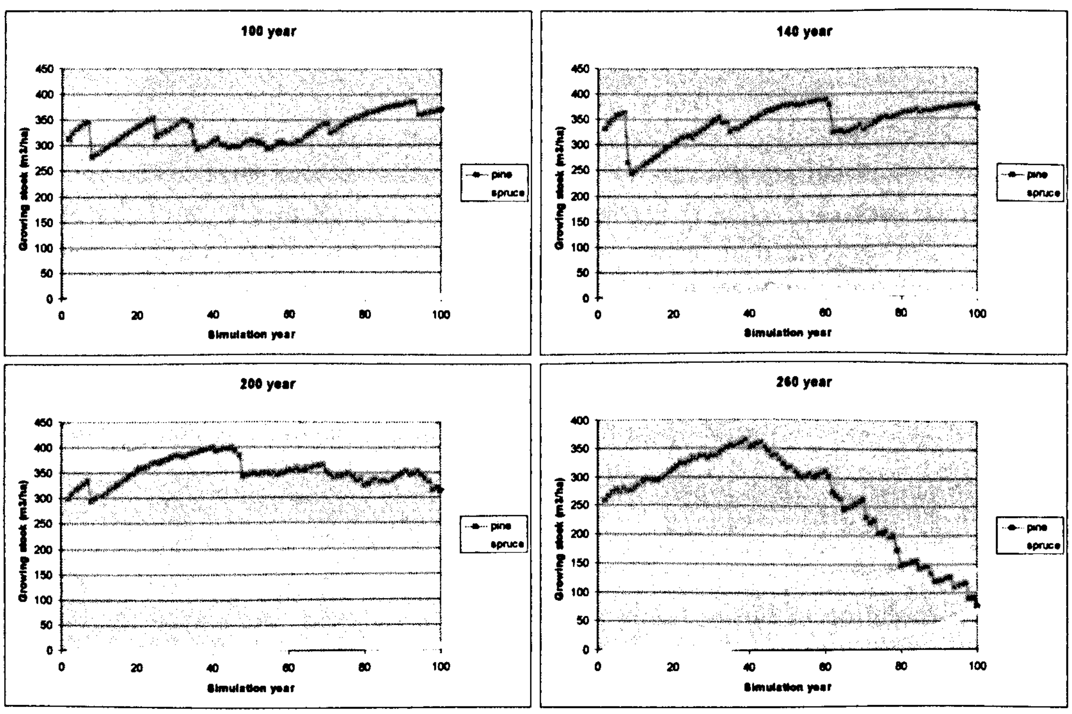


Figure 3.8. Simulation of pine stands with various initial ages and a seedling layer of spruce.

3.2.3.4. Spruce overstorey

Spruce is a climax species, and will only be replaced by other species through disturbances that kill many spruces, such as fire or windthrow. We would expect for both pine and birch that they will not be able to invade a closed spruce stand. This is confirmed in the simulations (Figures 3.9. and 3.10.), where the share of both species is neglible.

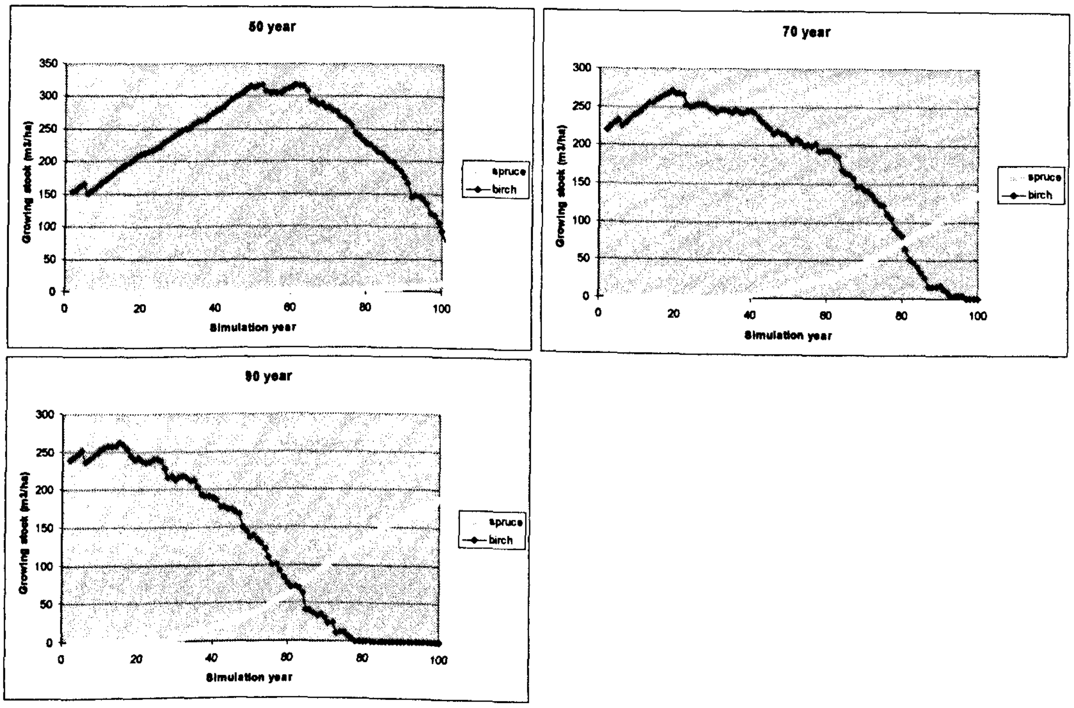


Figure 3.5. Simulation of birch stands with various initial ages and a seedling layer of spruce.

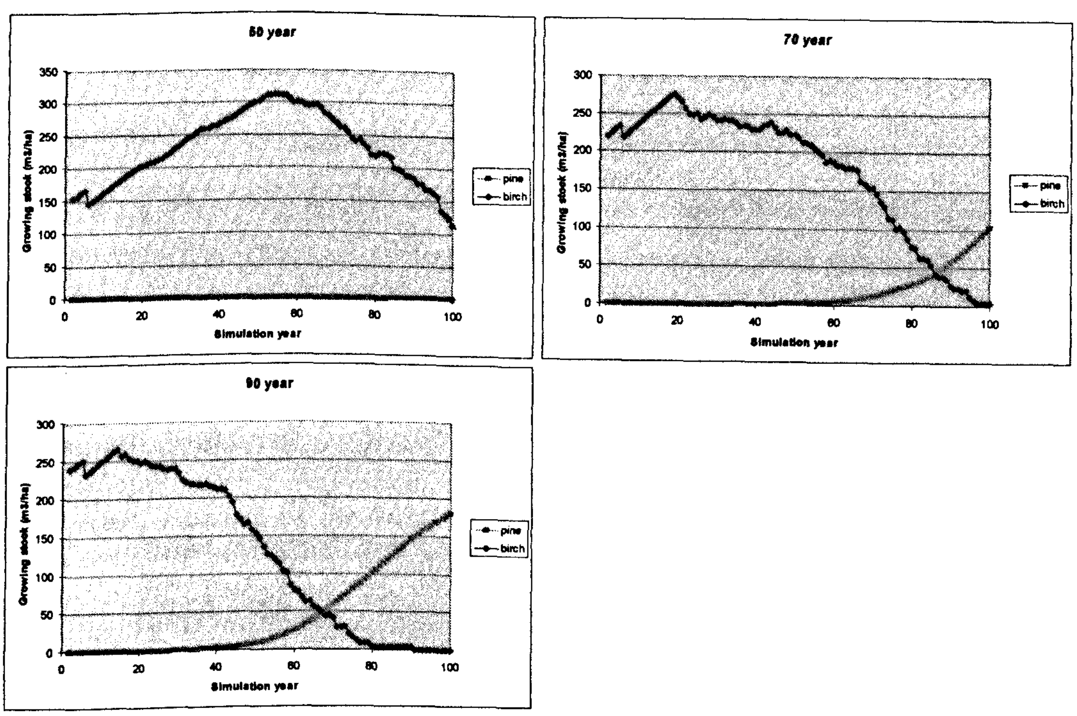


Figure 3.6. Simulation of birch stands with various initial ages and a seedling layer of pine.

3.2.3.3. Pine overstorey

Generally, the pine canopy also transmits relatively much light, especially at higher ages. Therefore, we would expect both spruce and birch to be able to establish regeneration under a pine canopy. Figure 3.7. shows the development of a pine-birch combination. We see in all simulations, reaching until an age of 360 year, that birch is not able to get a reasonable share in the total growing stock of the stand. In Figure 3.8. we see that only in the last simulation spruce is able to increase its share in the stand, probably facilitated by the degeneration of pine. However, the expectation that spruce

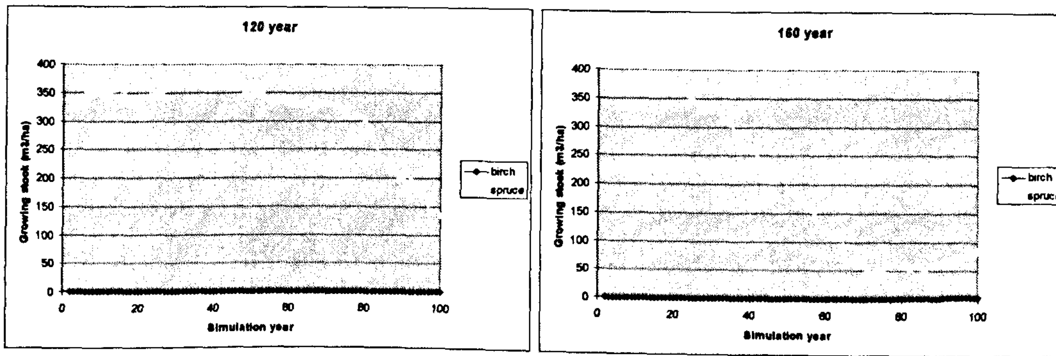


Figure 3.9. Simulation of spruce stands with various initial ages and a seedling layer of birch.

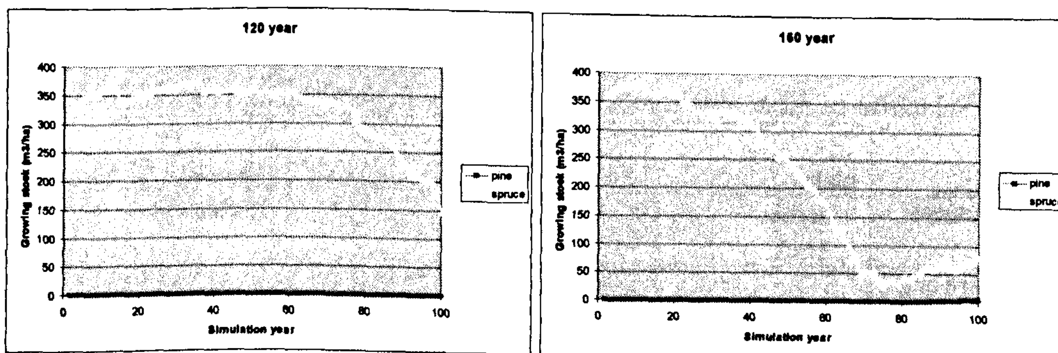


Figure 3.10. Simulation of spruce stands with various initial ages and a seedling layer of pine.

3.3.4. Testing of regeneration

The previous tests with seedlings all assumed an established seedling layer. In order to test the establishment process, we created an initial situation of three mono-species plots with mature individuals (120 years old) of all three species, and 22 plots without any trees. The mature trees provide seeds for the regeneration and are harvested after 20 years. Birch has very light seeds which are dispersed easily. This is very apparent in the development of the number of trees over time (Figure 3.11.). The other two species only have a very small share in the total number of species, but they do regenerate. Because of the large number of seedlings, birch dominates the growing stock until 100 years. Birch is a typical pioneer species, and therefore its dominance is plausible. However, the share of pine and spruce is very small, much less than could be expected. Especially spruce should be able to invade the birch stands and get at least a reasonable share in the total.

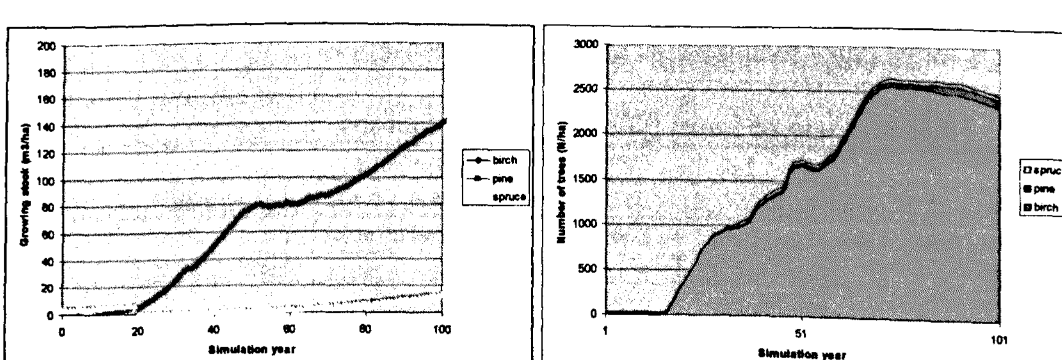


Figure 3.11. Simulation of spontaneous regeneration of Scots pine, spruce and birch.

3.4. Simulation set-up

3.4.1. Selection of forest types

For the final simulations, a set of representative forest types was needed. However, the Pechora River Basin is a very large area with a high diversity of biotic and abiotic conditions, leading to a multitude of forest types. For this pilot study only a limited set of forest types could be simulated. In order to still cover an area as large as possible, a very broad classification was needed. Another demand was that the selected forest types could be linked with the other maps in the PKS, like the MODIS classification, soil maps and the digital elevation model (DEM). Firstly, the vegetation zones as shown in Figure 2.2. were combined with three elevation zones: plains (<200m), pre-mountains (200-400m) and mountains (>400m). Since forest is only present in the three taiga zones, this yielded nine areas. For each of these nine areas the most abundant forest types were listed, based on regional field experience (Table 3.1). This yielded a total of 21 forest types.

Table 3.1. Selection of most abundant forest types by vegetation and elevation zone.

		elevation zone		
		plain	pre-mountain	mountain
vegetation zone	far northern taiga	1. spruce 2. birch	3. spruce 4. birch	no forest
	northern taiga	5. pine-lichen 6. pine-sphagnum 7. spruce-haircap 8. spruce-greenmoss 9. birch-haircap 10. birch-greenmoss	11. spruce-mix with fir-herb 12. spruce-mix with fir-greenmoss 13. birch-herb	11. spruce-mix with fir-herb 12. spruce-mix with fir-greenmoss 14. spruce mixed with larch
	central taiga	15. pine-lichen 16. pine-sphagnum 17. spruce-greenmoss 18. birch-haircap	15. pine-lichen 16. pine-sphagnum 19. spruce-mix with fir-herb 20. spruce-mix with fir-greenmoss	19. spruce-mix with fir-herb 20. spruce-mix with fir-greenmoss 21. willow-birch

However, not all of these types were visited during the field expeditions, so for some forest types no initial situation could be created due to a lack of data. Furthermore, from the field data it appeared that some forest types were very similar in terms of forest structure. Since the ground vegetation is not taken into account in the simulations, these forest types were considered as one type. After this second selection, 8 forest types remained, as shown in Table 4.2.

Table 3.2. Final selection of forest types for the simulations.

		elevation zone		
		plain	pre-mountain	mountain
vegetation zone	far northern taiga			
	northern taiga	5. pine-lichen 8. spruce-greenmoss		
	central taiga	15. pine-lichen 17. spruce-greenmoss 18. birch-haircap	15. pine-lichen 19. spruce-mix with fir	20. spruce-mix with fir

3.4.2. Selection of field plots for initialisation

During the field expeditions of 2002 and 2003 (see Figure 3.12, Van der Sluis 2005), respectively 14 and 57 forest plots were measured. At every plot general characteristics were recorded, such as dominant species and signs of natural or human disturbances. Furthermore, from all individuals higher than 0.5 meter, diameter at breast height (DBH) and height were measured and the species was recorded. For some trees the age was recorded as well, usually based on tree ring counts. In 2003, also the height of the crown base was measured. Furthermore, in 2003 the number of seedlings present on the plot were counted, split per species and approximate age class. The plot size in 2002 was 300 m^2, while in 2003 it was reduced to 100 m^2 for practical reasons

Figure 3.12. Location of field work areas; data was collected in the Pechora Delta, Bolshaya Sinya and Upper Pechora

All field plots that corresponded with one of the forest types from Table 4.2 were selected. From these, all plots that were described as being undisturbed were selected to serve as basis for the initialisation of the simulation runs. However, for birch also disturbed sites were selected, since birch usually only dominates at disturbed sites. All available plots for the pine lichen type in the pre-mountain zone in the central taiga had been subjected to selective felling, so also here the undisturbed criterion was left out. Table 3.3 shows the plots that were selected for the initialisation of the different forest types.

Table 3.3. Field plots used for initialisation of the different forest types.

elevation zone	vegetation zone	forest type	year	plot numbers
plain	northern taiga	pine-lichen	2002	6 and 7
		spruce-greenmoss	2002	8, 10, 11, 13, 18, 19, 22 and 24
plain	central taiga	pine-lichen	2003	212, 213, 215 and 226
		spruce-greenmoss	2003	120 and 140
		birch-haircap	2003	115, 121, 126, 127, 2051 and 218
pre-mountain	central taiga	pine-lichen	2003	404 and 406
		spruce-mix with fir	2003	413, 481, 422, 450, 451 and 452
mountain	central taiga	spruce-mix with fir	2003	305, 310, 313, 315, 316, 317, 319, 320 and 322

3.4.3. Initialisation procedure

3.4.3.1. General

For all forest types, an area of 4 ha was simulated, consisting of 10x10 pixels of 20x20 m. For each forest type only a few field plots were available, so we needed to generate an artificial initial situation based on the plot characteristics. Moreover, since the size of the field plots (300 and 100 m^2) did not match the pixel size of the model (400 m^2), we had to develop a procedure to scale the field plots to the required size. For the forest types that were based on the 2002 field plots, each of the 100 pixels was given the characteristics (trees and seedlings) of a randomly chosen field plot of that forest type. Moreover, each of the trees in that field plot received a 33% chance to be added to the pixel. The number of seedlings per cohort was simply multiplied with 1.33. For the forest types that were based on the 2003 field plots, each pixel got randomly the characteristics (trees and seedlings) of four of the field plots for that forest type. The number of field plots per forest type is low, but in this way at least some (artificial) variation is introduced.

3.4.3.2. Missing variables

The FORGRA model needs some initial tree characteristics that were not available from the field data for all trees and/or plots. Only for a few trees the age was assessed during the inventory, and for the 2002 plots the height of the crown base was missing. The height of the crown base was assumed to be depending on tree height: 60% for birch, 50% for pine and 20% for spruce. For the age of the trees, we fitted a regression line of age on diameter for those trees where age was measured. We chose diameter as explanatory variable, since diameter keeps increasing with age, whereas tree height tends to stabilise at higher ages. Since not many observations on age were available for each zone separately, observations were pooled for all zones. On the resulting dataset, a linear regression was done. For all data points, the relative error between the observed and estimated values were assessed, and it was concluded that most of the data were in a range plus or minus 50% of the observed value. However, this was not valid for small diameters, but for those diameters a few years deviation is already more than 100%. We assumed that the 95% confidence interval was between plus and minus 50%. We also assumed that the residuals were normally distributed. So, for each individual where the age was not known, we estimated the age according to the tree species and the regression lines as given in the Figures 3.13 till 3.15. Additionally a random number from a normal distribution with mean 0 and standard deviation of 0.25 was drawn, and multiplied with the estimated age to simulate the variability as found in the data.

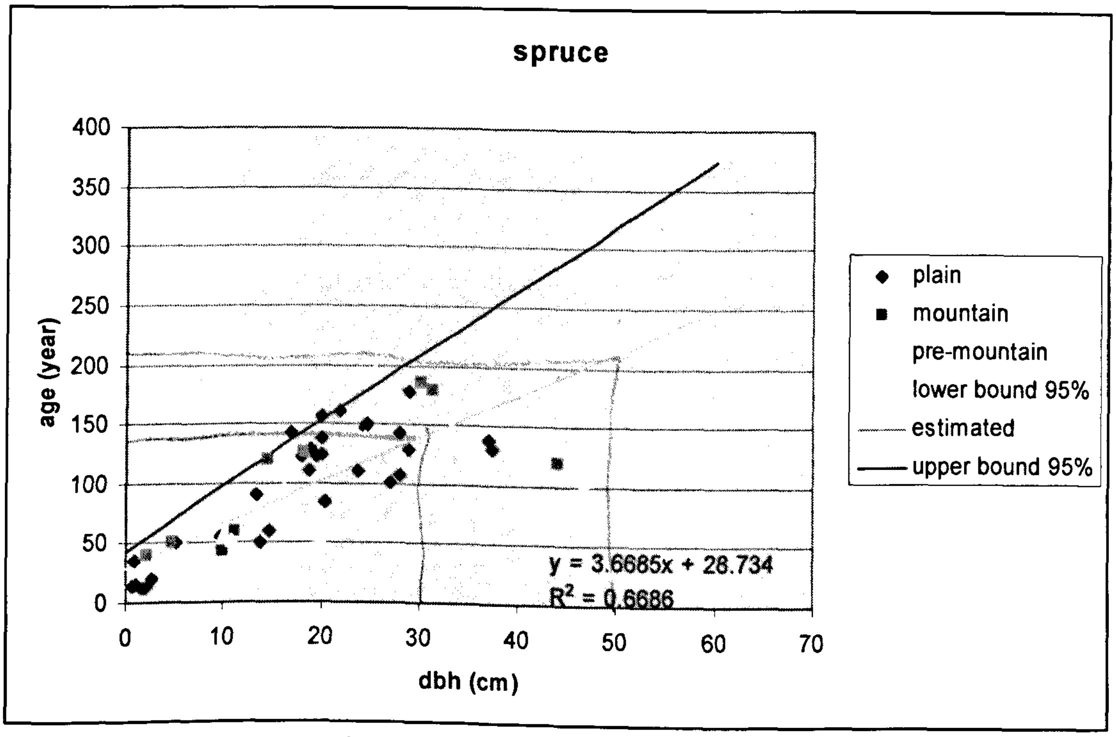


Figure 3.13. Linear regression of observations of age on dbh for spruce.

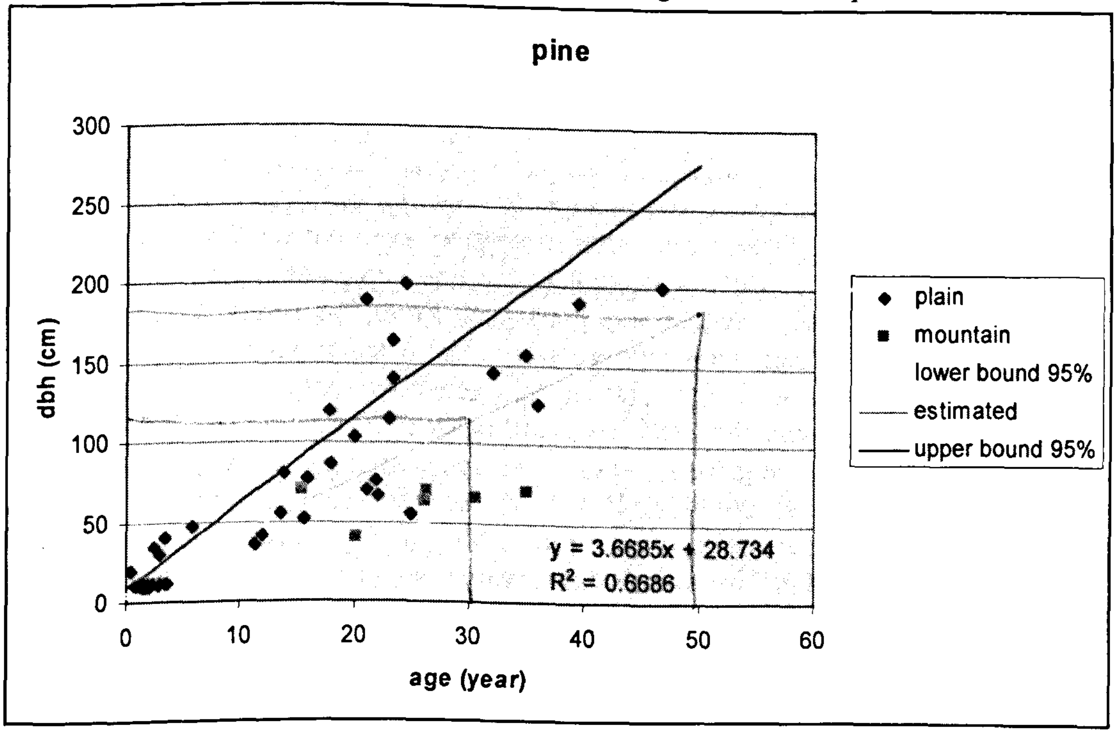


Figure 3.14. Linear regression of observations of age on dbh for pine.

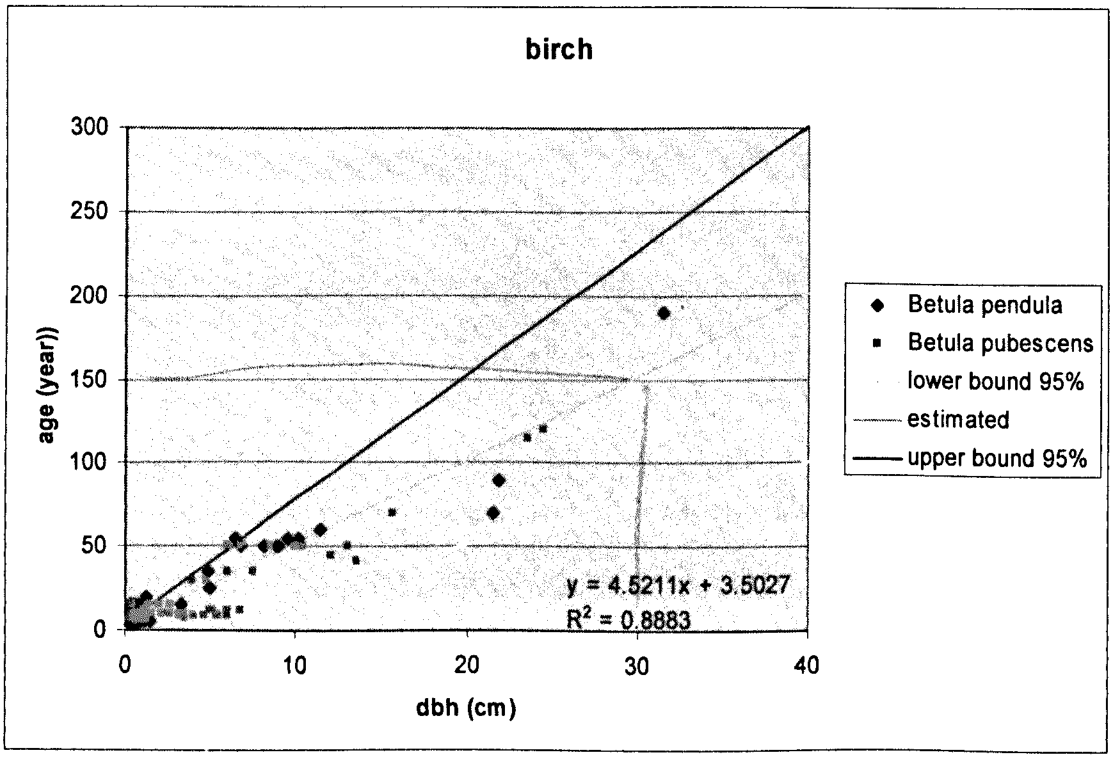


Figure 3.15. Linear regression of yield table data of age on dbh for birch.

3.4.4. Other simulation settings

3.4.4.1. Climate

Incoming radiation is the driving force of the FORGRA model. Other climatic parameters such as temperature and precipitation can be specified in the input, but are not used in the model. Data on incoming radiation were not readily available. With the help of the weather simulation module of the ForGem model (Kramer et al. 2004), a 10 year period of daily weather was generated. From this series, the average total monthly radiation was calculated (Figure 3.16). The weather generator is based on an analysis of a large global climate dataset, and generates daily weather with as input the latitude and longitude. We used the coordinates of Syktyvkar (61.70°N 50.90°E) as input. The length of the growing season is fixed within the model by specifying in which months growth is possible. Based on the generated temperature series we defined a 5-month growing season, from May to September (average monthly temperature above 5° C). This is 153 days, which is close to the estimated length of the growing season in the central taiga (158 days) and northern taiga (143 days) (Taskaev et al. 1999).

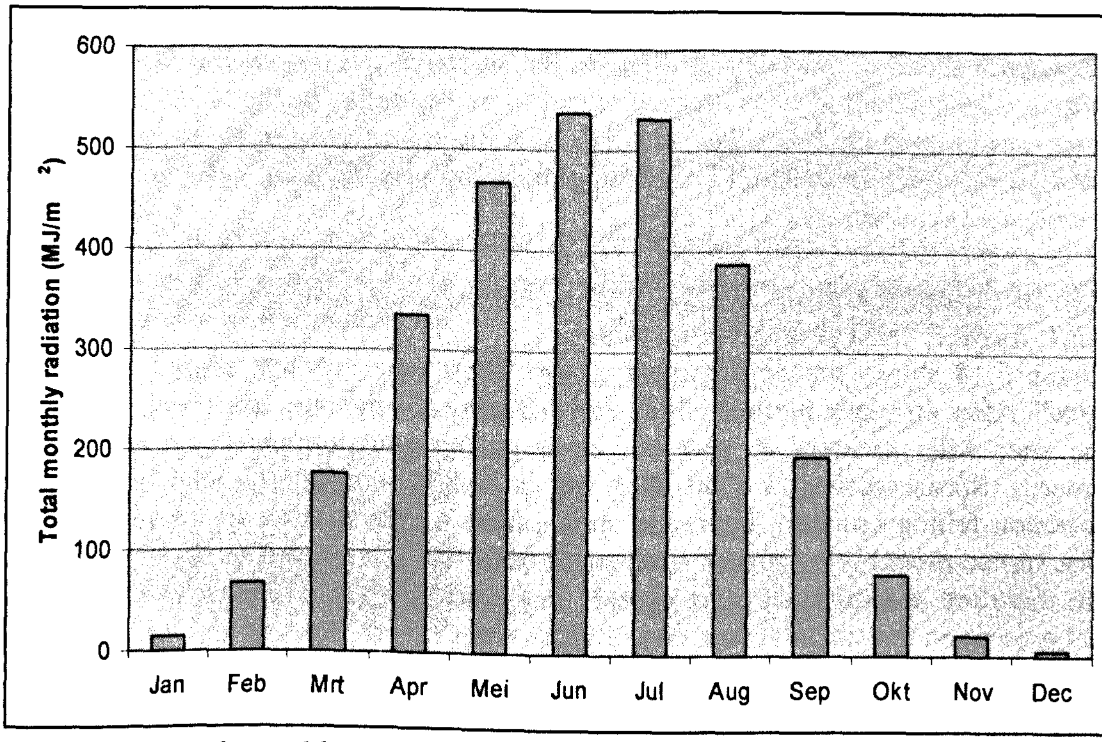


Figure 3.16. Total monthly radiation as used in the simulations

3.4.4.2. Light interception

The ForGra model was adapted for this study to take into account the effect of the vegetation in surrounding plots on the light availability within the plot. No quantitative data was available to parameterise this. Therefore, we assumed this influence as shown in Figure 3.17, based on the idea that plots located towards the south will have more influence on the central plot than plots towards the north.

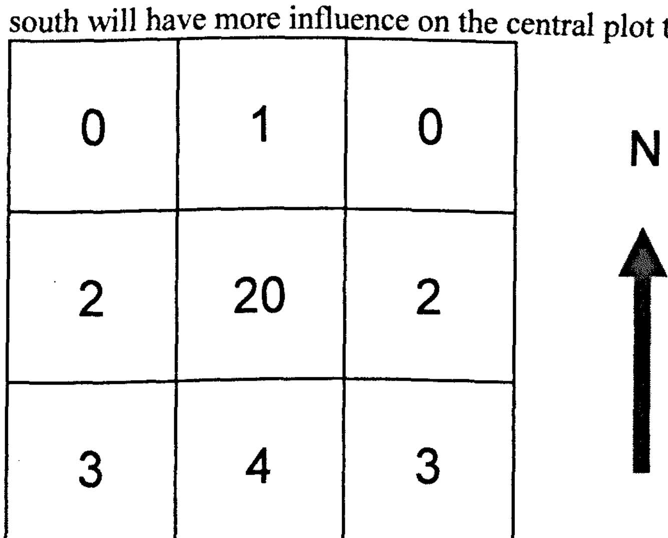


Figure 3.17. Relative weights of surrounding plots on the central plot with respect to light, as applied in the final simulations. Plot size is 20*20 m.

3.4.5. Management scenarios

Three scenarios are simulated for all forest types, for a 100-year period: 1) No management, 2) clearcut at an approximate age of 140 years of the dominating trees, and 3) selection felling at the same age. For the birch forest, only two scenarios are simulated: 1) No management, and 2) clearcut at an approximate age of 60 years. In the clearcut scenarios, all trees are removed. We assumed that skidding tracks are one pixel wide (20m) and all seedlings present in these tracks are killed. Distance between skidding tracks was assumed to be one pixel as well. Outside the skidding tracks, we assumed a seedling mortality of 30%. In the selective felling scenarios, the size and pattern of the skidding tracks was assumed to be the same. In the skidding tracks all trees were removed, but in between the skidding tracks only trees with a dbh of at least 10 cm were harvested. The seedling mortality was assumed to be the same as in the clearcut scenario.

3.5. Simulation results

3.5.1. Spruce, central taiga, plain zone

Figure 3.18 shows the development of the forest type "spruce, central taiga, plain zone". After 40 years, birch is eliminated and spruce is the only tree species present at the site. After clearcut at year 60, birch profits and dominates the regeneration process. Spruce comes in a bit later, but in smaller proportions than birch. In the selection felling scenario, birch and spruce have an equal share in the regeneration. The spruce probably originates from small trees that were saved from harvesting and are therefore able to react more quickly than under the clearcut scenario. Birch was not present on the site anymore, and originates most likely from seed.

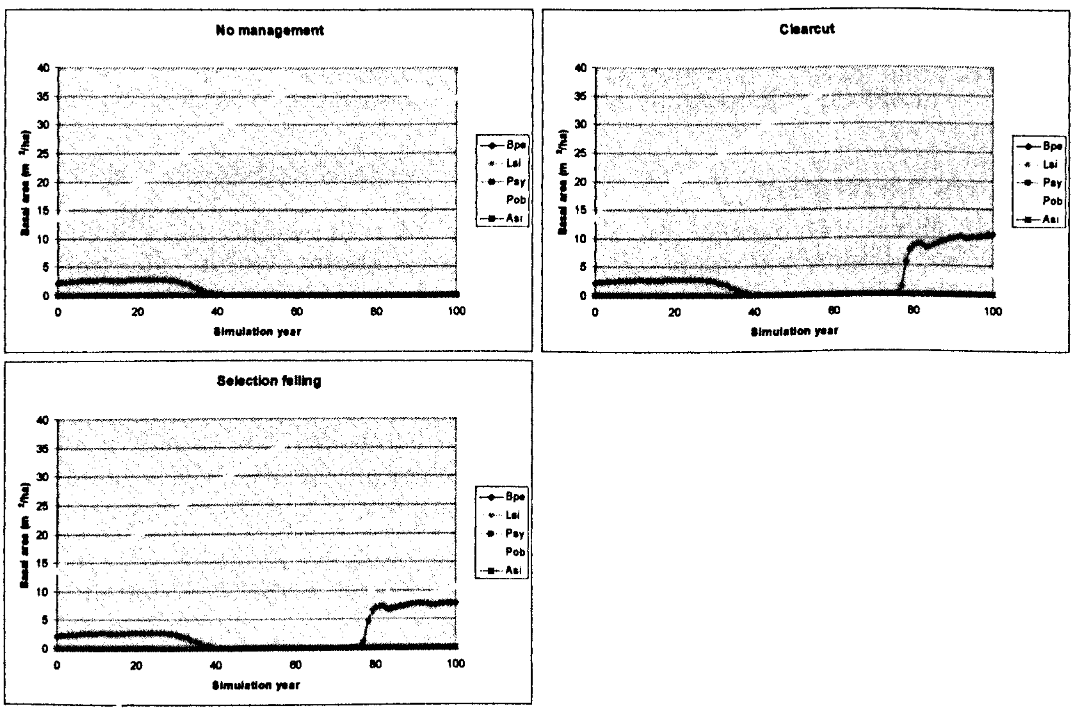


Figure 3.18. Basal area development of the forest type spruce, central taiga, plain zone under no management (a), clearcut at year 60 (b) and selection felling at year 60 (c).

3.5.2 Spruce-mix with fir, central taiga, pre-mountain zone

Figure 3.19 shows the development of basal area of the spruce-fir mixture in the central taiga, pre-mountain zone. The initial (5 years) decline in basal area of birch, spruce and fir is probably due to initialisation effects. The stand (tree) composition is not in balance yet with the growing conditions at the site, so part of the trees die. This might be caused by a higher actual fertility of the field plots than the assumed yield class in the model. If no management is applied, stand composition does not change much. The clearcut and selection felling scenario both show the same pattern: a fast initial increase of birch, while spruce and fir increase at a lower speed. Pine plays only a very minor role. A difference between the two managed scenarios is that the period of regeneration is shorter under selection felling, because more small trees are left at the site after harvesting. This also causes a faster development of spruce and fir in the selection felling scenario.

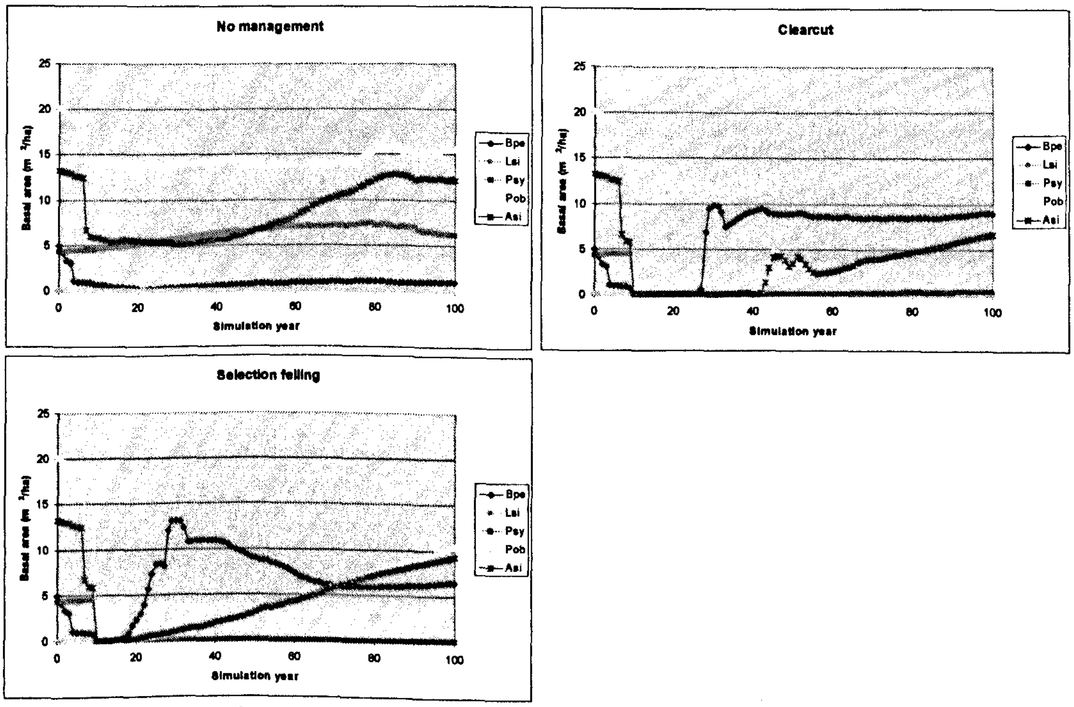


Figure 3.19. Basal area development of the forest type spruce-mix with fir, central taiga, pre-mountain zone under no management (a), clearcut at year 10 (b) and selection felling at year 10 (c).

3.5.3. Spruce-mix with fir, central taiga, mountain zone

The forest type "spruce-mix with fir, central taiga, mountain zone" shows somewhat different results compared to the same type in the pre-mountain zone (Figure 3.20). In the scenario without management, birch and pine are virtually eliminated after a period of 40 years. After clearcut, birch dominates the site for a long time. Also pine plays a minor role, in contrast to the simulation of the pre-mountain zone. Spruce and fir are gradually increasing and will eventually take over the dominance again. However, within the simulated time frame, the forest remains dominated by birch. Under the selection felling system, the regeneration period is shorter, just like in the pre-mountain zone. However, the increase of spruce and particularly fir is much faster.

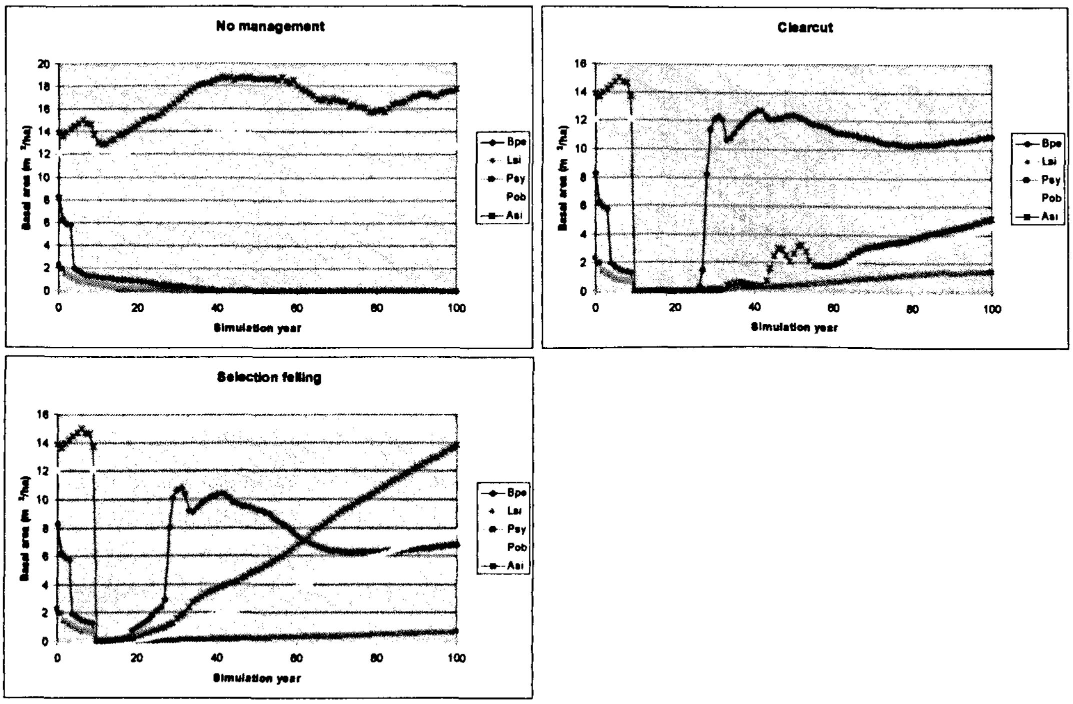


Figure 3.20. Basal area development of the forest type spruce-mix with fir, central taiga, mountain zone under no management (a), clearcut at year 10 (b) and selection felling at year 10 (c).

3.5.4. Spruce greenmoss, northern taiga, plain zone

The results for the forest type "Spruce greenmoss, northern taiga, plain zone" are shown in Figure 3.21. The total basal area increases considerably after simulation starts, mainly attributable to spruce and to a lesser extent to pine. The small share of birch that is initially present is soon reduced to virtually nothing. Without management, the site remains dominated by spruce. After clearcut, birch invades the site, and spruce regenerates at a slower rate. After selection felling, many small spruces are still present at the site, which is visible apparent from the small basal area visible in Figure 3.21c. These spruces start to grow after harvest, causing a gradual increase of the basal area of spruce. Birch also invades the site, but is not able to dominate. In none of the managed scenarios, pine is able to regenerate.

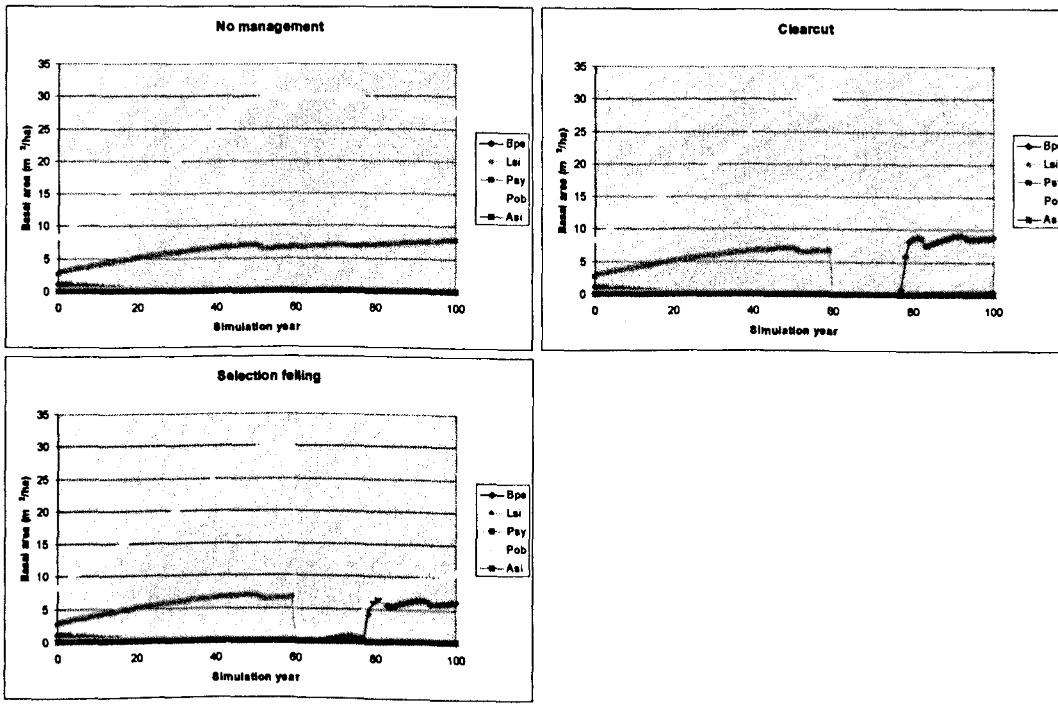


Figure 3.21. Basal area development of the forest type spruce greenmoss, northern taiga, plain zone under no management (a), clearcut at year 60 (b) and selection felling at year 60 (c).

3.5.5. Pine, central taiga, plain zone

The results for the forest type "pine, central taiga, plain zone" are shown in Figure 3.22. If this site is not harvested, pine continues to dominate the site. After year 60, spruce gradually increases its share in the total basal area. After clearcut, birch is the first species to regenerate, followed by pine, spruce and fir. The small peak visible in spruce and fir (Figure 3.22b and c) is most likely a model artefact, linked to the transition of regenerating trees from cohorts to individuals. When we neglect these peaks, we see that spruce starts to increase its share in the stand rapidly, while birch slightly declines. In the selection felling scenario, the increase of spruce is faster, leading sooner to dominance of this species.

The harvest of this pine stand leads to an accelerated succession of pine to spruce. Without harvest, eventually this succession would probably also have occurred. This indicates that somehow the spruce trees are much inhibited in their development by the pine overstory. This was also seen in the model test with seedlings under layers of various species. In reality, we would probably have seen a much faster invasion of spruce in this stand.

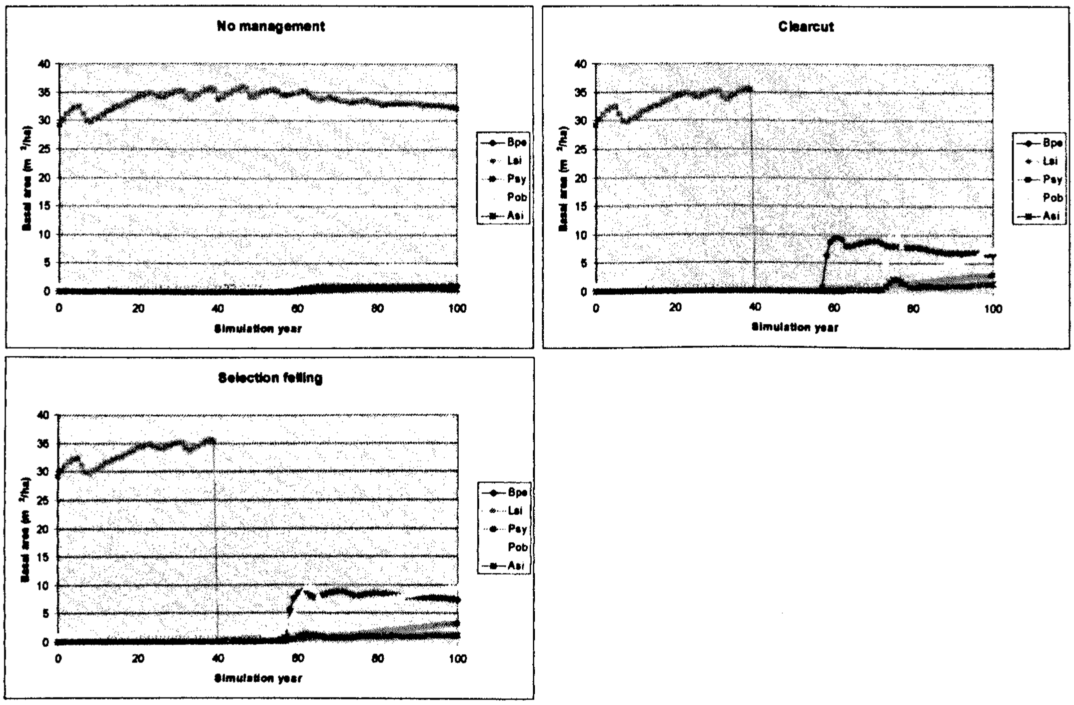


Figure 3.22. Basal area development of the forest type pine, central taiga, plain zone under no management (a), clearcut at year 40 (b) and selection felling at year 40 (c).

3.5.6. Pine lichen, central taiga, pre-mountain zone

The results of the simulations for the forest type "pine lichen, central taiga, pre-mountain zone" are shown in Figure 3.23. In the unmanaged scenario the share of pine is rather stable. Birch is eliminated after a few years, while spruce gradually increases its share. Birch is able to profit from a clearcut and dominates the regeneration. Spruce increases gradually, the peak is probably a model artifact. Pine has a very small share in the regeneration after clearcut. After selection felling, spruce reacts most strongly and dominates the regeneration. Birch also invades, but not to the same extent as spruce. The share of pine is very small, which can be explained by the structure of the stand just before the felling. The stand consists of mature pine trees, with an understory of spruce trees. With the harvest, all mature pines are removed, leaving only part of the small spruce trees. These are able to react to the increased light and dominate the regeneration. Birch probably invades the empty skidding tracks, facilitated by its good seed dispersal and numerous seeds.

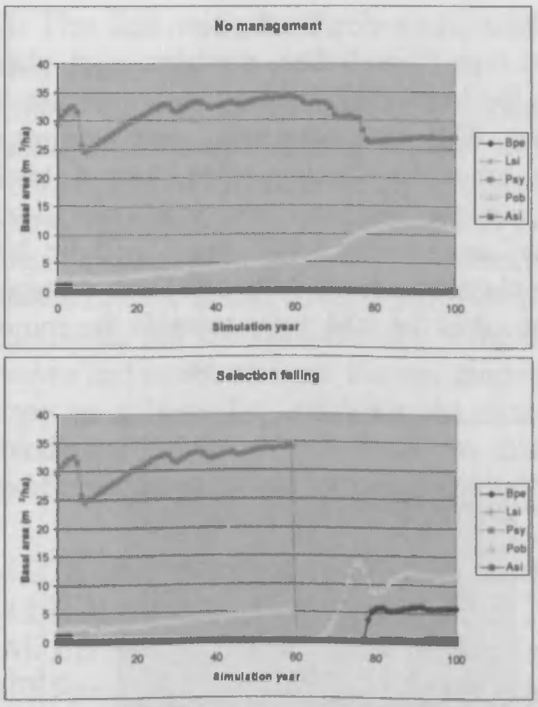


Figure 3.23. Basal area development of the forest type pine lichen, central taiga, pre-mountain zone under no management (a), clearcut at year 60 (b) and selection felling at year 60 (c).

3.5.7. Pine lichen, northern taiga, plain zone

The results of the simulations for the forest type "pine lichen, northern taiga, plain zone" are shown in Figure 3.24. Notable is the immediate, almost linear increase of the basal area after the start of the simulation. Without management, pine dominates the stand, without any developments in the other tree species. After clearcut, birch dominates the regeneration, whereas pine increases its basal area at a lower pace. Selection felling is favorable for the pine, since many small pines will be left untouched. This favors pine compared to the clearcut regime. Although birch manages to dominate the stand for a short while, pine takes the lead again towards the end of the simulation.

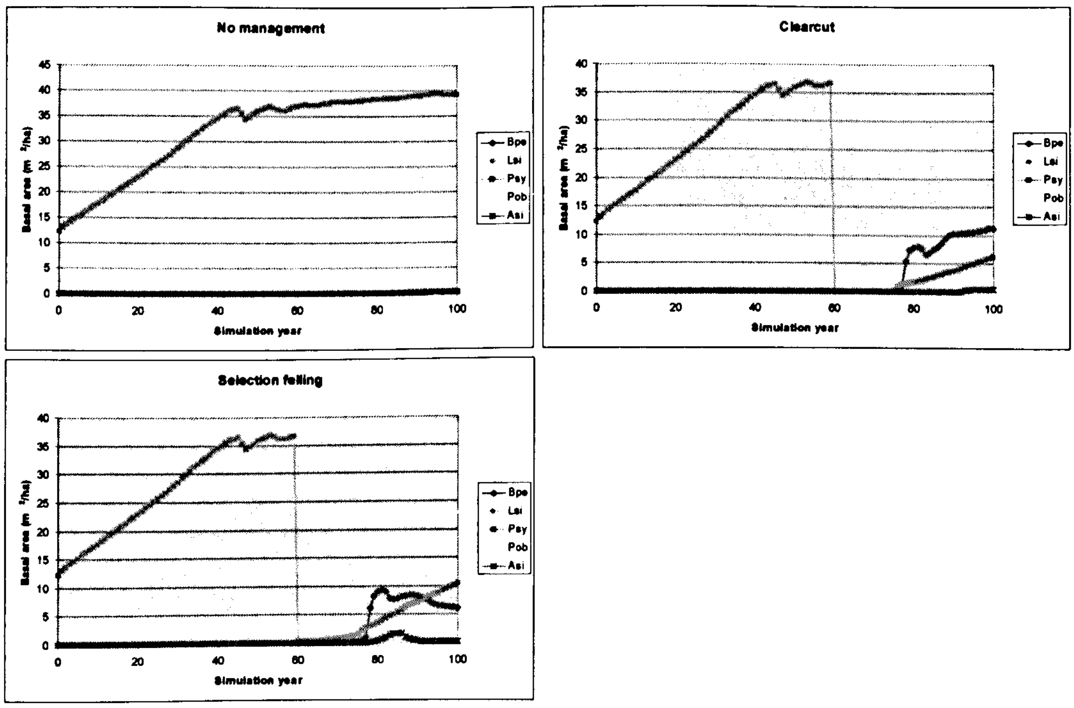


Figure 3.24. Basal area development of the forest type pine lichen, northern taiga, plain zone under no management (a), clearcut at year 60 (b) and selection felling at year 60 (c).

3.5.8. Birch, central taiga, plain zone

Figure 3.25 shows the development of a simulation of birch in the plains of the central taiga. If the stand is not harvested, birch will dominate for a long time. Towards the end of the simulation, spruce starts to increase, and presumably will become dominant in the longer run. After clearcut, birch is the only species that regenerates immediately. Spruce comes in after year 60, and becomes dominant at year 90.

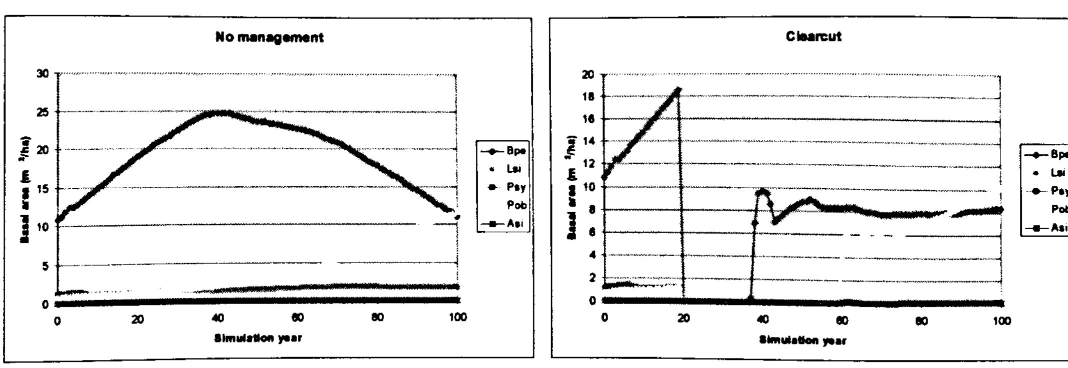


Figure 3.25. Basal area development of the forest type birch, central taiga, plain zone under no management (a) and clearcut at year 20 (b).

4. The link with the Pechora Knowledge System

4.1. General

One of the aims of this study is to combine the expected developments per forest type under different management regimes with management scenario maps in the PKS, so that impacts of different spatial management scenarios can be assessed. Furthermore, the developments per forest type will be used to give an insight into the effects of these management scenarios on biodiversity. In the PKS, many basic maps are available, like a land cover classification based on MODIS remote sensing data (Den Hollander and van Eerden 2004), a digital elevation model (DEM), maps with rivers, towns and roads, etcetera. For our purposes, we used the thematic MODIS land cover map as a basis for upscaling the simulation results to the basin level. Also the biodiversity indexes were linked to this classification, so no extra steps had to be performed to establish the link with biodiversity.

4.2. Interpretation of modeling results in relation to MODIS classes

4.2.1. Method

All simulations were done for a period of 100 years. In order to monitor changes in the forest type, the simulation results are classified every 10 years according to the MODIS classes. MODIS classes are based on remote sensing interpretation, and are thus only based on land cover (dominant vegetation) characteristics and not, as in our classification, on climate or altitude. In the MODIS classification, six forest types are distinguished, mostly based on the dominant tree species. Table 4.1 shows the rules used to classify our simulation results into MODIS classes. These rules are derived from common field classification, based on the dominance of the tree species with respect to basal area.

Table 4.1. Rules to classify simulation results into MODIS classes.

Modis class	**Modis description**	**Rule (depending on basal area)**
1	Pine forest	Pine>70%
2	Spruce/ dark coniferous forest	Picea+Abies>70%
4	Mixed forest, pine dominated	Pine 50-70%
5	Mixed forest, spruce dominated	Picea+Abies 50-70%
6	Mixed forest, birch dominated	Birch>50%
7	Disturbed forest, clearcut/regrowth	Basal area < 1m2/ha

4.2.2. Results

Table 4.2-4.9 show the interpretation in MODIS types of the model simulations. Usually, not much changes in the MODIS type when no management is applied. In all situations of management, there is a period that the forest is classified as disturbed forest, clearcut/regrowth. The length of this period is under selection felling usually shorter than under a clearcut regime. Furthermore, clearcutting favours the development of birch. In all cases of clearcut, after the disturbed phase the forest is classified for a period as mixed forest, dominated by birch. In some spruce forest types, spruce becomes dominant after approximately 70 years. Selection felling in spruce forests shows a much shorter period of birch dominance

a rather quick recovery of the spruce dominance, sometimes preceded by a period of birch dominance. Management in the pine forest often shows a shift of dominant tree species. After the management intervention, usually birch dominates, sometimes followed by a spruce dominance. Only in the case of pine, northern taiga, pre-mountain, a mixture evolves that is dominated by pine. Clearcutting of a birch stand does not affect the dominance of birch. After a short disturbance phase, birch dominates again.

Table 4.2. Classification of simulation results in MODIS types for spruce, central taiga, plain zone.

Simulation year	No management	Clearcut	Selection felling
0	2	2	2
10	2	2	2
20	2	2	2
30	2	2	2
40	2	2	2
50	2	2	2
60	2	7	7
70	2	7	7
80	2	6	5
90	2	6	5
100	2	6	5

Table 4.3. Classification of simulation results in MODIS types for spruce-mix with fir, central taiga, pre-mountain zone.

Simulation year	No management	Clearcut	Selection felling
0	2	2	2
10	2	7	7
20	2	7	6
30	2	6	6
40	2	6	6
50	2	6	6
60	2	6	5
70	2	6	5
80	2	5	2
90	2	5	2
100	2	5	2

Table 4.4. Classification of simulation results in MODIS types for spruce-mix with fir, central taiga, mountain zone.

Simulation year	No management	Clearcut	Selection felling
0	2	2	2
10	2	7	7
20	2	7	6
30	2	6	6
40	2	6	6
50	2	6	6
60	2	6	2
70	2	6	2
80	2	6	2
90	2	6	2
100	2	6	2

Table 4.5. Classification of simulation results in MODIS types for spruce greenmoss, northern taiga, plain zone.

Simulation year	No management	Clearcut	Selection felling
0	5	5	5
10	2	2	2
20	2	2	2
30	2	2	2
40	2	2	2
50	2	2	2
60	2	7	7
70	2	7	5
80	2	6	5
90	2	6	5
100	2	6	5

Table 4.6. Classification of simulation results in MODIS types for pine, central taiga, plain zone.

Simulation year	No management	Clearcut	Selection felling
0	1	1	1
10	1	1	1
20	1	1	1
30	1	1	1
40	1	7	7
50	1	7	5
60	1	6	6
70	1	6	6
80	1	6	6
90	4	6	5
100	1	5	5

Table 4.7. Classification of simulation results in MODIS types for pine lichen, northern taiga, pre-mountain zone.

Simulation year	No management	Clearcut	Selection felling
0	1	1	1
10	1	1	1
20	1	1	1
30	1	1	1
40	1	1	1
50	1	1	1
60	1	7	7
70	1	7	2
80	1	6	5
90	4	6	5
100	1	6	5

Table 4.8. Classification of simulation results in MODIS types for pine lichen, northern taiga, plain zone.

Simulation year	No management	Clearcut	Selection felling
0	1	1	1
10	1	1	1
20	1	1	1
30	1	1	1
40	1	1	1
50	1	1	1
60	1	7	7
70	1	7	7
80	1	6	6
90	1	6	6
100	1	6	4

Table 4.9. Classification of simulation results in MODIS types for birch, central taiga, plain zone.

Simulation year	No management	Clearcut
0	6	6
10	6	6
20	6	7
30	6	7
40	6	6
50	6	6
60	6	6
70	6	6
80	6	6
90	6	5
100	5	5

4.3. Interpretation of modeling results in relation to biodiversity

4.3.1. Method

During the field expeditions in 2002 and 2003, data on biodiversity have been collected for many species and functional groups in many different vegetation types. Van der Sluis (2005) analysed these data and linked it to the MODIS classes of Table 4.1. Different biodiversity indices have been calculated, one of these was the number of red list species per MODIS class. These values are listed in Table 4.10. For this pilot study, we simply linked the output of the forest simulations via the MODIS classifications in Tables 4.2-4.9 to the indicator "potential number of red list species" in Table 4.10. Further, we show an example how the link between forest modelling results and biodiversity could be made in a more sophisticated way.

Table 4.10. Number of red list species per MODIS class (Van der Sluis 2005). For empty cells no data was available.

Modis class nr.	Modis description	Birds	Insects (spec)	Fish	Plants	Lichens	Total
1	Pine forest	1	0	0	1.33	1.33	3.67
2	Spruce/dark coniferous forest	1.5	1	0	2	9.25	13.75
3	Meadows/willow shrub	1	0	0	2.5	8.5	12
4	Mixed forest, pine dominated	0	0	0	1	4	5
5	Mixed forest, spruce dominated	2	0	0	1	1	4
6	Mixed forest, birch dominated	0	1	0	2.5	6.25	9.75
7	Disturbed forest, clearcut/regrowth	0	0	0	0	0	0
8	Unclassified pine/bush fire	0	0	0	0	0	0
9	Mountain bare rocks						0
10	Mountain tundra	1	0	0	2	1	4
11	Mountains, Open forest	0	0	0	1	4	5
12	Northern tundra, dwarf shrubs & lichen						0
13	Northern tundra, dwarf shrubs & moss						0
14	Northern tundra, wet						0
15	Boggy tundra						0
16	Southern shrub tundra						0
17	Rich fen, Carex	0	0	0	1	0	1
18	Poor fen, raised bog	0	0	0	1	0	1
19	Poor fen, partly wooded with pine	0	0	0	3	3	6
20	Sandbank, bare soil, dunes	1	0	0	2	0	3
21	Water	2.25	0	1	0	0	3.25
22	Coastal meadows	0	0	0	0	0	0
0	no modis	2	0	0	1	0	3

4.3.2. Results

Based on the classification of the model results (Tables 4.2-4.9) and the potential number of red list species per MODIS type (Table 4.10.), the development of the potential number of red list species that can be expected under different harvest scenarios can be constructed. Figure 4.1 visualises the outcomes of this linkage. The MODIS type "dark coniferous forest" has the highest number of red list species, 13.75. Therefore, all management interventions in these forests lead to a decrease in expected number of red list species, since all interventions lead to changed forest type classification for at least some period. The interventions in the pine forest types lead in some cases to a temporary increase in potential number of red list species, since the mixed forest dominated by birch may have a higher number of red list species as the pine dominated forest.

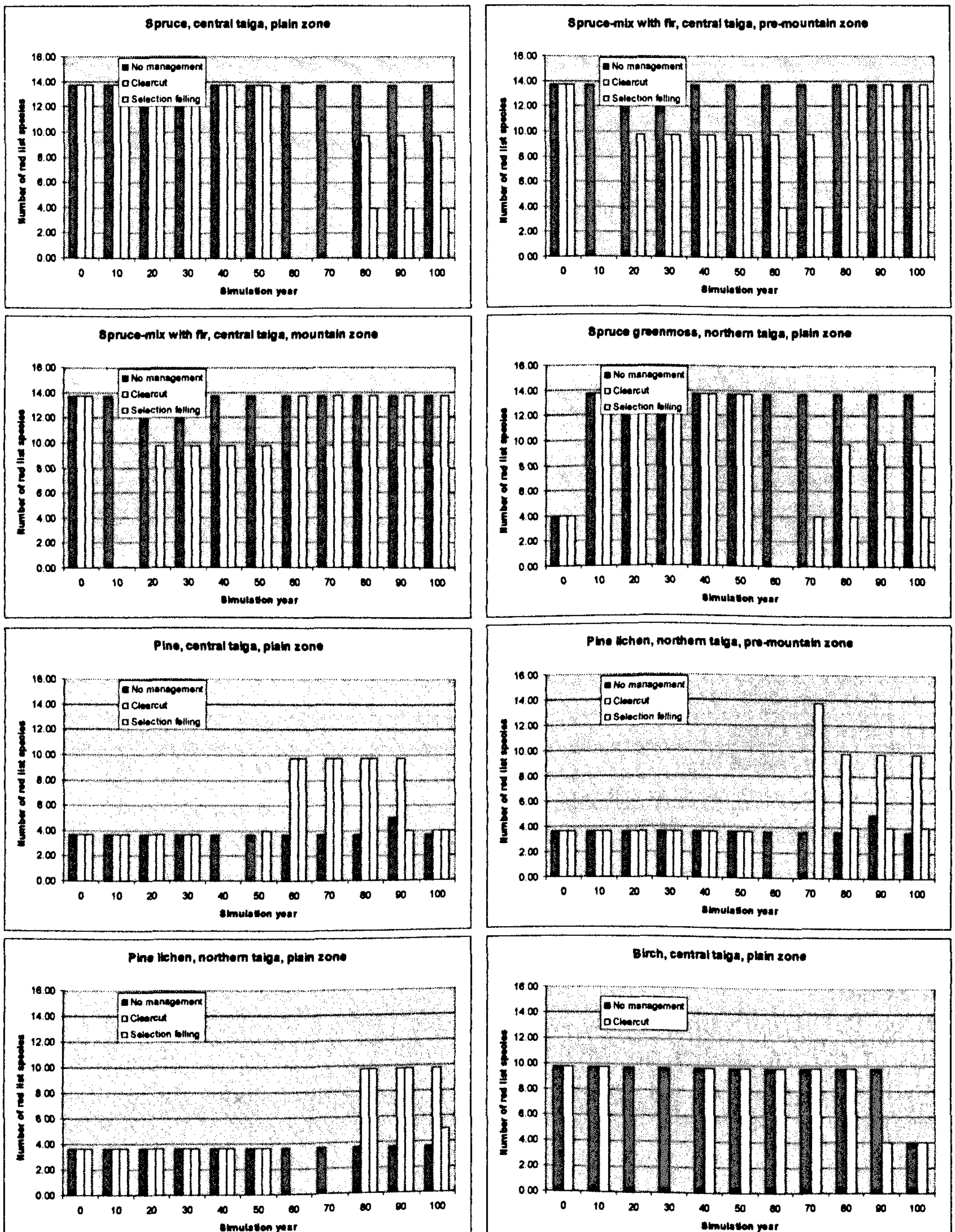


Figure 4.1 Development of expected number of red list species for the simulated forest types under the three different management scenarios

4.3.3. Example of other future linkages between model results and biodiversity

The link between forest development and biodiversity (Figure 4.1) is a very simple approach, linking a rather crude forest type classification to a total number of red list species from different groups. The variety in forest structure within a forest type can be considerable, with possibly totally different species living in it. Moreover, the forest type classification can change quickly with only minor "real" changes, whereas changes in the number of species may take a rather long time, especially if their dispersal ability is low. The output from the forest model is much more detailed than the forest type only, and could be used to make a much more sophisticated estimate of biodiversity. Here we demonstrate this on the basis of the forest type "Spruce-mix with fir, central taiga, pre-mountain zone".

Figure 4.2 and 4.3 show the development of respectively the total basal area and total growing stock volume for this forest type under the three different management scenarios. Both of these variables give an indication of the openness of a stand, which might be linked to certain species that need open or closed stands. Further, many species are known to depend on large trees. Figure 4.4 shows the development of the number of trees with a diameter larger than 40 cm. Initially 63 large trees per hectare are present. In the case without management, this number fluctuates between 56 and 103. After selection felling or clearcut, there are no large trees left. Within the simulation period, only under the selection felling scenario some large trees are again present, but not yet as many as under the unmanaged scenario.

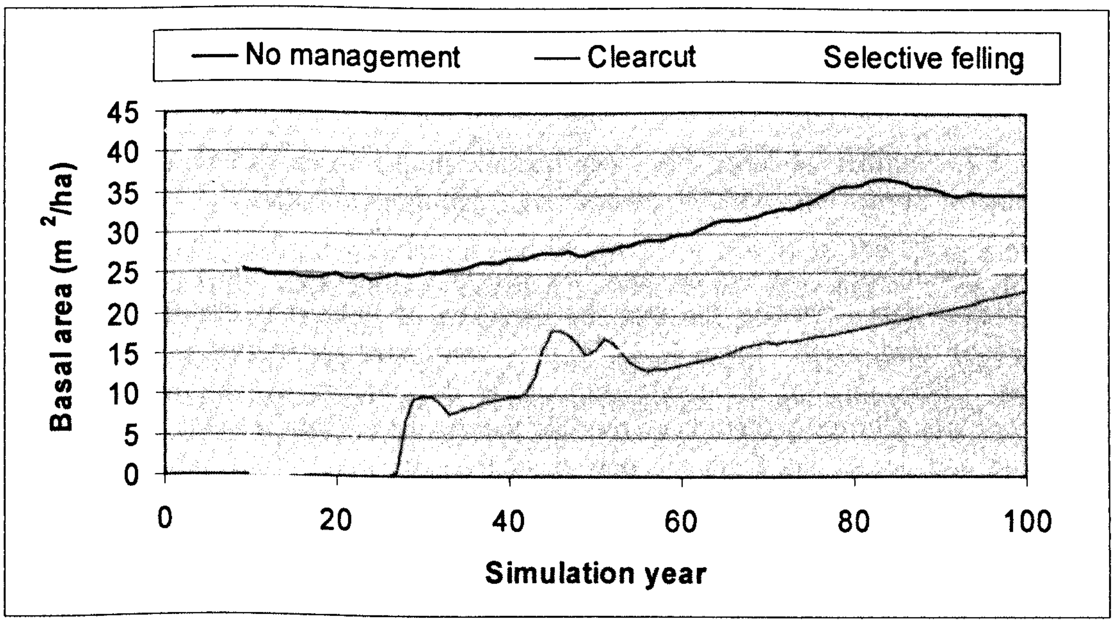


Figure 4.2. Basal area development in the three different management scenarios for Spruce-mix with fir, central taiga, pre-mountain zone.

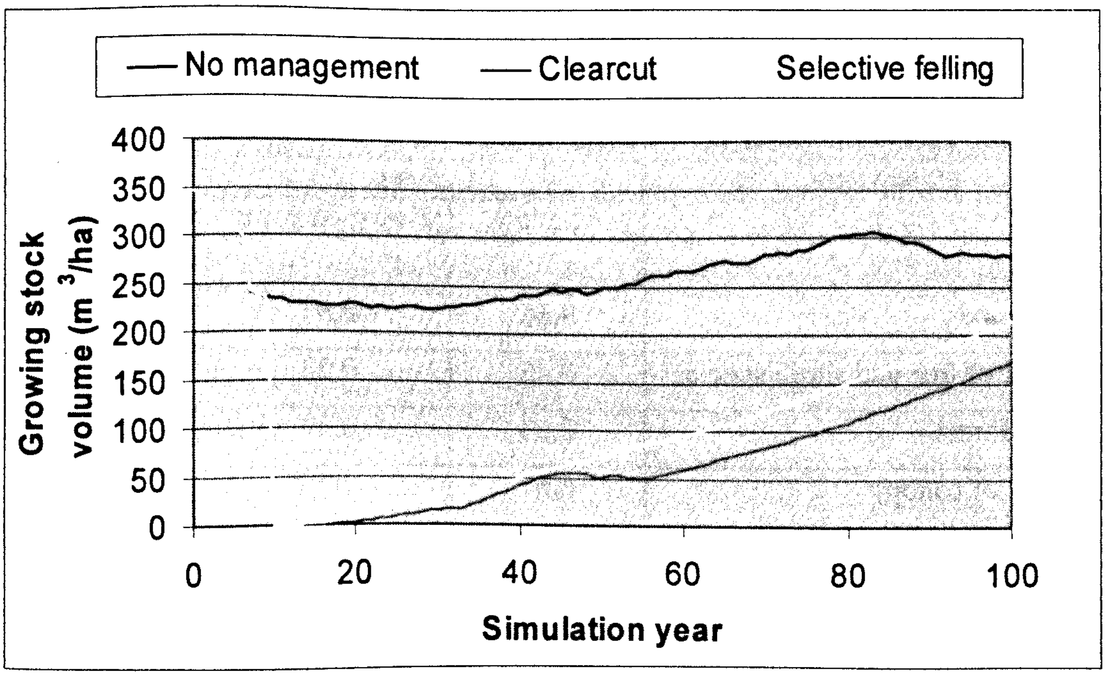


Figure 4.3. Growing stock development in the three different management scenarios for Spruce-mix with fir, central taiga, pre-mountain zone.

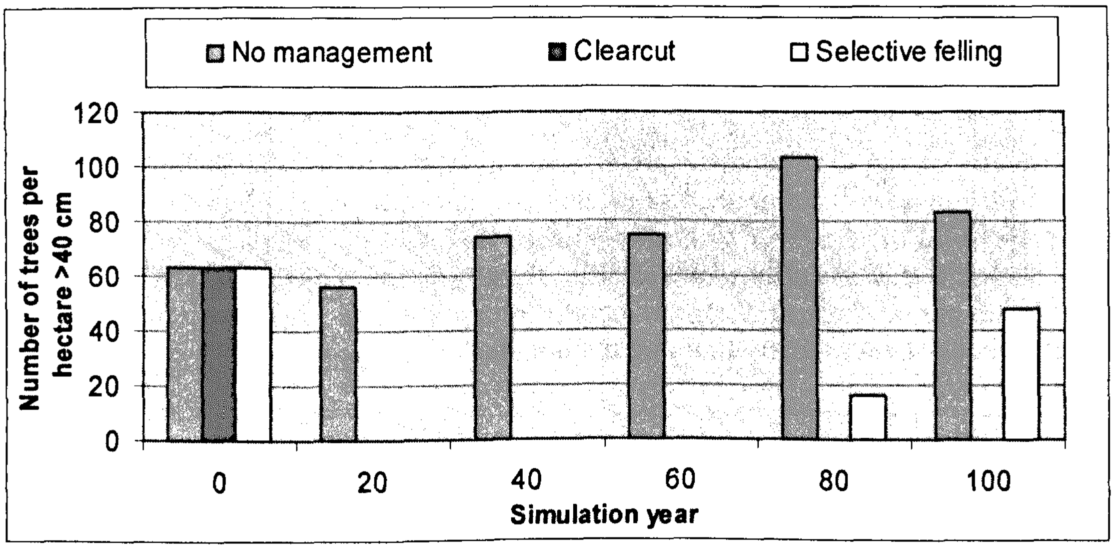


Figure 4.4. Number of large trees per hectare in the three different management scenarios for Spruce-mix with fir, central taiga, pre-mountain zone.

From a preliminary correlation analysis of the biodiversity data by T. Pystina (unpublished data), we can see that the presence of lichens is correlated with the presence of dead wood (Table 4.11). This is confirmed by studies in other regions (Jonsson 1998). One of the model outputs is the amount of new dead trees per diameter class. Currently there is no module that tracks the total amount of dead wood via input and decay, but from the new dead trees we can get an impression of the number and size of dead trees. In the scenario without management, there is a regular flow of a few new dead trees of larger dimensions, and many trees of smaller dimensions (Table 4.12). After clearcut, more new dead trees become available, but all have a diameter less than 20 cm. After selection felling, the same applies, except for the years 61-70, when also some trees of 21-30 cm become available. It is clear that harvesting has a pronounced effect on the dimensions of dead wood that is available on the site, and probably also on the total quantity. Many lichens are not only depending on dead wood, but particularly on large logs.

Table 4.11. Correlation (*r*) between number of lichen and vascular plant species and some parameters (T. Pistina, unpublished data.).

Parameters	Lichens		Vascular plants (all plots)
	All plots	Forest ecotopes	
Dead wood	**0,66**	**0,57**	-
Number of tree and shrub species	0,45	0,22	-
Age of forest	**0,64**	0,39	0,11
Density of canopy	**0,57**	-0,02	0,13
Wetness of ecotope	-0,15	-0,05	0,07
Richness of soil	0,22	0,22	**0,73**
Degree of ecotope disturbance	-0,18	-0,16	-0,23

Table 4.12. Input of "new" dead trees per 10 year simulation period and per diameter class under the three different management regimes.

	no management					clearcut					selection felling				
Diameter→ Year↓	5-9	10-19	20-29	30-40	>=40	5-9	10-19	20-29	30-40	>=40	5-9	10-19	20-29	30-40	>=40
0-10	447	383	84	35	1	447	382	84	33	1	447	383	84	34	1
11-20	0	0	2	4	4	0	0	0	0	0	0	0	0	0	0
21-30	0	0	0	0	4	0	0	0	0	0	211	219	0	0	0
31-40	4	0	0	0	1	8	0	0	0	0	177	171	0	0	0
41-50	21	0	0	0	4	1334	212	0	0	0	132	131	0	0	0
51-60	64	15	0	0	2	1337	65	0	0	0	238	69	0	0	0
61-70	307	1	0	0	3	343	5	0	0	0	160	29	13	0	0
71-80	59	1	0	0	1	440	30	0	0	0	264	3	0	0	0
81-90	71	13	0	0	4	279	7	0	0	0	233	1	0	0	0
91-100	2	3	0	0	3	244	5	0	0	0	204	0	0	0	0
Average	98	42	9	4	3	443	71	8	3	0	207	101	10	3	0

4.5 Integration of the Forgra model in the PKS

For the integration of the simulation and biodiversity results in the PKS, a tool was needed to draw maps with the future distribution of forest types and number of red list species. For this visualisation tool, several inputs were needed: Forest type, age and applied management. The forest type was derived by combining the MODIS classification with the vegetation zones map (Figure 2.2) and information about the elevation from the Digital Elevation Model. No forest age map was present, so we generated a map with a random age between 0 and 200 years assigned to each pixel. For the management map, we needed to know where management was allowed and were not. A forest protection map was derived by combining all protected areas, like natural parks, with a buffer around the main river of 1 km, and a buffer around the main tributaries of 500m. Then, three management maps were made, one with no management, one with clearcut outside the protected areas, and one with selection felling outside the protected areas. In a later stage, the user of the PKS may be offered the possibility to adjust these maps by him/herself. Now, for each pixel the initial forest type, age and management regime is known. From the simulation results, lookup tables were compiled with information about the sequence of forest types under the different management regimes. Within the PKS, it is thus possible to generate maps with the expected forest type at 10 year time intervals. Based on these expected forest types maps, also maps with the expected number of red list species can be created. Figure 4.6 shows the outline of the implementation in the PKS.

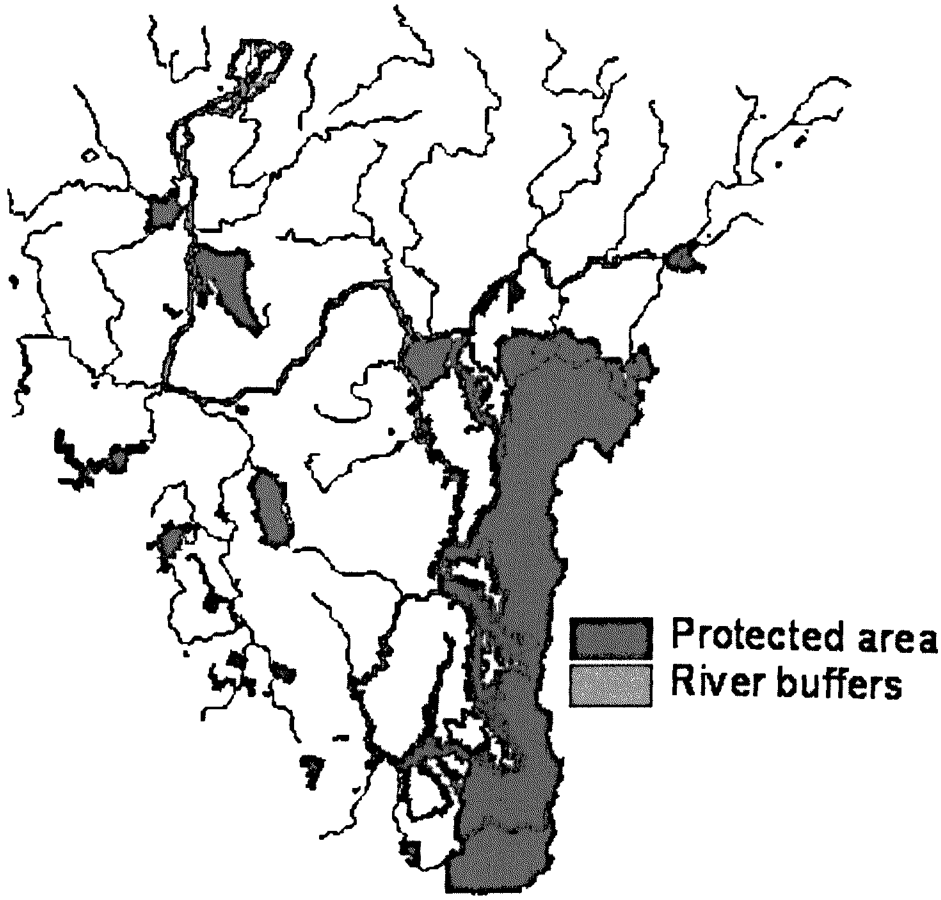


Figure 4.5. Protection zones as used in the PKS system.

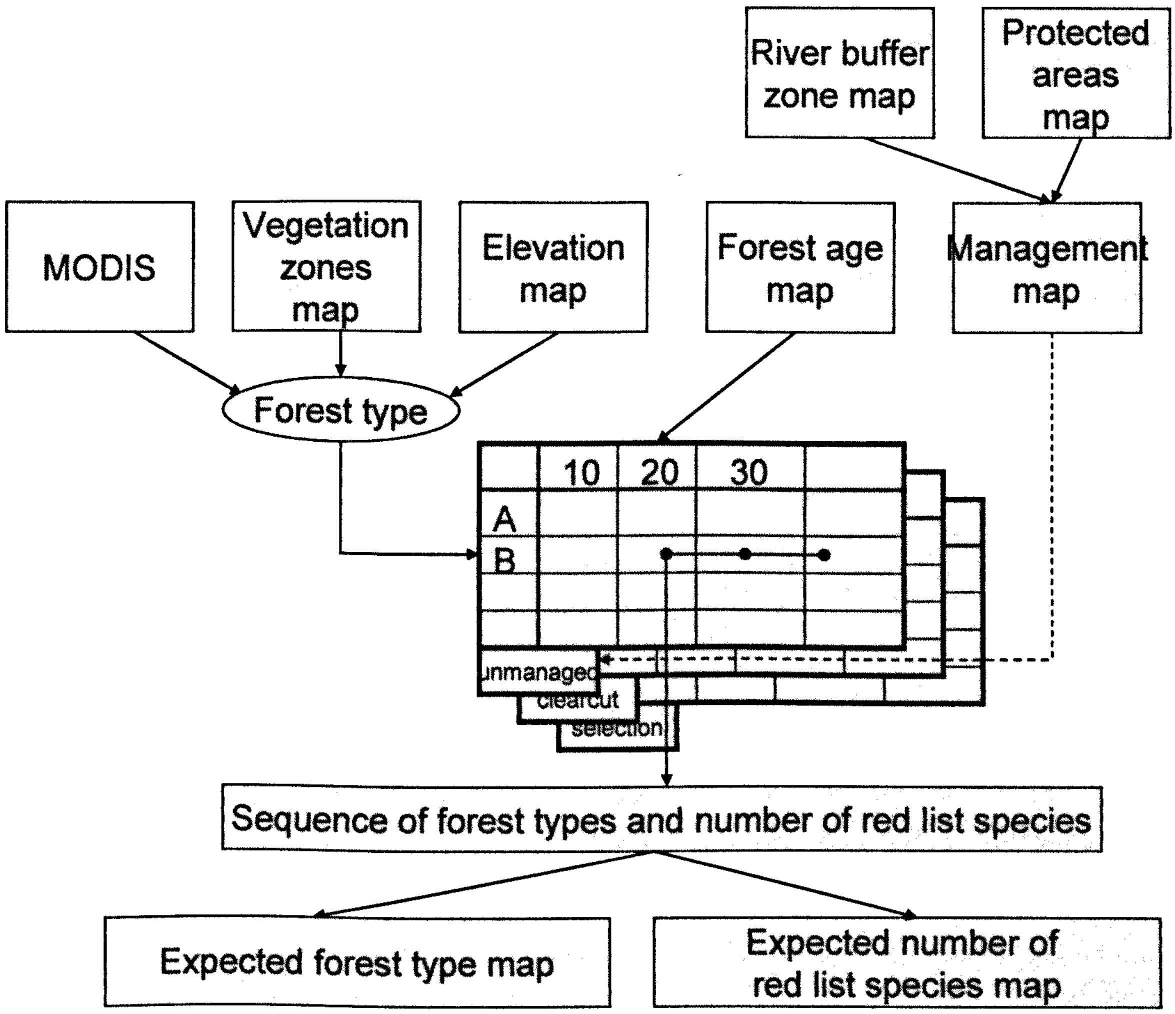


Figure 4.6. Outline of the forest simulation and biodiversity part of the PKS

5. Value estimation of forest sites

5.1. Forest value estimation method

5.1.1. Initial positions

For the value estimation of forests we will use the methodology developed within the framework of project PRIST. The following elements were considered:

- The forest was considered as an element of a geographical landscape;
- The forest site has a complex ecosystem, the next elements are considered: soil, trees, bushes, humus, flora and fauna (incl. micro organisms);
- The value of a forest site should reflect its economic significance:
  a) considering forest ecosystem rehabilitation,
  б) considering forests as a source of goods and functions.
- Value determination of a forest site should be based on:
  a) an estimation of products and functions provided by a forest,
  б) an estimation of the capacity of a forest ecosystem to produce resources.

5.1.2. Initial methodological positions

On the basis of the aspects stated above the following initial methodological positions of an estimation of forest value has been determined:

1. A natural forest cannot be estimated on the costs spent for its creation. The estimation of a forest site should be based on the effect from its economical use.

2. The estimation of a forest site is dependent of:

a) the growth conditions (the forest ground). Part of the net profit will be seen as the effect of the growth conditions.

б) The available resources, including products and functions.

3. The estimation of growth conditions should contain in its basis an estimation of potential productivity of the forest ground, which is defined by its natural fertility and by planting the most appropriate tree species.

4. The estimation should consider the amount of forest resources on a site at the moment of estimation.

5. The potential productivity value of forest ground depends of the harvesting period in total, and also we use the value increment percent of forest growth, in order to implement the factor of time.

6. The value estimation of a forest site considers an estimation of non-material functions: sanitary-and-hygienic, recreational, nature-protective functions. In a certain degree any forest site has such values.

5.1.3. Initial methodical positions

The following basic methodical aspects were considered:

1. The value estimation of a forest site considers which of all the variety of forest functions are actually in use and in demand during the given period.

2. The value estimation of additional forest products collected periodically during the whole production cycle (turpentine, berries, seeds, etc.) should be based on average annual gathering amounts.

If at the moment of estimation, annual gathering of such products has not come yet or it has already ended, it is considered that these resources are not present.

3. The value of forest products on the site is determined by calculation (multiplication) of the amount of each product with the rent value (governmental tax or market price), considering a discount coefficient.

4. In a rent estimation are considered:

- Prices at tenders, the market price of wood and additional goods,
- Governmental taxes on forest products.

If no data are available "minimal rates of payment for wood on stem" are used, and other general guidelines (calculated with use of official, governmental techniques).

5. The value estimation of forest functions should be estimated on a measurement the use it brings, the economy received exclusively as a result of positive influence of forests on other objects, and also the function of positive effect on the human-being.

Due to too little time, sometimes, some artificial methods of value estimation of forestry functions, which are common in forestry, were used.

6. The estimation of the total annual rent is based on all the rents of the separate forest products and functions together.

7. Considering multifunctional forestry the main product of forestry dominates the other functions.

8. The potential productivity of the growth conditions at a specific location, which could make possible an “optimal” or reference forest stand (optimal efficiency according to natural fertility of the forest ground and geographical location).

The mentioned methodological and methodical aspects form a conceptual basis, which was used to make a value estimation of forests.

5.1.4. Structure and the period of value estimation.

The next forest values were calculated:

1. Value of the forest ground.
2. Value of ecological functions of a forest.
3. Value of the basic resources of a forest.

The next basic resource values were calculated:

1. Value of merchantable wood.
2. Value of minor wood materials:
   - Value of green tree material,
   - Value of pine stump wood,
   - Value of seeds;
   - Value of spruce bark,
   - Value of birch bark,
   - Value of pine gum,
   - Value of forestry berries,
   - Value of mushrooms.

Their value was estimated on bases of the market price, governmental taxes and norms of use, and potential demand.

The period of value estimation was 100 years, in time-steps of 10 years.

5.1.5. The initial data.

The forest value estimation was based on data, submitted by colleagues from The Netherlands (model data FORGRA).

The calculations were carried out according to governmental normative and methodical documents, economic and silvicultural standards, wood price rates, used on the territory of the Republic of Komi (for the Pechora river basin).

The following parameters were used as initial data:

1. Number of the site (type of forest).
2. Forest enterprise
3. Forest district
4. Forest area, in hectares
5. Governmental wood on stem tax zone.
6. Governmental forest accessibility correction tax (Category of remoteness)
7. Productivity growth class

8. Amount of industrial wood (marketability) in an optimal (sound growth) forest stand
9. Age of harvest (years)
10. Forest wood stock (m^3/hectare)
11-15. Russian system of forest specification, type of tree-species 1st (most), 2, 3, 4, 5 (less), e.g. Spruce, Pine, Fir, Birch
16-20. Quota (ratio) of species 1-5 in %
21-25. Height (average) of species 1-5 (in meters)
26-30. Diameter (average) of species 1-5 (cm.)
31-35. Age (average) of species 1-5 (years)
36-39. Amount of industrial wood (marketability) in a sound growth forest stand of species 1-5
40. Governmental forest group (category of forest protection)

5.1.6. Methods of implementing norms and the initial data

In a significant number of cases the data of average diameter and height, simulated for different tree species, are not included in the available governmental Russian silvicultural and economic standards (norms). In this case, it is needed to calculate additional values by corresponding methods.

In cases when the data totally fell outside all limits, and were not to be calculated by any norms, normative values were determined by experts. As experts were appointed foresters, governmental forest management officials and forest economists.

If needed, the following presumptions and techniques were used:

- If there was no parameter available for the average diameter or height of trees, the wood stock or average age of trees this tree-species was ignored. Such problems occurred mainly young stands;
- If this occurred, the volume of the wood however was distributed to the closest tree-species or was distributed proportionally between all others. Such facts;
- In case of the significant contradiction between the simulated values of average diameters, heights and ages, experts corrected data using Russian silvicultural norms.
- Forest plots have been adhered to forest enterprises and forest divisions in order to use territorial zones of forest tax rates.
- Forest tax rates were used for a uniform distance of wood transportation (to exclude the influence of this factor).
- Classes of wood quality of reference forest stands and tree-species were determined by experts, with use of a technique identical to all forest sites.
- The governmental category of forest protection was taken uniform for all stands.
- The influence of protection category on value estimation of ecological functions and the total value of forest sites was not analyzed. Such estimations were not considered within the project.

5.1.7. Forms of representing initial data and results

The initial data by all considered variants are shown in tables and are submitted in the electronic form.

The computed results of all estimated variants are submitted in electronic form and as graphics (in Microsoft Excel format).

The graphics represent (for each variant) not all, but the following parts of the results of value estimation:

1. Value estimation of a forest plot (per hectare).
2. Value of forest ground.

3. Value of ecological functions.
4. Value of forest resources.
5. Value of merchantable wood.
6. Value of additional forest resources (in total).

5.2. Results (economic estimation of modeled forest plots and an influence on them).

5.2.1. Spruce, central taiga, plain zone.

Forest plot (07 in electronic base). V class quality of locality.
Variants of calculation: 07-01 - a site without influence, 07-02 - clear cutting, 07-03 - selective cutting.

Parameters of schedules 5.1, 5.2, 5.3 reflect dynamics of a complex economic estimation and its separate parts of 1 hectare of a forest plot during 100 years. Middle age of the main breed - fir-trees - at the beginning of the period makes 62 years; a stock of wood on 1 hectare of 75,7 m3; species structure – 84 % spruce + 16 % birch.

For the modeled period of a forest stand dynamics without external influences on it (schedule 5.1) there were following changes:

1) Value of 1 hectare of a site has increased from 10,6 thousand roubles up to 35,2 thousand roubles;

2) Value of 1 hectare of the forest ground for the period has not changed and has made 3,7 thousand roubles;

3) Value of available resources has increased from 0,6 thousand roubles up to 10,4 thousand roubles;

4) Value of liquid wood has increased from 0,5 thousand roubles up to 10,4 thousand roubles;

5) Value of secondary forest materials up to age of main cutting (120 years) grew up to 0,3 thousand roubles, and during the subsequent period was up to level, not exceeding 50 roubles;

6) Value of useful functions - a derivative from value of the ground and available resources. It has increased with 6,4 up to 21,1 thousand roubles.

By comparison of a concerned site 07 with a site 03 it is necessary to note, that younger age of a forest stand (it is younger for 15 years) is one of the reasons of its lower cost.

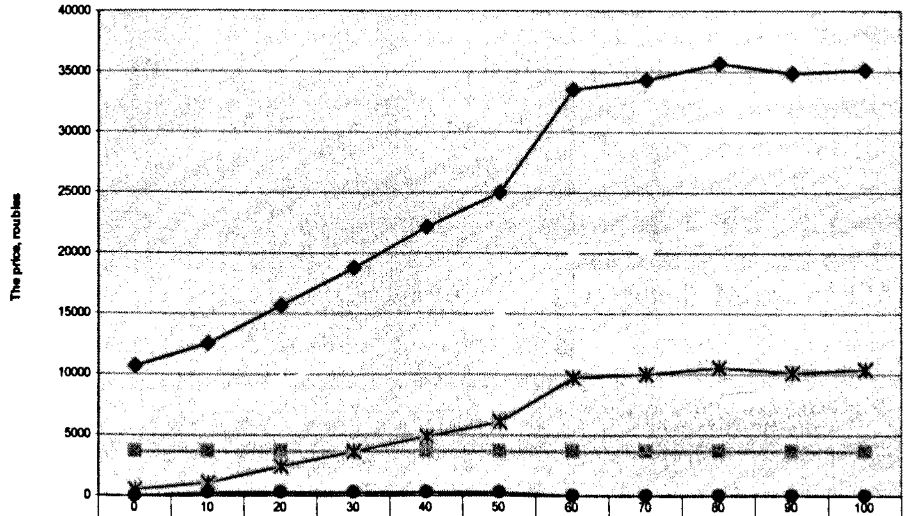
Other reason it is - higher percent of an impurity of a birch which wood is realized under lower prices, than wood of coniferous breeds. Besides, on a site 03 in structure of coniferous breeds there was more expensive pine.

All this has served as the reason of that at the equal price for the ground, a site 07 there was less valuable, than a site 03.

As well as on schedule 5.10, on schedule 5.1 it is traced during 50-60 years sharp rise of cost of stocks of the liquid wood which have entailed rise of the complex price of a forest plot. The same reason: sharp increase in thick wood in commodity structure of raw material. For this reason it is expedient to carry out on a forest plot clear or selective cuttings later (in an interval of modeling of 60-70 years). It corresponds to age of a forest stand 122-132 years.

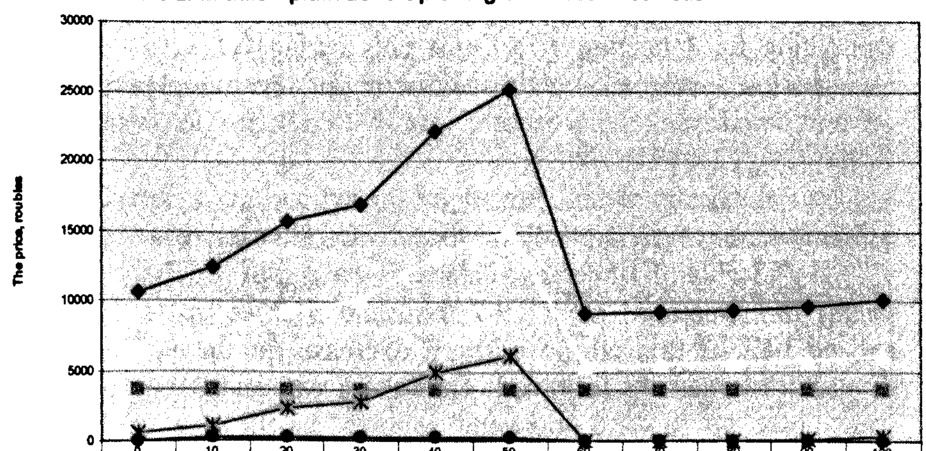
At carrying out so-called «selective cutting» preservation on a root of a part of planting (0,5 m3) practically brings in the same result, as well as at clear cutting. It is necessary to leave on a root more grove thinners trees and viable undergrowth.

Schedule 5.1. Middle - plain zone Spruce-greenmoss No management



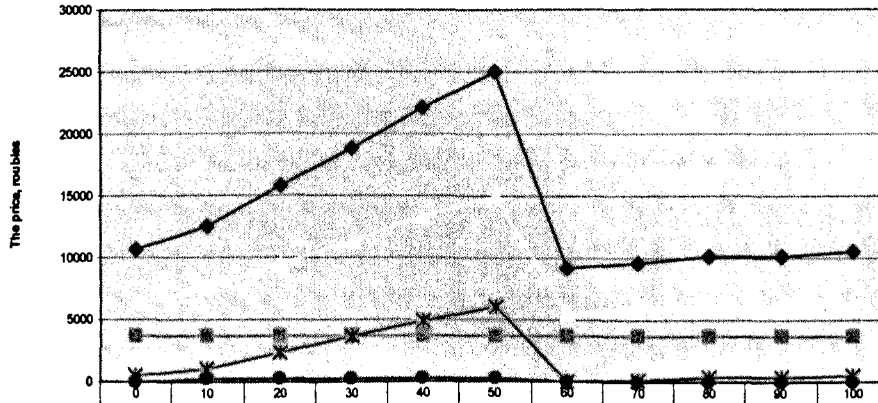
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	10626	12513	15732	18843	22100	25036	33486	34268	35621	34797	35193
Estimation of the forest ground	3682	3682	3682	3682	3682	3682	3682	3682	3682	3682	3682
Estimation of ecological functions	6375	7508	9439	11306	13260	15022	20091	20561	21373	20878	21116
Estimation of forest resources	569	1324	2611	3856	5158	6333	9713	10026	10567	10237	10396
Estimation of merchantable wood	549	1110	2373	3637	4919	6062	9667	9979	10521	10192	10354
Estimation of minor forest resources	20	213	238	218	239	271	46	47	46	45	42

Schedule 5.2. Middle - plain zone Spruce-greenmoss Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	10626	12513	15732	16938	22105	25036	9124	9262	9397	9633	10147
Estimation of the forest ground	3682	3682	3682	3682	3682	3682	3628	3628	3682	3682	3682
Estimation of ecological functions	6375	7508	9439	10163	13263	15022	5442	5580	5638	5780	6088
Estimation of forest resources	569	1324	2611	3094	5161	6333	0	38	77	172	377
Estimation of merchantable wood	549	1110	2373	2875	4921	6062	0	27	55	147	348
Estimation of minor forest resources	20	213	238	218	239	271	0	11	22	24	29

Schedule 5.3. Middle - plain zone Spruce-greenmoss Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	10626	12513	15732	18843	22105	25036	9205	9593	10159	10084	10576
Estimation of the forest ground	3682	3682	3682	3682	3682	3682	3682	3682	3682	3682	3682
Estimation of ecological functions	6375	7506	9439	11306	13263	15022	5523	5756	6095	6051	6345
Estimation of forest resources	569	1324	2611	3856	5161	6333	0	155	382	352	549
Estimation of merchantable wood	549	1110	2373	3637	4921	6062	0	141	363	329	522
Estimation of minor forest resources	20	213	238	218	239	271	0	15	19	23	27

5.2.2. Spruce-mix with fir, central taiga, pre-mountain zone

Forest plot (11 in electronic base), productivity class 5.

Variants of calculation: 11-01 - a site without influence, 11-02 - clear cutting, 11-03 - selective cutting.

Submitted graphics 5.4, 5.5, 5.6 reflect the dynamics of a total value estimation for 1 hectare of a forest plot during 100 years. Average age of the main tree-species – spruce - at the beginning of the modeled period was 90 years; the general wood stock per 1 hectare was 346,6 m3; species structure - 51 % spruce, 28 % fir (Abies), 12% pine, 9 % birch.

For the modeled period of dynamics of a forest stand without external influences on it (graphic 5.4) we found the following results:

1) Value of 1 hectare of a site at the end of the first half of modeled period (50 years) has increased from 19,7 thousand roubles up to 22,5 thousand roubles. In second half of this period a sharp decrease (at the age of 150 years) up to 20,4 thousand roubles has followed. Then there was an increase in value of 1 hectare of a forest plot up to 21,8 thousand roubles (at the age of 180 years) and decrease {reduction} at the end of modeled period - up to 20,8 thousand roubles;

2) Value of 1 hectare of the forest ground for the period did not change and has made 2,0 thousand roubles;

3) Value of available resources in an initial stage has made the sum of 5,8 thousand roubles, to the middle of the period has reached the maximal size - 13,6 thousand roubles, and on the end of the period it has decreased to 12,5 thousand roubles;

4) Value of merchantable wood was equal at the beginning of the modeled period to 5,3 thousand roubles; to the middle of the period it has reached 7,0 thousand roubles, and by the end of the period it has decreased to 6,1 thousand roubles;

5) Value of secondary wood products and non wood products of a forest changed in limits from 0,1 thousand roubles up to 0,5 thousand roubles, reaching the maximal values at the beginning and at the end of the period;

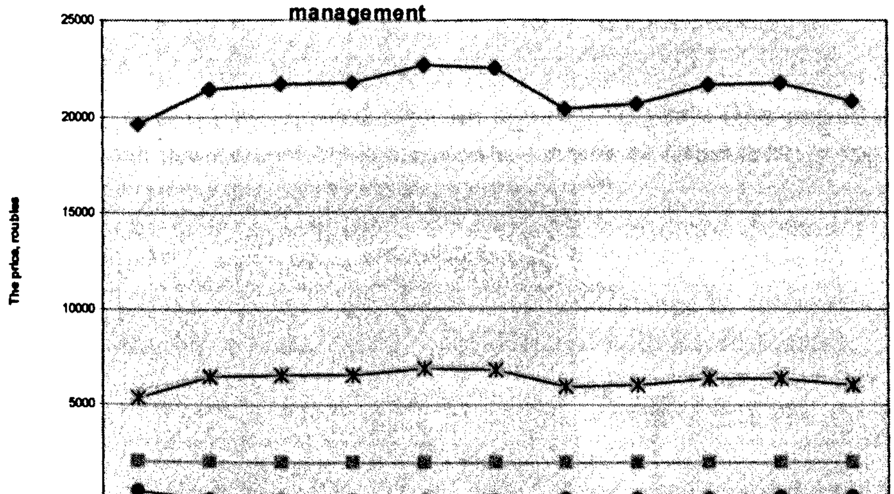
6) Value of useful functions of a forest in an initial stage was equal to 11,8 thousand roubles, to the middle of the period it has increased up to 13,6 thousand roubles, by the end - it has decreased to size of 12,5 thousand roubles.

Apparently from parameters of graphic 5.4, character of curves of change of value of functions and the total value of a forest plot is predetermined by changes of value of stock of merchantable wood. During the period from 90 till 140-150 years its value continues to increase due to increase of a share of large wood of coniferous species in forest structure and of round wood qualities. It occurs, despite of decreased increment and of the fact that from the general stock the trees birch and a fir (Abies) are disappearing. Then after 150 years processes of degradation start in overmature forests, especial due to fir (Abies) and partly spruce, which reaches an irreversible character after 170 years.

Considering the character of accumulation dynamics on a site of forest products and increase in its value, to carry out clear or selective cutting should not be done at the age of 100 years (the period of modeling is 10 years) but at the age of 130-140 years.

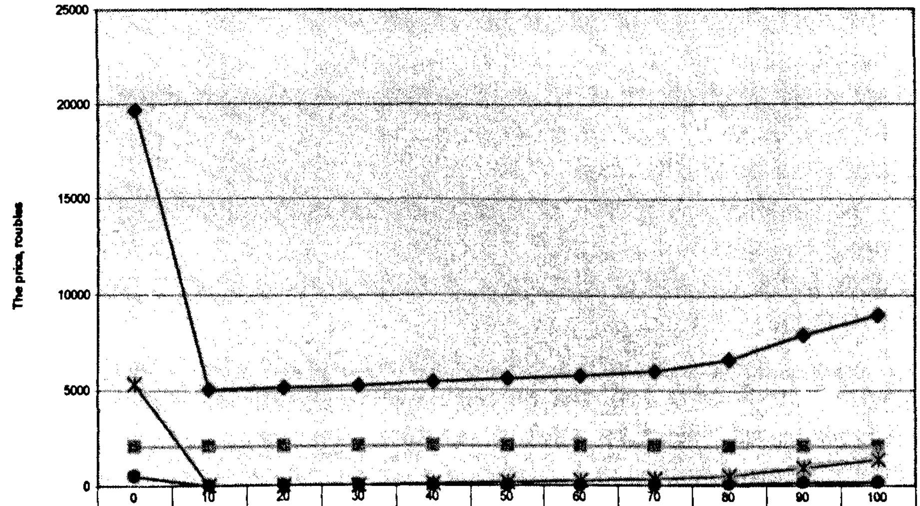
Selective cuttings are beneficial for reforestation (the part of a forest stand with a stock of 0,2 m^3 per hectare is left). By the end of the period value of available resources at selective cutting (graphic 5.6) exceeds the given parameter at clear cutting (graphic 5.5) in 1,7 times.

Schedule 5.4. Middle - pre-mountain zone Spruce-mix with fir-greenmoss No management



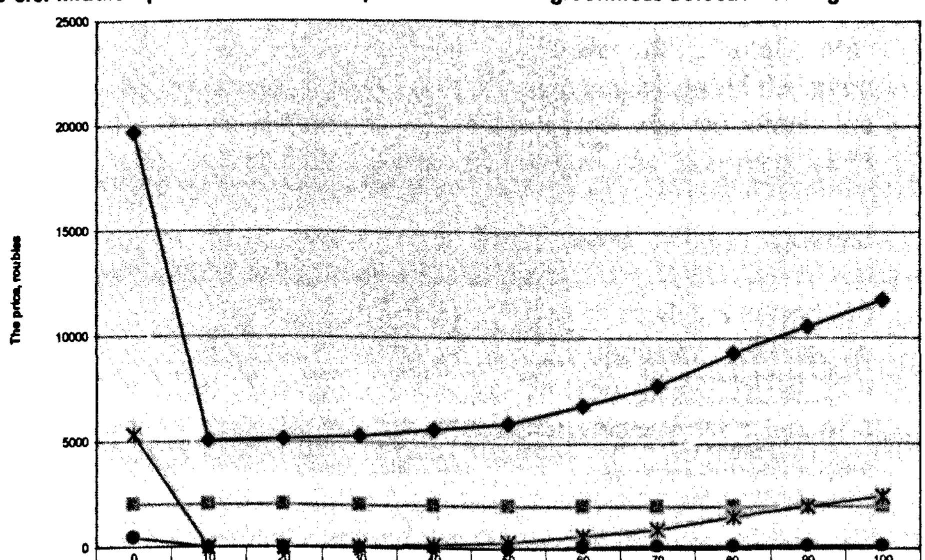
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	19662	21447	21710	21759	22668	22489	20408	20674	21635	21761	20841
Estimation of the forest ground	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027
Estimation of ecological functions	11797	12868	13026	13055	13601	13493	12245	12405	12981	13057	12504
Estimation of forest resources	5838	6551	6657	6676	7040	6968	6136	6243	6627	6677	6309
Estimation of merchantable wood	5344	6476	6574	6599	6952	6868	5977	6059	6427	6417	6057
Estimation of minor forest resources	494	76	83	78	88	100	159	184	200	260	252

Schedule 5.5. Middle - pre-mountain zone Spruce-mix with fir-greenmoss Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	19662	5067	5140	5213	5388	5622	5724	5993	6626	7918	8959
Estimation of the forest ground	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027
Estimation of ecological functions	11797	3040	3084	3128	3233	3373	3434	3596	3975	4751	5375
Estimation of forest resources	5838	0	29	58	128	222	262	370	623	1140	1556
Estimation of merchantable wood	5344	0	18	36	96	193	230	330	499	987	1368
Estimation of minor forest resources	494	0	11	21	32	29	33	40	124	153	188

Schedule 5.6. Middle - pre-mountain zone Spruce-mix with fir-greenmoss Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	19662	5067	5168	5349	5619	5941	6815	7727	9281	10528	11793
Estimation of the forest ground	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027
Estimation of ecological functions	11797	3040	3101	3209	3371	3565	4089	4636	5569	6317	7076
Estimation of forest resources	5838	0	40	113	220	349	699	1064	1685	2184	2690
Estimation of merchantable wood	5344	0	22	87	190	316	632	942	1541	2034	2535
Estimation of minor forest resources	494	0	18	26	30	33	67	122	144	150	155

5.2.3. Spruce-mix with fir, central taiga, mountain zone

Forest plot (12 in electronic base), productivity class 5.

Variants of calculation: 12-01 - a site without influence, 12-02 – clear cutting, 12-03 - selective cutting.

Submitted graphics 5.7, 5.8, 5.9 reflect dynamics of a total value estimation per 1 hectare of a forest plot during 100 years. Average age of the main tree-species - spruce - at the beginning of the modeled period is 97 years; the general wood stock per 1 hectare - 257,4 m^3; species structure - 35 % spruce, 40 % fir, 20 % birch.

For the modeled period of dynamics of a forest stand without external influences on it (graphic 5.7) we found the following results:

1) Value of 1 hectare of a site has reached the maximum on midpoint time (the period of modeling is 50 years), it has increased from 15,3 thousand roubles up to 26,4 thousand roubles, then it has decreased by the end of the period to 16,0 thousand roubles;

2) Value of 1 hectare of the forest ground for the period has not changed and has made 2,9 thousand roubles;

3) Value of available resources in first half of period has increased from 3,2 thousand roubles up to 7,7 thousand roubles, in second half – it has decreased to 3,6 thousand roubles;

4) Value of wood in first half of modeled period has increased from 2,9 thousand roubles up to 7,7 thousand roubles, in second half - it has decreased to 3,2 thousand roubles;

5) Value of secondary wood materials and non-wood products of a forest in the beginning the modeled period made 0,4 thousand roubles, then it has decreased to 0,02 thousand roubles, and by the end of the period it has increased up to 0,4 thousand roubles;

6) Value of useful functions of a forest plot in the first half of period has increased from 9,2 thousand roubles up to 15,8 thousand roubles, in second half it has decreased to 9,6 thousand roubles.

Specific feature of the given forest is a strongly pronounced degradation of overmature forest stands, which was showed after an age of 150 years (the period of modeling is 50 years). It has been increased by a significant mix of fir (Abies) being a less steady tree-species.

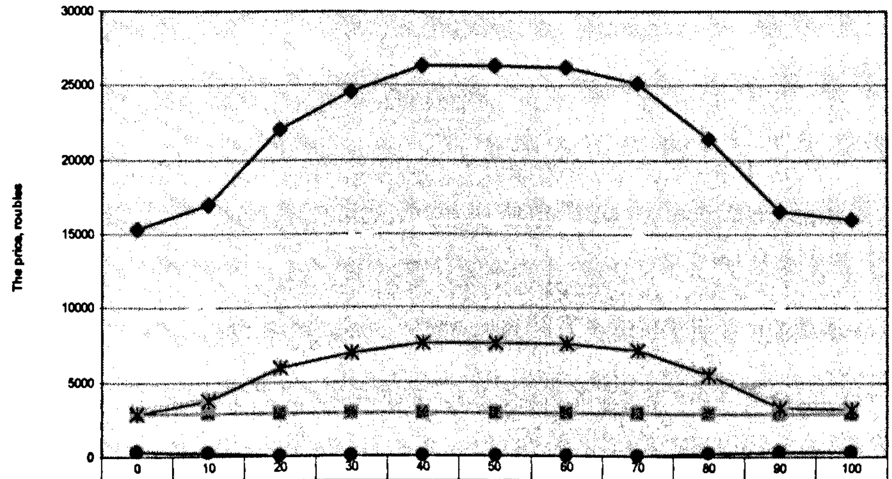
The curve of merchantable wood stock value has predetermined dynamics of value of useful functions and the total value of a forestry site.

Dynamics of secondary forest materials value is predetermined by resources of green tree materials and tanning, which presence is age-related with a forest stand.

From a position of accumulation of available resources and change of forest site value it is best to carry out (in this case) clear and selective cuttings at the age of 150 years.

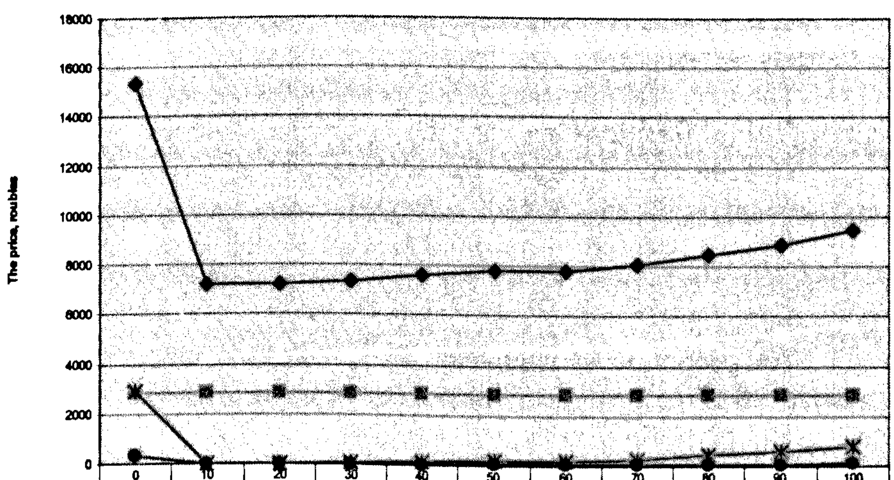
The economic advantage of selective cutting before clear cutting is reflected in graphics 5.8 and 5.9. Regeneration of a forest on a site at preservation after selective cutting of a part of a forest stand with a stock of 5,8 m^3 per hectare, instead of 3,1 m^3 (after continuous cabin) occurs more vigorously. By the end of the considered period value of available resources after selective cutting exceeds the given parameter after clear cutting 3 times.

Schedule 5.7. Middle - mountain zone Spruce-mix with fir No management



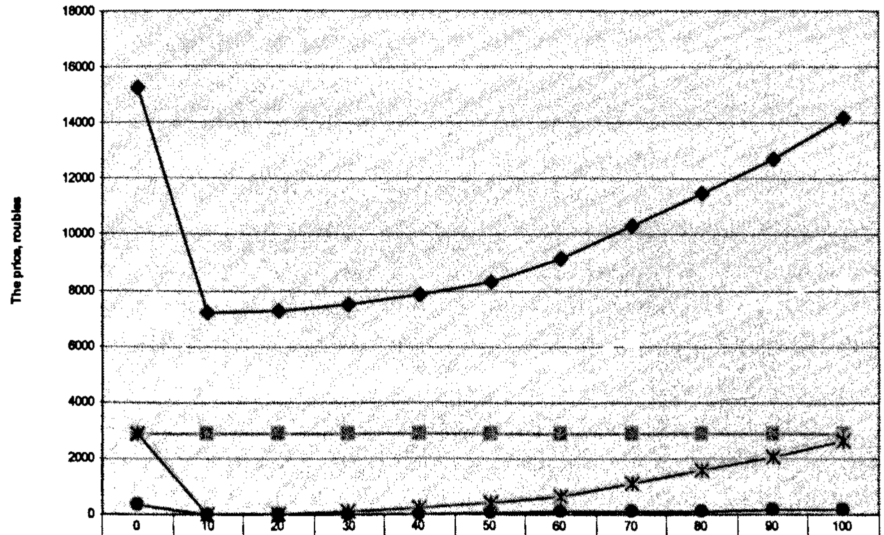
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	15281	17039	22064	24597	26332	26381	26218	25198	21400	16490	16037
Estimation of the forest ground	2876	2876	2876	2876	2876	2876	2876	2876	2876	2876	2876
Estimation of ecological functions	9169	10224	13239	14758	15799	15829	15731	15119	12840	9894	9622
Estimation of forest resources	3236	3940	5950	6963	7657	7676	7611	7203	5684	3720	3539
Estimation of merchantable wood	2879	3722	5922	6937	7633	7654	7589	7180	5509	3357	3175
Estimation of minor forest resources	358	218	28	26	23	23	23	23	175	363	364

Schedule 5.8. Middle - mountain zone Spruce-mix with fir Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	15353	7190	7240	7354	7629	7783	7805	8042	8494	8856	9470
Estimation of the forest ground	2876	2876	2876	2876	2876	2876	2876	2876	2876	2876	2876
Estimation of ecological functions	9212	4314	4364	4412	4577	4670	4683	4825	5096	5314	5682
Estimation of forest resources	3265	0	33	66	176	237	246	341	522	666	912
Estimation of merchantable wood	2906	0	21	41	146	202	206	296	471	610	793
Estimation of minor forest resources	359	0	12	24	29	36	40	45	50	57	119

Schedule 5.9. Middle - mountain zone Spruce-mix with fir Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	15239	7227	7283	7522	7841	8333	9145	10313	11463	12725	14184
Estimation of the forest ground	2876	2876	2876	2876	2876	2876	2876	2876	2876	2876	2876
Estimation of ecological functions	9144	4336	4370	4513	4705	5000	5487	6188	6878	7635	8511
Estimation of forest resources	3220	15	37	133	260	457	782	1249	1709	2214	2798
Estimation of merchantable wood	2863	0	21	110	232	400	664	1110	1567	2049	2624
Estimation of minor forest resources	357	15	17	23	29	57	118	139	143	165	174

5.2.4. Spruce greenmoss, northern taiga, plain zone

Forest plot (03 in electronic base), IV productivity growth class.

Variants of calculation: 03-01 - a site without influence, 03-02 - clear cutting, 03-03 - selective cutting.

Submitted graphics 5.10, 5.11, 5.12 reflect dynamics of a total value estimation and its separate parts of 1 hectare of a forest plot during 100 years. Average age of the main tree-species - spruce - by the beginning of the modeling period is 82,3 years. The general wood stock per hectare – 77,3 m^3; species structure – 69 % Spruce + 23 % Pine + 7 % Birch.

For the modeling period of a forest stand dynamics without external influences on it (graphic 5.10) we found the following results:

1) Value of 1 hectare of a forest plot has increased from 13,7 thousand roubles up to 84 thousand roubles;

2) Value of 1 hectare of the forest ground for the period has not changed and has made 3,7 thousand roubles;

3) Value of available resources has increased from 1,8 thousand roubles up to 15,6 thousand roubles;

4) Value of the basic part of available resources - merchantable wood - has increased from 1,7 thousand roubles up to 15,5 thousand roubles;

5) Value of secondary wood materials and non-wood products of a forest at the beginning has increased up to age of clear cut from 0,1 - up to 0,3 thousand roubles, then it has decreased on the end of the period to 0,1 thousand roubles;

6) Value of useful functions of a forest plot is a derivative from value of the ground and all available resources. It has increased with 8,2 up to 28,9 thousand roubles.

If to compare economic parameters of this and previous site (01 - the pine forest lichen) it can be noted, that a lower total value of the site (by the beginning of the modeling period and in its dynamics) is caused by lower prices of fir-tree wood, than pine wood.

Besides, in the list of secondary wood materials, in fir-tree plantings there is no such valuable product, as pine gum.

On graphic 5.10 reflecting dynamics of complex estimation of a forest plot value, during age of clear cut (127-137 years) the steep slope is marked. It occurs due to sharp increase in commodity structure of a fir-tree forest stand (of IV productivity growth class) shares expensive to sizable wood.

Therefore, following these data, the clear cut was best not during the period between 50 and 60 modeled years, but during the subsequent period, at the age of a forest stand of 137 years and more.

To a similar conclusion there come also the experts of a forestry investigating conditions of formation of coniferous forest stands in the North of the European part of the Russian Federation.

In later period, approximately from 167 years, reduction in value of a forest plot is marked. It is caused by falling of increment of wood and reduction in the general stock of planting. During this period the number of unhealthy and dying trees increases and the class of marketability of wood is reduced.

It is obvious that to contain planting in declining age (after 167 years) becomes economically inbest.

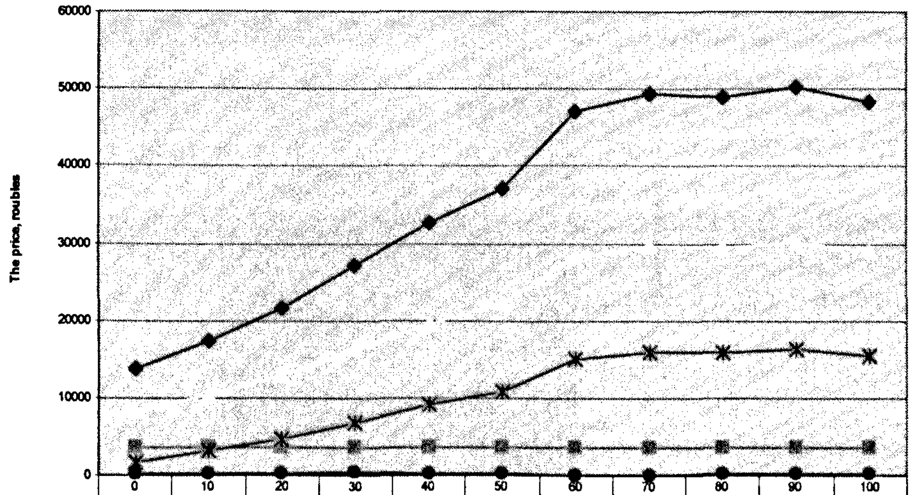
From the data of graphic 5.10 it is visible, that value of secondary wood materials in the beginning increases. It is caused by that stock of the given products of a wood are a combination of two variables: the specification of their output on 1 m^3 of a wood stock (which with increase in age of planting is reduced) and the wood stock (which up to age of main cutting tends to increase).

To age of clear cutting the combination of these two variables conducts to increase of value of stocks of secondary wood materials. After age of clear cutting, in connection with reduction in increment and a wood stock, value of stocks of secondary wood materials tends to reduction.

On graphics 5.11 and 5.12 dynamics of parameters, for conditions of carrying out of clear and selective cabins (spent at the age of the main felling) is resulted.

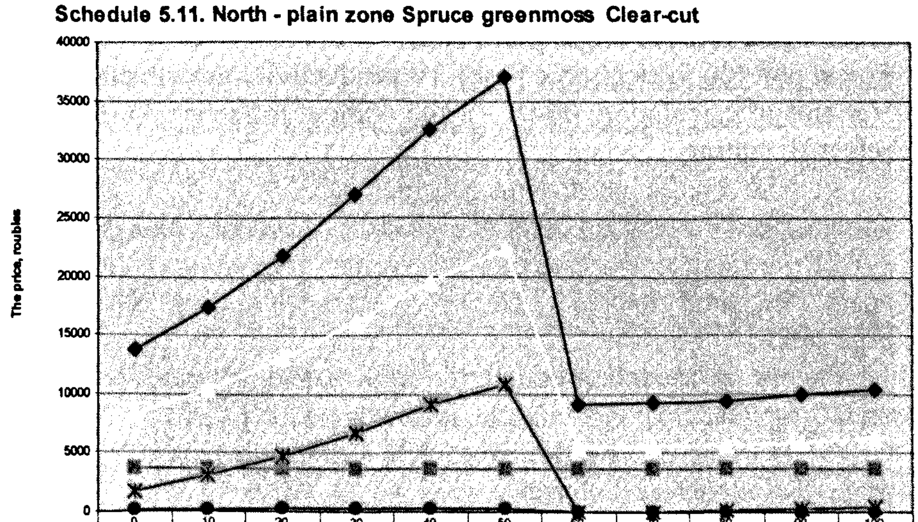
On a site 03, as well as on a site 01 (a pine forest lichen) as a result of performance of selective cutting (a variant 03-03) have been left grove thin trees and understory trees. It rendered positive influence on increment of value of available resources (it has increased in 1,67 times) and increment of value of merchantable wood (it has increased in 1,7 times) in comparison with clear cutting without left grove thin trees and understory trees by variant 02.

Schedule 5.10. North - plain zone Spruce greenmoss No management



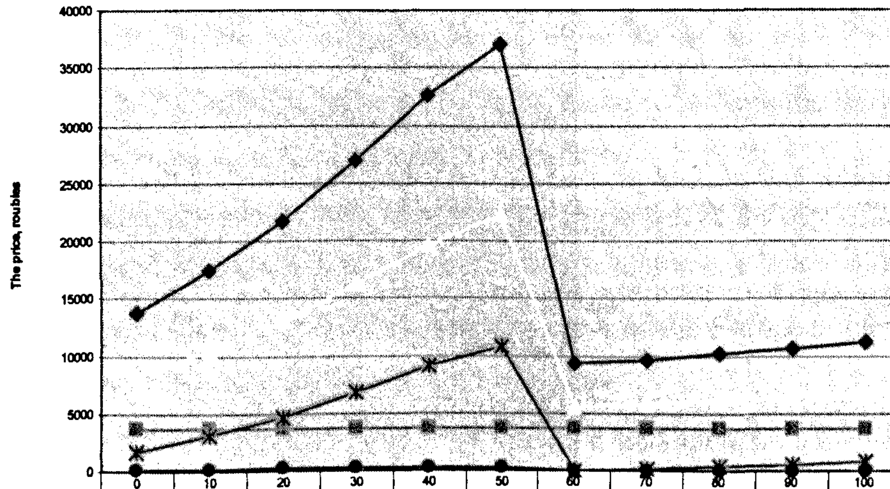
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	13692	17377	21691	27055	32613	37084	47032	49340	49058	50319	48241
Estimation of the forest ground	3668	3668	3668	3668	3668	3668	3668	3668	3668	3668	3668
Estimation of ecological functions	8215	10426	13014	16233	19568	22251	28219	29604	29435	30192	28945
Estimation of forest resources	1808	3283	5008	7154	9377	11165	15145	16068	15955	16460	15628
Estimation of merchantable wood	1693	3094	4736	6813	9124	10851	15041	15965	15844	16344	15496
Estimation of minor forest resources	115	188	272	341	253	314	103	103	111	116	133

Schedule 5.11. North - plain zone Spruce greenmoss Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	13707	17407	21691	27009	32613	37084	9170	9240	9404	9917	10429
Estimation of the forest ground	3668	3668	3668	3668	3668	3668	3668	3668	3668	3668	3668
Estimation of ecological functions	8224	10444	13014	16205	19568	22251	5602	5572	5642	5950	6257
Estimation of forest resources	1815	3295	5008	7135	9377	11165	0	47	93	299	503
Estimation of merchantable wood	1699	3106	4736	6794	9124	10851	0	35	71	275	475
Estimation of minor forest resources	115	188	272	341	253	314	0	11	22	24	28

Schedule 5.12. North - plain zone Spruce greenmoss Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	13692	17377	21646	27009	32585	37065	9294	9625	10181	10651	11266
Estimation of the forest ground	3668	3668	3668	3668	3668	3668	3668	3668	3668	3668	3668
Estimation of ecological functions	8215	10426	12987	16205	19551	22239	5576	5775	6109	6391	6759
Estimation of forest resources	1808	3283	4990	7135	9366	11158	49	182	404	592	838
Estimation of merchantable wood	1693	3094	4718	6794	9113	10843	35	166	386	571	812
Estimation of minor forest resources	115	188	272	341	253	314	15	16	19	22	26

5.2.5. Pine, central taiga, plain zone

Forest plot (06 in electronic base), IV productivity growth class.

Variants of calculation: 06-01 - a site without influence, 06-02 - clear cutting, 06-03 - selective cutting.

The data submitted on graphics 5.13, 5.14, 5.15 reflect dynamics of a total value estimation and its parts of 1 hectare of a forest plot during 100 years. Average age of the main tree-species - pine - at the beginning of the modeling period is 106 years. The wood stock is 273,5 cubic meters per hectare. Structure of planting: 97 % a Pine-tree.

For the modeling period of a forest stand dynamics without external influences on it (graphic 5.13) we found the following results:

1) Value of 1 hectare of a forest plot has increased from 32,9 thousand roubles up to 47,9 thousand roubles;

2) Value of 1 hectare of the forest ground for all period has not changed and has made 4,7 thousand roubles;

3) Value of available resources has increased from 8,5 thousand roubles up to 14,4 thousand roubles;

4) Value of merchantable wood has increased from 7,5 thousand roubles up to 13,0 thousand roubles;

5) Value of secondary wood materials was on the average at a level of 1.5 thousand roubles with deviations from 1,0 thousand roubles up to 2,5 thousand roubles.

6) Value of useful forest functions is a derivative from value of the ground and available resources. It has increased in 100 years from 19,8 thousand roubles up to 28,7 thousand roubles.

In comparison with a site 01 (a pine forest lichen in the North of the republic), the pine forest stand on a considered site is more mature of age (for 33 years). Therefore on graphic 5.13 at planting after 166 years decrease in value of a wood stock is marked. It is caused by degradation of a forest stand. It has caused decrease in value of the available resources, useful functions and the total value of a forest plot. On graphic 5.19 such decrease is not present.

Preservation of planting on a site after 166 years, as well as in the previous case (a site 03), is economically best.

From the point of view of dynamics of available resources value to carry out clear and selective cuttings on a site followed at the age of 160-170 years that is for 30-40 years later.

Lower value of 1 hectare of a forest plot 06 in comparison with value of a site 01 is caused by the following reasons:

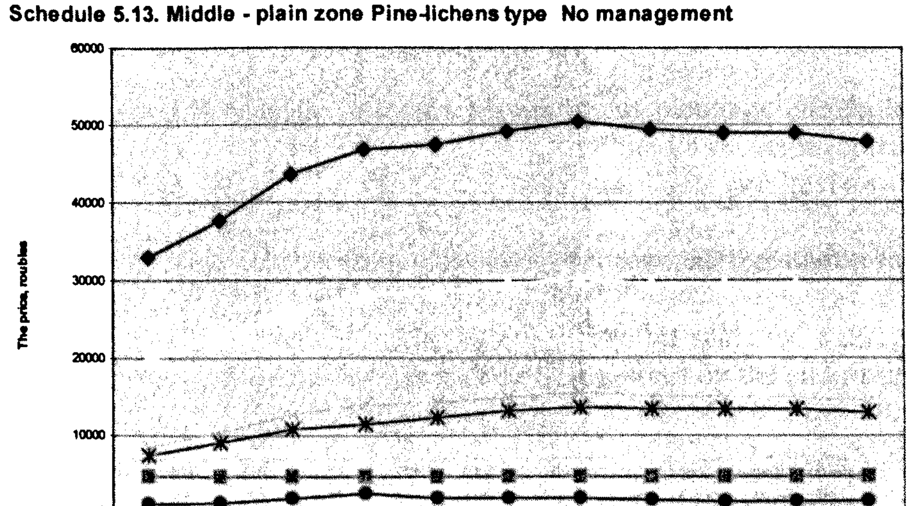
- Different efficiency of the forest ground on these sites. It takes place despite of close parameters such as a type of forest and a productivity growth class. It proves to be true the data of tables going growth of normal forest stands (on a site 01 higher, than on a site 06);

- In commodity structure of round wood on a site 01 (the North of republic) higher share of expensive thick wood, than on a site 06;

- On a site 06 lower stocks of available forest resources and other products of a forest.

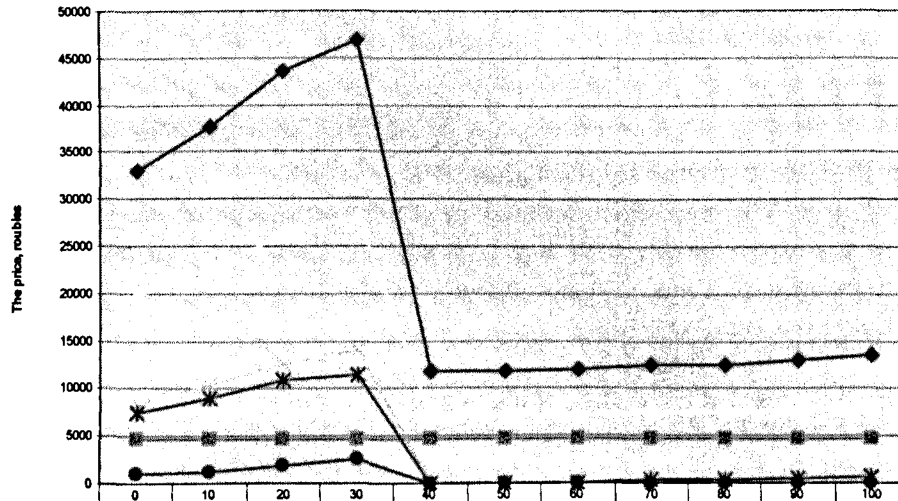
Character of Regeneration of a forest and dynamics of increase of round wood stocks value after clear and selective cuttings confirm (as well as in the previous cases) preferability of selective cuttings before clear cuttings. Presence after selective cuttings of a part of planting with a wood stock on a root at a rate of 17,4 m^3 provides by the end of the considered period achievement of value of a cash stock of resources in the sum of 1,8 thousand roubles. It exceeds the given parameter at continuous cutting 2,4 times.

Schedule 5.13. Middle - plain zone Pine-lichens type No management



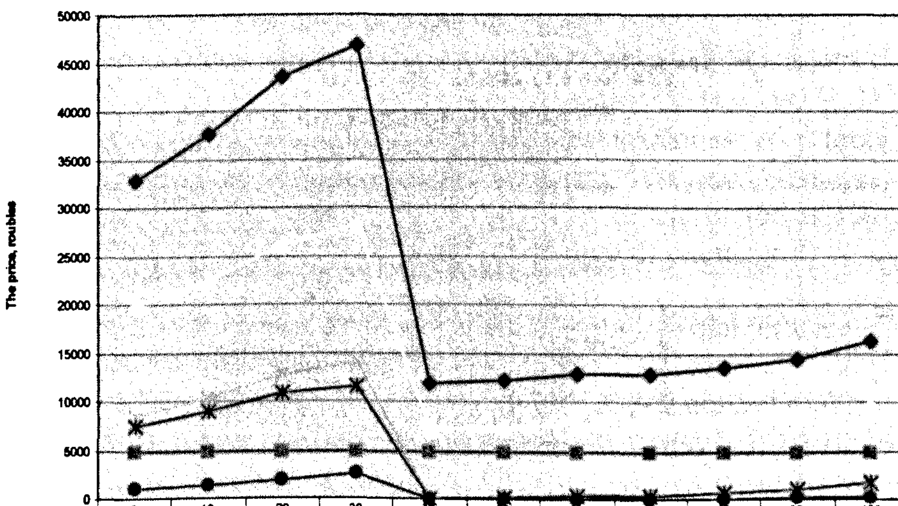
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	32919	37596	43593	46847	47405	49188	50452	49339	48686	49027	47888
Estimation of the forest ground	4695	4695	4695	4695	4695	4695	4695	4695	4695	4695	4695
Estimation of ecological functions	19752	22558	26156	28108	28443	29513	30271	29603	29331	29416	28733
Estimation of forest resources	8473	10343	12742	14043	14267	14980	15488	15040	14859	14916	14460
Estimation of merchantable wood	7479	9065	10897	11451	12298	13092	13663	13387	13335	13320	12972
Estimation of minor forest resources	994	1278	1845	2593	1970	1888	1823	1653	1523	1595	1488

Schedule 5.14. Middle - plain zone Pine-lichens type Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	32919	37598	43593	46847	11737	11867	11949	12500	12549	13005	13616
Estimation of the forest ground	4695	4695	4695	4695	4695	4695	4695	4695	4695	4695	4695
Estimation of ecological functions	19752	22558	26156	28108	7042	7172	7170	7500	7530	7803	8170
Estimation of forest resources	8473	10343	12742	14043	0	43	85	305	324	507	751
Estimation of merchantable wood	7479	9065	10897	11451	0	28	56	272	291	471	710
Estimation of minor forest resources	994	1278	1845	2593	0	15	29	33	34	36	41

Schedule 5.15. Middle - plain zone Pine-lichens type Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	32919	37598	43593	46847	11831	12160	12871	12869	13545	14433	16234
Estimation of the forest ground	4695	4695	4695	4695	4695	4695	4695	4695	4695	4695	4695
Estimation of ecological functions	19752	22558	26156	28108	7098	7296	7722	7721	8127	8680	9740
Estimation of forest resources	8473	10343	12742	14043	37	169	453	452	723	1078	1798
Estimation of merchantable wood	7479	9065	10897	11451	14	144	424	418	684	985	1691
Estimation of minor forest resources	994	1278	1845	2593	23	25	29	34	39	92	107

5.2.6. Pine lichen, central taiga, pre-mountain zone

Forest plot (09 in electronic base). IV productivity growth class.

Variants of calculation: 09-01 - a site without influence, 09-02 - clear cutting, 09-03 - selective cutting.

Parameters of graphics 5.16, 5.17, 5.18 reflect dynamics of a total value estimation and its separate parts of 1 hectare of a forest plot during 100 years. Average age of the main tree-species - pine - at the beginning of the modeled period is 81 year. The general wood stock per hectare - 273,1 m^3; species structure – 92 % pine-tree, 6 % spruce, 2 % birch.

For the modeled period of a forest stand dynamics without external influences on it (graphic 5.16) we found the following results:

1) Value of 1 hectare of a forest plot up to age of 140 years (the period of modeling - 50 years) grew from 31,1 thousand roubles up to 48,8 thousand roubles, and then - on the end of the period - it has decreased to 45,8 thousand roubles;

2) Value of 1 hectare of the forest ground for the period of modeling remained a constant and 6,1 thousand roubles was equal;

3) Value of available resources has increased from 6,3 thousand roubles up to 13,4 thousand roubles at the age of 140 years, and then, by the end of the modeled period, by 180 years, it has decreased to 12,2 thousand roubles;

4) Value of available resources of merchantable wood up to age of 140 years grew from 5,9 thousand roubles up to 12,3 thousand roubles, and then, by the end of the modeled period it has decreased to 11,4 thousand roubles;

5) Value of secondary wood materials and products of collateral using, also, by 150 years has increased from 0,4 thousand roubles up to 1,1 thousand roubles, then, by the end of the period it has decreased to 0,8 thousand roubles;

6) Value of useful functions grew up to age of 150 years from 18,6 thousand roubles up to 29,3 thousand roubles, and then, by the end of the modeled period it has decreased to 27,5 thousand roubles.

Comparing parameters of graphic 5.16 with parameters of graphic 5.13 (a similar site in an average part of Republic Komi) the greater reduction in value of merchantable wood stocks, which has followed after age of 150 years is possible to note.

Probably, as the reason of this sharper reduction presence at planting a mix of fir-trees has served. The fir-tree is less steady forest tree-species than a pine.

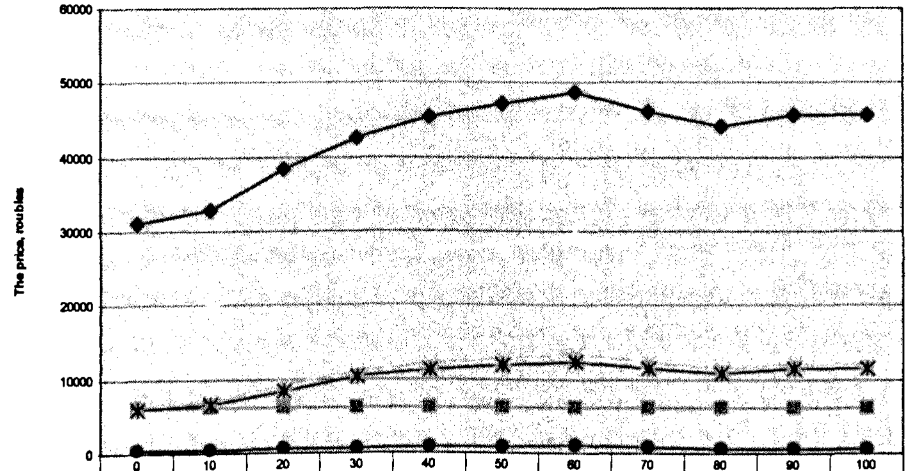
Reduction in value of the merchantable wood, caused by reduction of its stocks and increase faulty wood, has entailed decrease in value of other products of a forest, value of useful functions and a complex estimation of a site as a whole.

As well as in the previous cases (the site 07) in similar plantings should be carried out clear and selective cuttings after age of 150 years, that is on achievement of the maximal value of cash wood stock and other forest products per hectare of planting.

It is possible to note also, that on the influence on process reafforestation the "selective" cutting is more preferable than clear cutting.

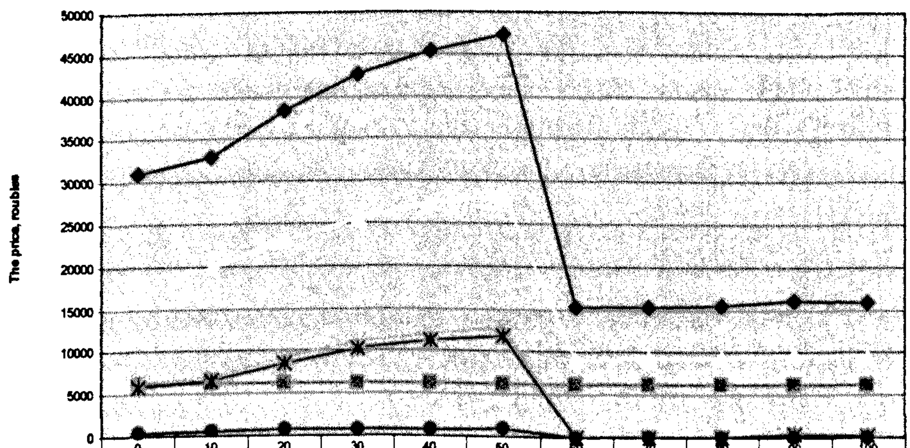
In spite of the fact that the wood stock left on a root (after selective cutting) made only 1,4 m^3 per hectare, value of a stock of available resources on the end of the modeled period more than in 2,8 times exceeded value of a stock of resources after clear cutting.

Schedule 5.16. Middle - pre-mountain zone Pine-lichens type No management



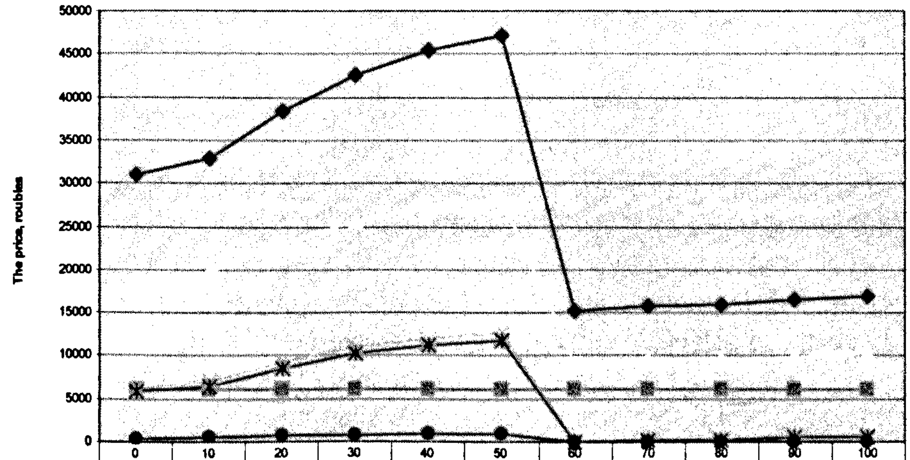
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	31067	32908	38408	42646	45429	47218	48781	46111	44037	45573	45755
Estimation of the forest ground	6108	6108	6108	6108	6108	6108	6108	6108	6108	6108	6108
Estimation of ecological functions	18640	19745	23045	25588	27257	28331	29269	27667	26422	27344	27453
Estimation of forest resources	6319	7055	9256	10951	12064	12779	13405	12337	11507	12122	12194
Estimation of merchantable wood	5859	6543	8485	10265	11195	11819	12339	11433	10762	11405	11432
Estimation of minor forest resources	460	512	770	686	869	960	1066	904	745	716	762

Schedule 5.17. Middle - pre-mountain zone Pine-lichens type Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	31067	32908	38408	42646	45429	47218	15270	15370	15470	16092	15875
Estimation of the forest ground	6108	6108	6108	6108	6108	6108	6108	6108	6108	6108	6108
Estimation of ecological functions	18640	19745	23045	25588	27257	28331	9162	9222	9282	9655	9525
Estimation of forest resources	6319	7055	9256	10951	12064	12779	0	40	80	329	242
Estimation of merchantable wood	5859	6543	8485	10265	11195	11819	0	25	49	298	208
Estimation of minor forest resources	460	512	770	686	869	960	0	15	31	31	34

Schedule 5.18. Middle - pre-mountain zone Pine-lichens type Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	31067	32908	38408	42646	45429	47218	15270	15840	15978	16558	16989
Estimation of the forest ground	6108	6108	6108	6108	6108	6108	6108	6108	6108	6108	6108
Estimation of ecological functions	18640	19745	23045	25588	27257	28331	9162	9504	9587	9935	10194
Estimation of forest resources	6319	7055	9256	10951	12064	12779	0	228	284	516	688
Estimation of merchantable wood	5859	6543	8485	10265	11195	11819	0	207	258	487	657
Estimation of minor forest resources	460	512	770	686	869	960	0	22	25	29	31

5.2.7. Pine lichen, northern taiga, plain zone

Forest plot (01 in electronic base), IV productivity growth class.
Variants of calculation: 01-01 - a site without influence, 01-02 - clear cutting, 01-03 - selective cutting.

Submitted graphics 5.19, 5.20, 5.21 reflect dynamics of a total value estimation and its separate parts of 1 hectare of a forest plot during 100 years. Average age of the main tree-species - a pine - by the beginning of the modeling period is 73 years. The general wood stock per hectare – 89,4 m^3; species structure – 100 % Pine.

For the modeling period of a forest stand dynamics without external influences on it (graphic 5.19) we found the following results:

1) Value of 1 hectare of a site has increased from 3,2 thousand roubles up to 84,0 thousand roubles;

2) Value of 1 hectare of the forest ground for the period has not changed and has made 9,8 thousand roubles;

3) Value of available resources has increased 3,0 thousand roubles up to 23,8 thousand roubles;

4) Value of the basic part of available resources - merchantable wood - has increased from 2,9 thousand roubles up to 21,7 thousand roubles;

5) Value of secondary wood materials and non-wood products of a forest - (minor products of a forest) - has changed about 85 roubles up to 2,2 thousand roubles;

6) Value of useful functions of a forest is a derivative from value of the ground and all available resources. Value of useful functions of a forest has increased with 19,2 up to 50,4 thousand roubles.

In II variant (01-02) dynamics of the same parameters, but under condition of carrying out of continuous cutting with the subsequent independent Regeneration of a forest is reflected.

In III (01-03) variant dynamics of the above-stated parameters under condition of carrying out of selective cabins in the same terms is resulted.

In II variant, after carrying out of final deforestation on 60 year of modeling (at the age of the main felling) the value of 1 hectare of a forest plot has decreased: from 65,0 thousand roubles - up to 24,4 thousand roubles.

In III variant, after carrying out of selective cutting (during the same period, as the main felling) the value of 1 hectare of a forest plot has decreased from 65,0 thousand roubles to 24,6 thousand roubles.

In both variants reduction in value of a forest plot has taken place due to withdrawal of a stock of merchantable wood and merchantableation of stocks of secondary wood materials and non-wood products of a forest. Secondary wood materials have not been withdrawn - their stocks have practically been destroyed at the moment of carrying out of cutting.

The resulted parameters testify that by the value estimations of influence of clear and selective cutting in essence - are identical. It is consequence of the high intensity of selective cutting, which has been carried out.

Diagrams in II and III variants show that after cutting the gain of the value of 1 hectare of a forest plot is much lower than increment of this value up to cutting.

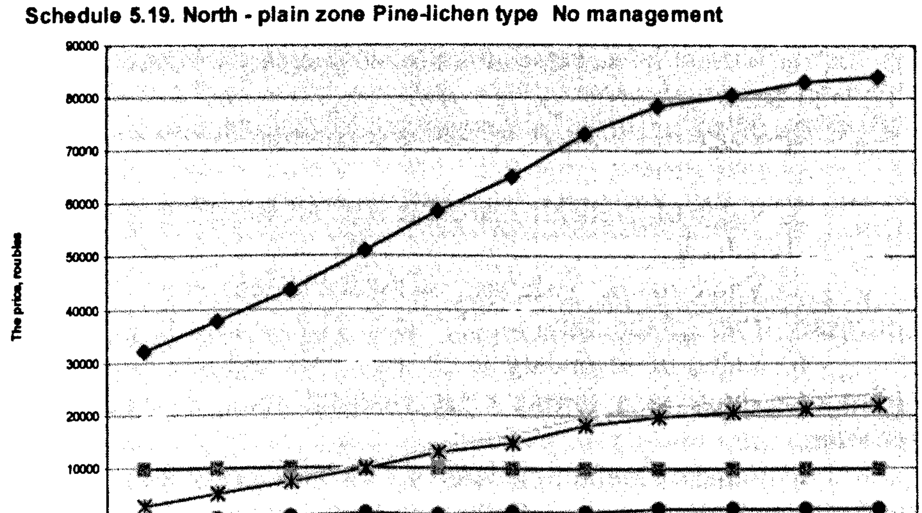
It is defined by that at a stage of Regeneration of a forest (formation of a young forest) - a mid-annual common gain of forest stands is submitted by thin not valuable wood.

The term «selective cutting», applied for a designation of III variant is conditional. The ratio of the chosen and left wood does not correspond to exact Russian definition of the term of selective cutting.

In this variant all commodity wood is practically chosen and is left grove thin trees and understory trees. Their presence also provides more intensive gain of available resources in general and a wood stock, in particular, in comparison with II variant where such grove thin trees and understory trees it has not been left.

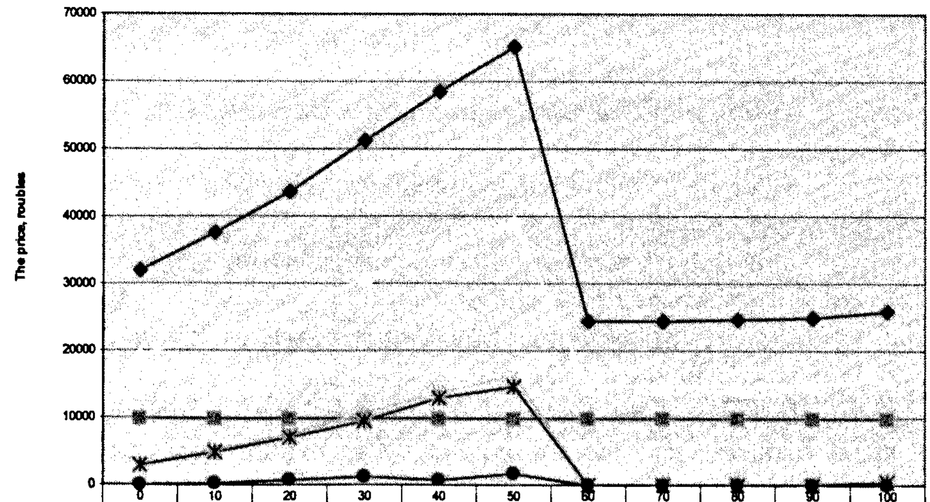
Value of the forest ground of a site without influence on it, with clear and selective cuttings does not vary. The reason of it is that influence of cuttings on pedogenesis does not result processes in essential changes of efficiency of the ground. Changes of quality of the forest ground in the given cases do not fall outside the limits one class of the quality of locality.

Schedule 5.19. North - plain zone Pine-lichen type No management



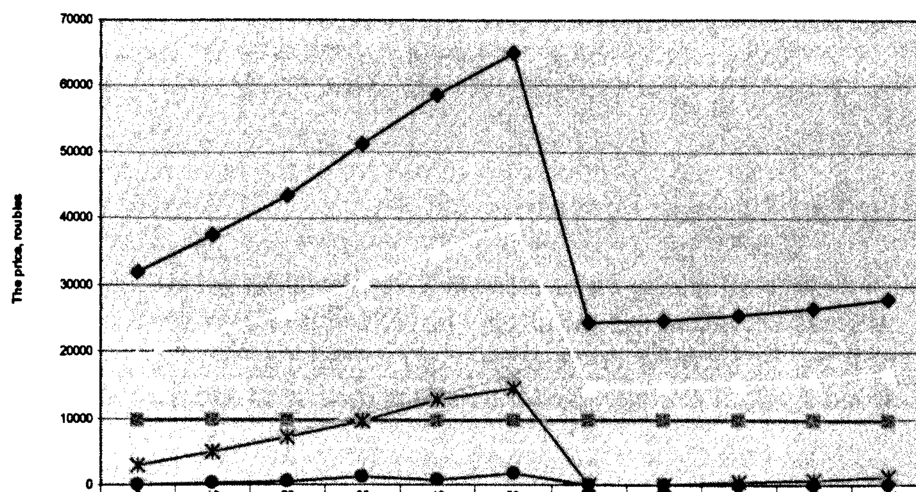
	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	31938	37570	43549	51138	58624	65071	73326	78390	80718	83149	83990
Estimation of the forest ground	9755	9755	9755	9755	9755	9755	9755	9755	9755	9755	9755
Estimation of ecological functions	19163	22542	26130	30663	35174	39043	43996	47034	48431	49689	50394
Estimation of forest resources	3020	5273	7665	10700	13695	16274	19576	21601	22532	23505	23841
Estimation of merchantable wood	2936	4923	7051	9572	12862	14571	17958	19499	20436	21241	21658
Estimation of minor forest resources	65	350	614	1128	832	1702	1617	2102	2097	2264	2183

Schedule 5.20. North - plain zone Pine-lichen type Clear-cut



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	31940	37570	43549	51138	58624	65072	24388	24445	24578	24763	25869
Estimation of the forest ground	9755	9755	9755	9755	9755	9755	9755	9755	9755	9755	9755
Estimation of ecological functions	19164	22542	26130	30683	35175	39043	14633	14690	14747	14858	15521
Estimation of forest resources	3021	5273	7665	10700	13695	16274	0	38	76	150	593
Estimation of merchantable wood	2936	4923	7051	9572	12862	14571	0	23	47	112	555
Estimation of minor forest resources	85	350	614	1128	832	1703	0	14	29	38	37

Schedule 5.21. North - plain zone Pine-lichen type Selective cutting



	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	31940	37570	43549	51138	58624	65072	24517	24665	25408	26432	27968
Estimation of the forest ground	9755	9755	9755	9755	9755	9755	9755	9755	9755	9755	9755
Estimation of ecological functions	19164	22542	26130	30683	35175	39043	14710	14799	15245	15859	16781
Estimation of forest resources	3021	5273	7665	10700	13695	16274	52	111	408	818	1432
Estimation of merchantable wood	2936	4923	7051	9572	12862	14571	30	88	377	768	1343
Estimation of minor forest resources	85	350	614	1128	832	1703	22	24	31	50	89

5.2.8. Birch, central taiga, plain zone

Forest plot (08 in electronic base), IV productivity growth class.

Variants of calculation: 08-01 - a site without influence, 08-02 - clear cutting.

Parameters of graphics 5.22 and 5.23 reflect dynamics of a total value estimation and its parts of 1 hectare of a forest plot for 100 years. Average age of the main tree-species - birches - at the beginning of the modeled period is 40 years; the general stock - 75,2 m^3; species structure – 89 % birch, 7 % pine-tree, 4 % spruce.

For the modeled period of a forest stand dynamics without external influences on it (graphic 5.22) we found the following results:

1) Value of 1 hectare of a site has increased from 4,6 thousand roubles up to 14,5 thousand roubles;

2) Value of 1 hectare of the forest ground for the period has not changed and has made 1,5 thousand roubles;

3) Value of available resources has increased from 0,4 thousand roubles up to 4,3 thousand roubles;

4) Value of merchantable wood has increased from 0,3 thousand roubles up to 4,2 thousand roubles;

5) Value of secondary wood materials and non-wood products was in limits from 28 roubles up to 168 roubles;

6) Value of ecological functions has increased from 2,8 thousand roubles up to 8,7 thousand roubles.

In spite of the fact that the modeled period includes a stage of birch forest stand maturing and the subsequent (after mature age) stage of its degradation and natural destruction, on the graphic is observed constant (without recession) increase in value of a forest plot.

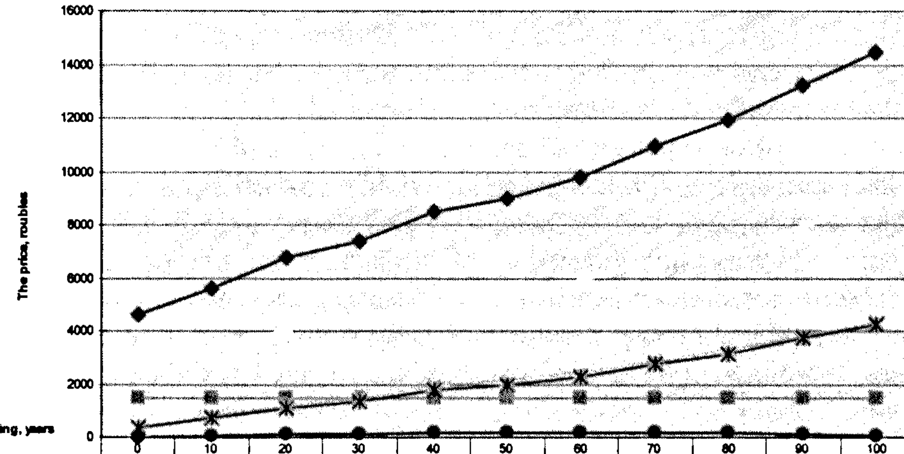
Initially in birch planting there was a mix of a pine and fir-trees. During growth and accumulation of large diameter wood simultaneously with the drain of birch increased shares of a fir-trees and a pine. Higher price of coniferous tree-species provides overlapping loss of value of stocks of the merchantable wood connected with attritions of a birch. Besides at natural plant destruction there is a strengthening of a growth of the rest of a fir-trees and a pine on diameter. All this together also has led to a constant increase of value of a forest stand, which at the end of the period has reached average-aged 140 years.

Reduction in value of the given forest plot connected with the subsequent degradation of its coniferous component lies outside the analyzed period (the modeled period).

Graphic 5.23 reflects the dynamics of the birch site value after clear cutting at the age of the main tree-species - 60 years.

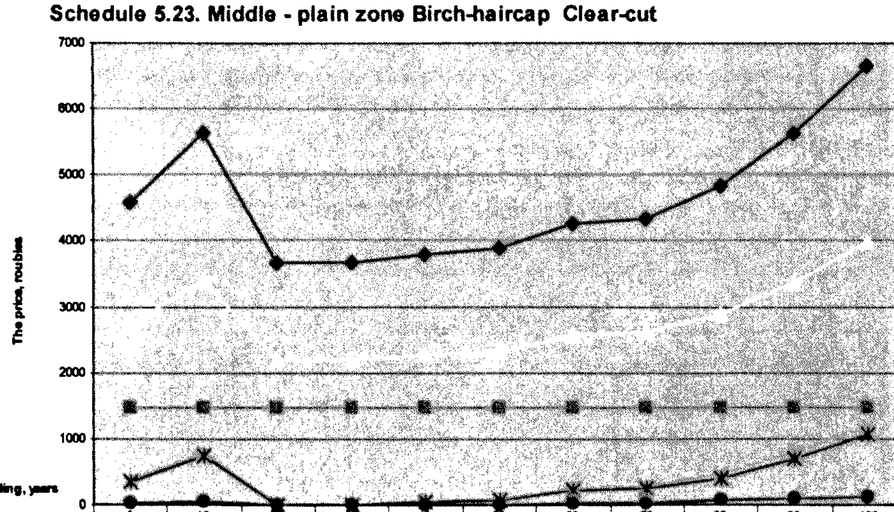
According to graphic 5.22, it is impossible to approve categorically the advantage of cutting later. If the activity is conducted with the purpose of birch round wood later cutting can negatively be reflected in its quality and quantity. Financially it will not be seen (to be compensated) because of the increase in total value of round wood stock of average-aged pine and spruce trees and their young growth.

Schedule 5.22. Middle - plain zone Birch-haircap No management



The period of modelling, years	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	4586	5629	6799	7385	8501	8998	9804	10942	11956	13222	14483
Estimation of the forest ground	1462	1462	1462	1462	1462	1462	1462	1462	1462	1462	1462
Estimation of ecological functions	2752	3377	4079	4431	5101	5399	5882	6565	7174	7933	8690
Estimation of forest resources	373	790	1258	1492	1939	2137	2460	2915	3321	3827	4332
Estimation of merchantable wood	344	747	1135	1345	1771	1978	2294	2758	3186	3729	4253
Estimation of minor forest resources	28	42	122	147	168	159	166	157	155	97	79

Schedule 5.23. Middle - plain zone Birch-haircap Clear-cut



The period of modelling, years	0	10	20	30	40	50	60	70	80	90	100
Estimation of a forest plot	4586	5629	3655	3655	3777	3876	4259	4340	4824	5620	6645
Estimation of the forest ground	1462	1462	1462	1462	1462	1462	1462	1462	1462	1462	1462
Estimation of ecological functions	2752	3377	2193	2193	2286	2326	2556	2604	2894	3372	3967
Estimation of forest resources	373	790	0	0	49	89	242	274	468	786	1196
Estimation of merchantable wood	344	747	0	0	43	78	228	257	405	696	1077
Estimation of minor forest resources	28	42	0	0	6	11	14	17	62	88	119

***

Comparing the results of value estimation of forest sites we see that its value is mainly determined by the main tree-species. The calculations show, that 1 hectare of pine forest has in 1,5-2 times more value, than 1 hectare of spruce, and 1 hectare of spruce has 2-4 times more value than 1 hectare of birch.

The influence of such characteristics as productivity of the forest ground (productivity class), age and forest stand condition on the value of a forest site is less.

Within the range of one tree-species, its age and percent of merchantable wood have direct influence on the quality structure (characteristics) of wood on stem. This influence is taken into account, when we estimated the value of the real and model (reference) forest stand.

The density of valuable wood in mature and maintained forest stands is higher. This rule is underlined by analysis of wood growth tables.

Especially it is necessary to take into account, that at a value estimation of a forest site, except for the listed above factors, greatly is dependent on the zone of tax rates to, which the territory of a site is related.

For example, site 01 located in the North of Komi is related to the 52nd zone of tax rates and site 09, located in the middle part of Komi is related to the 72nd zone of tax rates.

For example, the price of large diameter timber of a pine on site 01 is 69 rubles a cubic meter (4 category of tax rate), and the price for the same wood quality on site 09 is 39 rubles a cubic meter. Such distinction in price results in different rent estimations for a hectare of forest ground, located in different tax regions of republic.

So, for an value estimation of a hectare of forest it is necessary to take into account, that it is dependant not only on the type of a forest, species structure, age and a class of marketability of forest stands, but also on distinctions in prices for wood on stem in various zones and tax rate categories. This position is of importance also to other forest products.

The government of the Republic of Komi is responsible for the establishment of tax zones and rate categories for as well wood on stem, as for other forest products.

6. Discussion and conclusions

In this pilot study, we explored the possibilities of using the ForGra forestry model to evaluate different forest management strategies in the Pechora Basin in terms of forest production, forest development, biodiversity and economics. A second aim was to integrate these results in the PKS. Based on the existing parameter sets for comparable species for The Netherlands and additional literature, the five most important tree species were parameterised and calibrated against local growth and yield tables. Based on a very broad classification (according to vegetation zone, altitude and dominant tree species) and availability of field data, a selection of eight forest types was made that were studied further. Each forest type was subjected to three different forest management regimes: no management, clearcut and selection felling. For the latter management option, some modifications were made to the ForGra model.

The simulation outcomes generally reflected succession patterns as observed in the field and as reported in existing literature (Degteva 2004). However, some aspects of parameterisation and calibration would need further investigation, particularly the competition between overstory and seedlings/understory trees.

The simulation outcomes were classified in the same way as the MODIS classification. By combining this with the biodiversity assessment, we were able to give an indication of the development of the potential number of red list species that could be expected under the different management scenarios. Further, a tool was developed to integrate the simulation results into the PKS. This tool can generate maps of forest type and potential number of tree species for a 100 year period, based on initial forest type, forest age and management regime. In a way similar to the biodiversity assessment, the outcomes of the simulations were analysed in economic terms.

This study demonstrates that it is very well possible to model the development of individual forest types and use the results for subsequent analyses, as demonstrated by the biodiversity and economic assessments. However, the forest model is sensitive to uncertainties in the parameterisation and calibration of the model and thus simulation results should be interpreted with care. The link with biodiversity is implemented in a very rough way, because a detailed analysis of dependencies of species on specific forest characteristics was lacking. However, we demonstrated that this link can be made in a much more sophisticated way, which seems a promising way to continue this kind of work. Also the link with the PKS could be improved, with more options for the user to edit the management maps and with a better classification.

7. Recommendations

7.1. General

This study was meant to be a pilot study to explore the possibilities for the application of forest models in the Pechora Basin and their use in evaluating the effects of forest management on biodiversity and economics. Although it proved to be very well possible to use the ForGra model for this purpose, several issues came up that would need attention or consideration in a possible follow-up of this project. In this chapter we would like to give some recommendations for possible follow-up projects or other future research in this field.

7.2. The forest simulation model

In the current application of ForGra, some processes are not included that might be important for the simulation of forests in the boreal region. A prominent example is the role of fire. Forest fires are an important part of the boreal ecosystem and can change the succession pattern drastically. However, fire is a highly stochastical event, depending on abiotic conditions and the spatial dimension is very important. Inclusion of fires would therefore probably need different types of models, able to operate on a much larger scale.

Within this study, no effects of ground vegetation were taken into account. However, ground vegetation can severely hamper natural regeneration, and can be in itself a very important part in determining forest type and biodiversity. Within the current version of Forgra, limited options are available to include ground vegetation.

Site conditions are currently not taken into account directly in Forgra. Large parts of the boreal forests are covered with peat bogs, sometimes sparsely populated by pines. Simulation of such forest types would probably lead to an immediate increase of tree cover and standing volume, because the effects of a high ground water table on tree growth and regeneration is not included in the model.

7.3. Parameterisation and calibration

In the calibration process, the simulation of seedlings or very young trees proved to be very difficult. It is not clear what the cause of the difficulties is, but this should be a point of attention in future applications of the model.

Many parameters that are needed in the model are difficult to obtain from literature, such as the germination and survival of seedlings in relation to light availability. We used the parameterisations for The Netherlands in case no alternative was available, but the background of these parameters is not always clear.

In the current study, only the five most important (abundant) tree species were taken into account. However, less abundant species can be very important for biodiversity and forest structure as well. Therefore, it would be very important to include more species in the simulations.

7.4. Initialisation and set up of the model

For the initialisation of the different forest types, only a limited number of suitable field plots were available. Further, they are from a very small geographic area. It is therefore questionable how well these represent the total forest area of such a type. Moreover, the field plots did not match the pixel size of the model. We therefore needed to modify the information of the field plots to get the desired pixel size. This may amplify uncertainty in the initial situation. In future applications, the field work should be planned more carefully to avoid such mismatches, and to allow a more stratified sampling of the forest types that will be simulated. Furthermore, more field plot data may be present at the Russian institutes from earlier field expeditions.

The driving variable in the model is the amount of light that is available each month. Because we did not have a dataset available for the study area, we acquired this via a weather generator. Considering the huge area of interest, this driving dataset should take into account the variation over the entire area. Also the growing season length is now fixed for all locations, but should vary with the location. However, this would call for a totally new parameter set for each region, which was not feasible in the current project.

7.5. Integration with the PKS

The extrapolation of the model results on a few field plots via a few forest types to such a huge area is certainly questionable. Future studies should be more aware of this problem, with either a focus on a particular area or a better representation of forest types.

The current possibilities of exploring the forest simulations in the PKS are only limited. The user cannot define a forest management map himself, but has to choose from three pre-set maps. It would be much more interesting for the user to be able to focus on a certain area and have the possibility to play with it. Furthermore, a very weak point is the lack of information on current forest age. It is likely that the older clearcuts are located close to settlements and roads, while we assumed a totally random pattern. An accurate forest age map would be very valuable to reveal current patterns in relation to other objects, such as roads, and also for decisions for possible future harvest areas.

The economic analysis could also be linked into the PKS system, in a way similar to biodiversity. This would allow the generation of forest values maps at different scales. It would then also be possible to link the economic analysis to other characteristics, such as transporting distances to the mill.

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Annex 1. Parameter values of different species as used in the FORGRA simulations

	Betula	Pinus/Larix	Picea/Abies
Maximum seed number to be produced	120000	20000	45000
Average seed weight, air dry	0.15	6	10
Fraction sound seeds produced out of total seed production	0.73	0.9	0.7
Frequency of volmast	0.3	0.2	0.2
Frequency of halfmast	0.6	0.4	0.3
Frequency of deelmast	0.8	0.5	0.5
Initial height newborns (m)	0.01	0.01	0.01
Initial shoot/root ratio newborns	0.7	0.3	0.7
Specific leaf area (cm2 gr-1)	150	41	50
Specific wood density (kg.m-3),	300	350	420
Radiation use efficiency (gr MJ-1)	0.7	1	0.925
Radiation extinction coefficient	0.5	0.5	0.5
Maximum age (years)	200	600	300
Maximum crown radius	3	4	5
Chapman-Richards growth equation parameter 1	0.023334	0.018659	0.02471
Chapman-Richards growth equation parameter 2	1.688474	1.318261	2.432852
Chapman-Richards growth equation parameter 3	24.34528	21.63548	22.58489
Shumacher Hall stem volume parameter 1	0.0696	0.0561	0.0879
Shumacher Hall stem volume parameter 2	1.5429	1.8208	1.9005
Shumacher Hall stem volume parameter 3	1.2423	1.0743	0.8073
Threshold for mortality of tree: number of years with insufficient diameter growth	3	3	6
Maximum H/D ratio	3	4	4
Mortality parameters dependent on age	8	6	8
Mortality parameters dependent on h/d-ratio	10	10	4
Parameters allometric relation seedlings 1	3.45	4.05	4.05
Parameters allometric relation seedlings 2	2.89	2.15	2.15
Parameters allometric relation for shoot weight 1	5.38	3.947	2.047
Parameters allometric relation for shoot weight 2	1.08	0.962	1.135
Parameters allometric relation for shoot weight 3	0	0.255	0.397
Parameters allometric relation for root weight 1	-0.451	0.164	0.936
Parameters allometric relation for root weight 2	0.9294	0.831	0.758
Parameter concerning optimal distribution of dry matter 1	-1.2585	-1.1734	-1.0711
Parameter concerning optimal distribution of dry matter 2	-0.4566	-0.1762	-0.2005
Parameter concerning optimal distribution of dry matter 3	-0.0451	-0.0137	-0.0119
Parameter concerning optimal distribution of dry matter 4	0	-0.0028	-0.0011
Parameter concerning optimal distribution of dry matter 5	-0.586	-1.1929	-1.0793
Parameter concerning optimal distribution of dry matter 6	-0.2472	-0.0208	-0.0536
Parameter concerning optimal distribution of dry matter 7	-0.0453	-0.0368	-0.0419
Parameter concerning optimal distribution of dry matter 8	0	0.0022	0.0031
Relative growth rate seedlings	0.7	0.45	0.35

Age related seed production, as fraction of absolute maximum

Betula	Age	1	10	20	300
	Fraction	0	0	1	1
Pinus/Larix	Age	1	15	60	300
	Fraction	0	0	1	1
Picea/Abies	Age	1	25	50	300
	Fraction	0	0	1	1

Relation between light availability at forest floor (fraction of total light) and establishment of germinated seeds (fraction of sound seeds)

	Fraction of light available	0	0.4	0.6	0.8	1
Betula	Fraction established	0	0.02	0.1	0.16	0.4
Pinus/Larix	Fraction established	0	0.01	0.05	0.08	0.2
Picea/Abies	Fraction established	0.01	0.3	0.3	0.2	0.1

Relative loss rate branches per month

Month	1	2	3	4	5	6	7	8	9	10	11	12
Betula	0.01	0.01	0.01	0	0	0	0	0	0	0	0.01	0.01
Pinus/Larix	0.01	0.01	0.01	0	0	0	0	0	0	0	0.01	0.01
Picea/Abies	0.01	0.01	0.01	0	0	0	0	0	0	0.01	0.01	0.01

Relative loss rate foliage per month

Month	1	2	3	4	5	6	7	8	9	10	11	12
Betula	0	0	0	0	0	0	0	0	1	0	0	0
Pinus/Larix	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1
Picea/Abies	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1

Relative loss rate roots per month

Month	1	2	3	4	5	6	7	8	9	10	11	12
Betula	0.02	0.02	0.02	0	0	0	0	0	0	0	0.02	0.02
Pinus/Larix	0.02	0.02	0	0	0	0	0	0	0	0	0.02	0.02
Picea/Abies	0.02	0.02	0.02	0	0	0	0	0	0	0	0.02	0.02

Minimum diameter growth rate (cm) required for survival (dbh-dependend)

Betula	DBH	0	1.5	5.5	8.1	10.9	13.3	15.3	16.8	17.8	20	25	26
	Growth rate	0	0	0.01	0.03	0.05	0.1	0.1	0.1	0.12	0.17	0.2	0
Pinus/ Larix	DBH	0	1.5	5.6	15.5	19	21.9	23.9	24.6	25.5	29.6	32	50
	Growth rate	0	0	0.03	0.1	0.1	0.1	0.1	0.1	0.2	0.25	0.05	0
Picea/ Abies	DBH	0	3	4.3	6.8	9.4	15.9	17.4	20.6	22	23.1	3	100
	Growth rate	0	0	0.03	0.04	0.05	0.05	0.05	0.05	0.03	0.05	0.05	0

Seedling mortality in relation to light availability

	Fraction of light available	0	0.1	0.25	0.5	0.75	1
Betula	Seedling mortality	1	0.2	0.1	0.06	0.01	0
Pinus/Larix	Seedling mortality	1	0.2	0.1	0.06	0.01	0
Picea/Abies	Seedling mortality	1	0.5	0.1	0.035	0.018	0

Reduction factor seedling growth in relation to light availability

	Fraction of light available	0	0.25	0.5	0.75	1
Betula	Growth reduction factor	0	0.3	0.6	0.9	1
Pinus/Larix	Growth reduction factor	0	0.3	0.6	0.9	1
Picea/Abies	Growth reduction factor	0	0.45	0.7	0.9	1

Fraction of seeds dispersed

Month	1	2	3	4	5	6	7	8	9	10	11	12
Betula	0.1	0.1	0.1	0.1	0	0	0	0	0	0.4	0.1	0.1
Pinus/Larix	0	0	0.1	0.4	0.5	0	0	0	0	0	0	0
Picea/Abies	0	0	0.2	0.5	0.1	0	0	0	0.1	0.1	0	0