Critical evaluation of frequent thinnings from the aspect of energy consumption and damages in the stands

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Abstract

The co-natural forest management has been demanded in Forest Act in Slovenia for many years. A part of co-natural approach is based on tending the stands, which is done repeatedly with the thinnings. So far, there has been a clear tendency to act in the forest intensively in time if the stands are able to react positively to our measures. The effect of tending is highest in young development phases but in these phases the principle is faced with strongest economical limitations. The consequences of the cuttings in younger phases are also damages of the standing trees which remain in the stands for a long time - until the end of the rotation period. Accumulated damages of the standing trees seriously endanger the positive effects of the tending. Evaluating the above statements, we used a mathematical model and simulations. The results from the model were also compared to the field observations in the stands of different ages. The comparison showed a close connection between the model results and the real situation in the forest. The paper discusses possible improvements. With later and less frequent thinnings we could probably get higher value of wood with less energy consumption and with better economical result. Present technologies of felling trees and long wood extraction are not adapted to intensive forest management on the principle of co-natural, sustainable and multifunctional forest management. One of the reasons is a very large share of damaged remaining trees during every forest operation (around 20 %). Where possible, the technologies should be changed to shortwood systems. Forest operations should be planned and done much more carefully.

Keywords: damages, forest operations, thinnings, co-natural, forest management, Slovenia

1 Introduction

Despite proclaimed principles of sustainability, co-natural and multifunctional management is in practice many times contrary to possibilities of man's cappabilities. They remain distant wishes. The difference between the desired and the possible remains a source of discussions among foresters. The arguments give legacy to those who say modern techniques are not adapted enough to forest environment, and also to those who argue that the ways of practical forest management do not include sustainable economics and real possibilities of forestry operations. Even-aged and mainly spruce alpine stands in Slovenia are very suitable for the study of coordination between silvicultural concepts and technical abilities to do proper work. The reason they were chosen for this study lays in good comparability with some parts of Europe as the Alps and some parts of Scandinavia where similar stands and terrain conditions could be found as well. With this we do not ignore the specifics of the Slovenian sites. We are only trying to simplify the comparison. In this paper we were interested in, what kind of long term consequences we can expect from widely used concept of early, low intensity and frequent thinnings on rationality of the management of these stands. For estimating the rationality we took in account the performed energy, harvesting costs, damages of remaining standing trees and the value of annual volume cut. The goal of research was to build a model of spruce stand development and to find relations between age and tree diameter distribution on one side and harvesting time, energy consumption (machine and manual work), harvesting costs and the value of timber from undamaged and damaged trees when they are cut.

2 Methods

2.1 Model of spruce stand development

Input data for the model are the number of trees per hectare, average stand diameter, growing stock and the data of thinnings in certain age (Halaj et al. 1987, Kotar 1995). For achieving distribution of stand diameters in certain age we used the Gauss normal function. The parameters for each age (a five-year interval) distribution were arithmetical mean of stand diameter or mean diameter of the thinning and standard deviation which were 1/3 of the mean. The result was the distribution of stand diameters as well as volumes according to age for original stand and for each thinning during the rotation age of 160 years. These data were used for computing cutting time (motor-manual) and wood extraction (adapted tractor). Model covers the period from the end of previous regeneration period to the beginning of establishing next generation. Rotation period of 160 years which is too long for normal spruce stands is chosen according to silvicultural practice in mountain forests where the possibility of producing high quality and large timber is the most important goal.

2.2 Working time and energy spent for cutting and wood extraction

Working times for cutting with a motor saw were calculated with regression analysis of data of the actual workers' performance during two last years in alpine spruce stands. Equation (1)is valid for cutting spruce on high mountain plateaus and for bucking up to 12m long assortments without barking.

$$Ntsec = 29.2 + 12.6/v - 0.017/v^3 + 1.24 \cdot v \quad (1)$$

Where:

Ntsec working time in min/ m^3;
v volume of timber in tree in m^3.

Standard times for wood extraction with adapted wheeled tractors were calculated according to the acquation:

$$Ntspr = 1.13/v + 12.90 \quad (2)$$

Where:

Ntspr working time in min/m^3;
v volume of timber in tree in m^3.

Fuel consumption for cutting with motor saw (l/m^3) was calculated:

$$Ecsec = 0.0092 \cdot Ntsec \quad (3)$$

Fuel consumption for wood extraction (l/ m^3) was calculated:

$$Ecspr = 0.05 \cdot Ntspr \quad (4)$$

Energy consumption of the machine and manual work during cutting and skidding was calculated with assumption that a motor saw needs 0.67l/kW of gasoline, a tractor 0.31l/kW of diesel oil, a cutter needs 29.3 and a tractor operator 14.7 kJ/min of work.

2.3 Value of timber and operational costs

The value of timber was calculated from the structure of assortments in dependance on brest height diameter of the tree (Fig.1). This value was calculated for every thinning in different ages and for every tree diameter in the stand. We took the following selling prices of the timber: veneer 16,500SIT, sawlogs I – 12,000SIT, sawlogs II – 9,500SIT, sawlogs III – 6,500SIT and pulpwood and other assortments – 4,000SIT/ m^3 (data for January 1998, 1DEM = 92SIT).

The value of timber that is bucked from damaged trees was calculated with correction of the value dependant on the age of the wounds in the stand. Damaged trees in first thinnings remain in the stand for a very long time and their final value was only 20 % of undamaged trees.

The costs of cutting were taken as 2,406 SIT/h, costs of tractor skidding 4,332 SIT/ m^3 (January 1998). The fuel prices were: 1l of motor saw gasoline – 108.56 SIT/l and diesel oil – 86.20 SIT/ m^3. The costs of 1 kWh in cutting was therefore 72.74 SIT in tractor skidding 26.72 SIT. The costs of manual work during cutting were 1,175.00 SIT and in wood extraction 588.00 SIT/kWh.

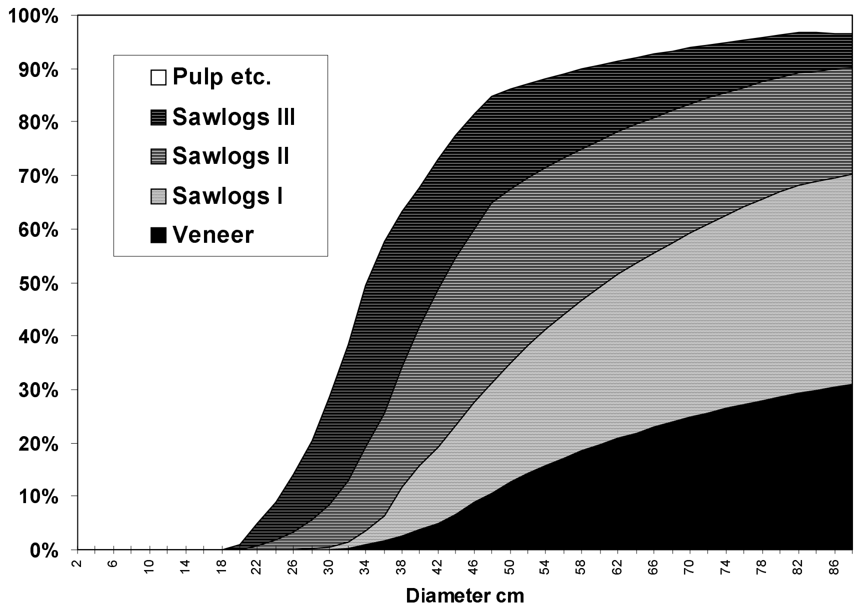

Figure 1. Structure of assortments in dependance on brest height diameter of the tree.

2.4 Damages of the standing trees

Parameters which influence the share of damaged standing trees (new and old damages) after each thinning are the intensity of thinning and the share of damaged trees in actual thinning. After many thinnings the damages are accumulated in the stand and the final result is calculated from the following formula (Košir, Cedilnik 1996, Košir 1996, 1998):

$$D_n = 1-(1-D_0) \cdot \prod_{i=1}^{n} (1-d_i) \qquad (5)$$

Where:

- n number of years;
- D_0 share of the damaged trees before the thinnings began (original stand),
- d_i share of the damaged trees in i thinning.

When we repeat thinnings the new damages join the previous ones, and the share of damaged trees is increasing and slowly approaching 100%. The final share depends on the number of thinnings and on the share of the damaged trees before the thinnings begin.

3 Results

3.1 Model of stand development

Model of stand development gave us diameter structure of the stand for each five-year period according to so frequent thinnings. The growing stock of the stand before and after thinning was therefore defined, as well as the diameter structure and timber volume of each thinning. Distribution of tree diameters was normal, therefore the distribution of the tree volume was slightly assimetrical. That was true for the stand as well as for the thinnings. Total value of number of the trees and their volume through the rotation period is shown in Fig. 2, where the dependance of the tree number and their

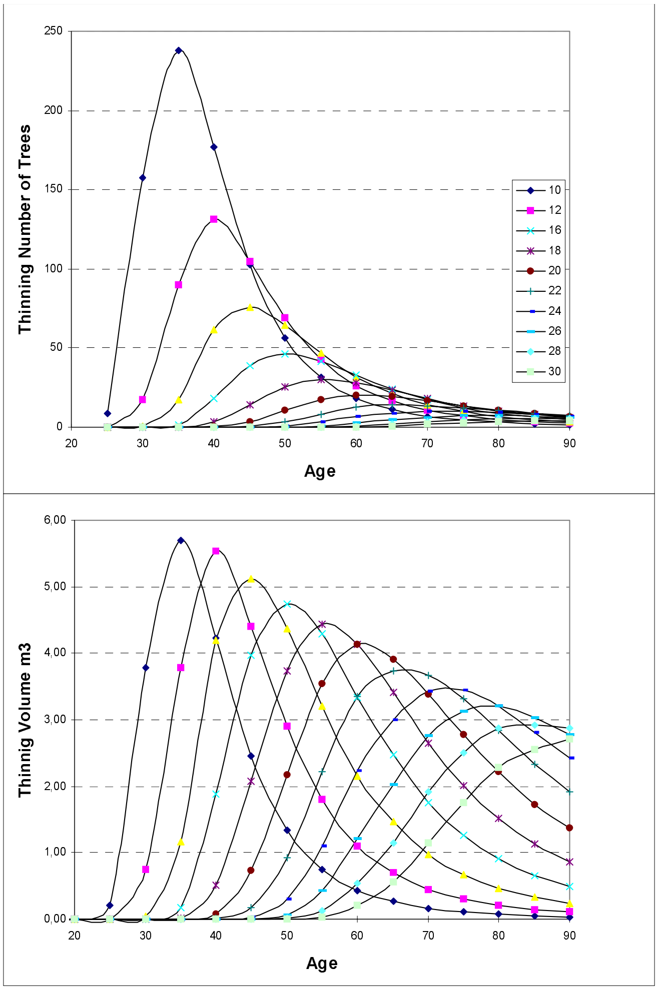

Figure 2. Distributions of trees according to age and diameter (range 10 to 30 cm as an example).

volume on the age of thinning is also displayed. Small wood prevails during the whole rotation period because larger tree diameters emerge in late ages.

This type of distribution significantly influenced the results. According to the input data we had to handle with great number of thinnings – as it is built in the concept of intensive forestry - where intensities of removed trees in thinnings are very small. The number of removed trees decreased very fast with the age whereas the volume of the thinning stood on almost the same level. The distribution of tree diameters in the whole rotation period has therefore a typical assimetrical distribution with modus around 26 cm.

Comparison with the similar study that was done for similar reasons in different places in Slovenia in spruce stands of prealpine region shows the essential difference in shorter rotation age and more intensive thinnings as we assumed in our case (Krajcic 1996). That resulted in smaller average tree diameter and volume, which can be explained with different silvicultural concept.

3.2 Working time spent, consumption of energy and operational costs

Tree diameter structure is directly involved in harvesting working time and needed energy. Working time is defined with standard times functions and degresively decreases with the tree diameter. The working time spent in harvesting in the juvenile stage of the new stand equals zero. At this time we do in the young stand first silvicultural works which are not included in the model. After the age of 25 years we start with the first thinnings where the majority of work is devoted to cutting the trees with a motor saw. The share of working time used for wood extraction in later development phases increases (Fig.3).

Working time is closely connected to energy consumption. The energy consumption in harvesting in dependance on the age of thinning shows very similar feature, slightly in favour of cutting because in wood extraction the energy consumption is higher. Most of the fuel we need in the whole rotation period is spent in thinnings up to 80–90 years (Fig.4). In later thinnings the demand for energy slowly decreases. Connection between this reasoning and emissions to the environment that have origin in burning fossil fuel and using lubricants shows us that in the time of early thinnings – where we can influence important selection of individual trees - the impact on environment is the greatest.

In total costs of working with machine the costs of energy represent a signifficant share (Fig.5), because they consist the sum of direct costs of fuel as well as the costs of manual work. In cost calculation of working hour we also find other costs which make the dependancy between the energy consumption and total costs of working hour unclear, but are important for comparison with the selling price of timber. Machine and manual work, differing in ammount of input energy per unit of production, show the state of technology in certain time. If we do not include the diversity of working conditions in wood extraction, the tree size has the major imact on the input energy. It is obvious that in whole rotation period the number and intensity of thinnings are also extremely important when we talk of energy consumption.

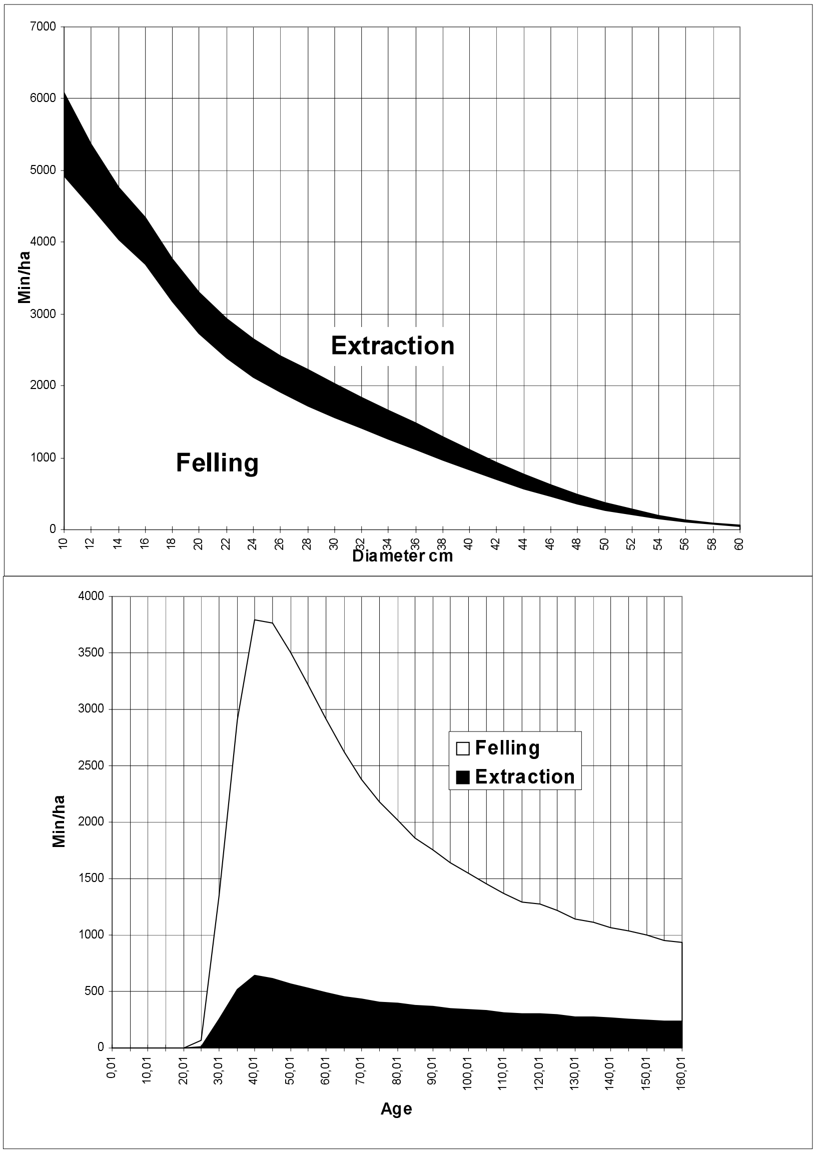

Figure 3. Working time of felling and wood extraction (min/ha).

Energy consumption of the manual work is within existing technology at every tree diameter smaller than machine work, and reaches the level of 10–12 manday/100m^3 at the trees larger than 30cm. Machine work energy input is at those tree dimensions around 33–35 kWdays/100 m^3. This estimation is true mostly for larger trees, while for modus of tree diameters (26cm, 0.46 m^3/tree) the input of manual work would be 15 manday/100 m^3 and machine work 41 kWdays/100 m^3.

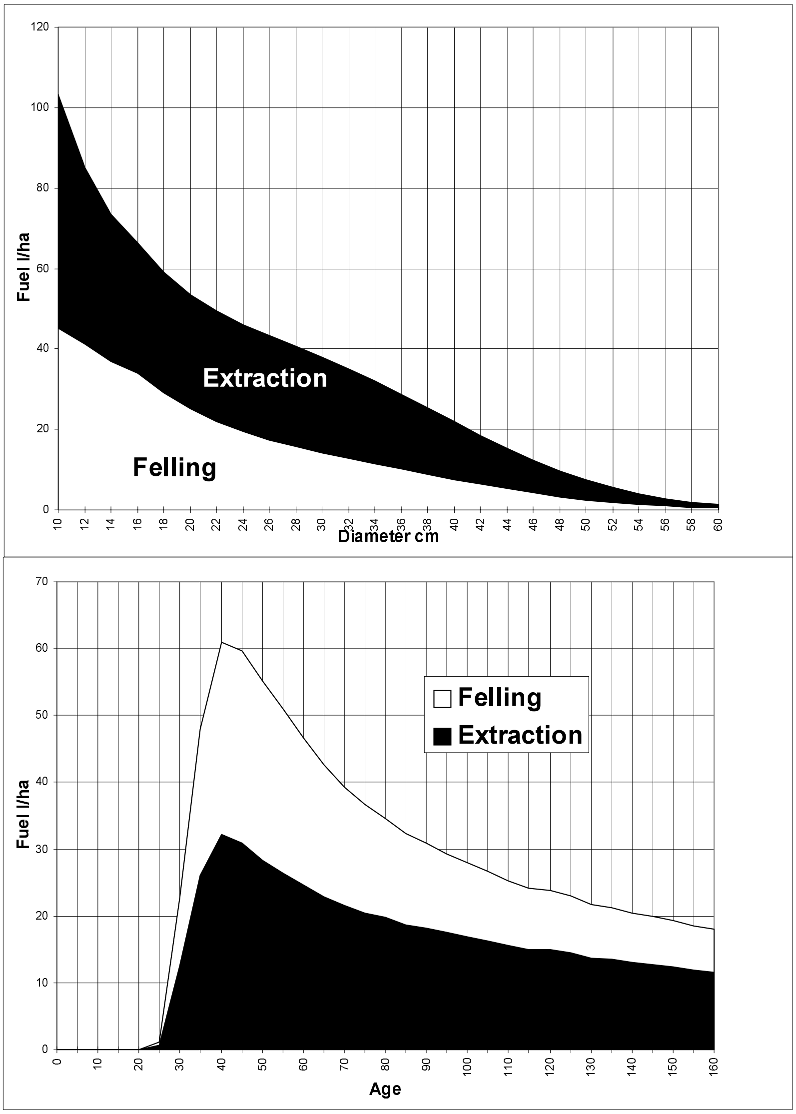

Figure 4. Fuel consumption of felling and wood extraction (l/ha).

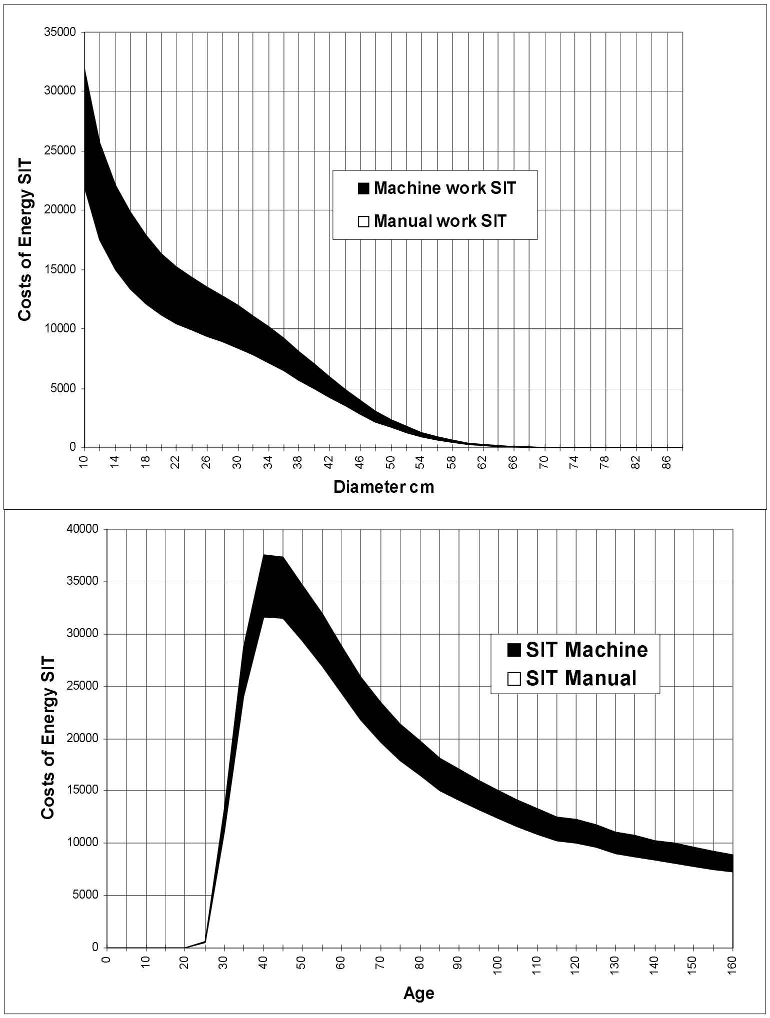

Figure 5. Energy costs of manual and machine work in relation to tree diameter and age of the stand.

3.3 Damages of standing trees

When cutting and skidding timber, the damages of standing trees are unavoidable consequences of this action. They accumulate in the stand in time, despite the removal of some of the most damaged trees in repeated thinnings. Field observations showed that a large share of damages occurs in regeneration period when heavy timber is transported through the regenerated area. In our calculations the damages in young stand were not included, therefore we supposed that the stand at 25 years, when we start with the first thinning, is entirely undamaged. The share of damaged standing trees increases very quickly and after several first thinnings reaches 50 % of remaining standing trees (Fig.6). At the time of greatest energy input we cause the most severe damages in the stand and in the environment through emmissions. This practice is very dubious and critical if we have in

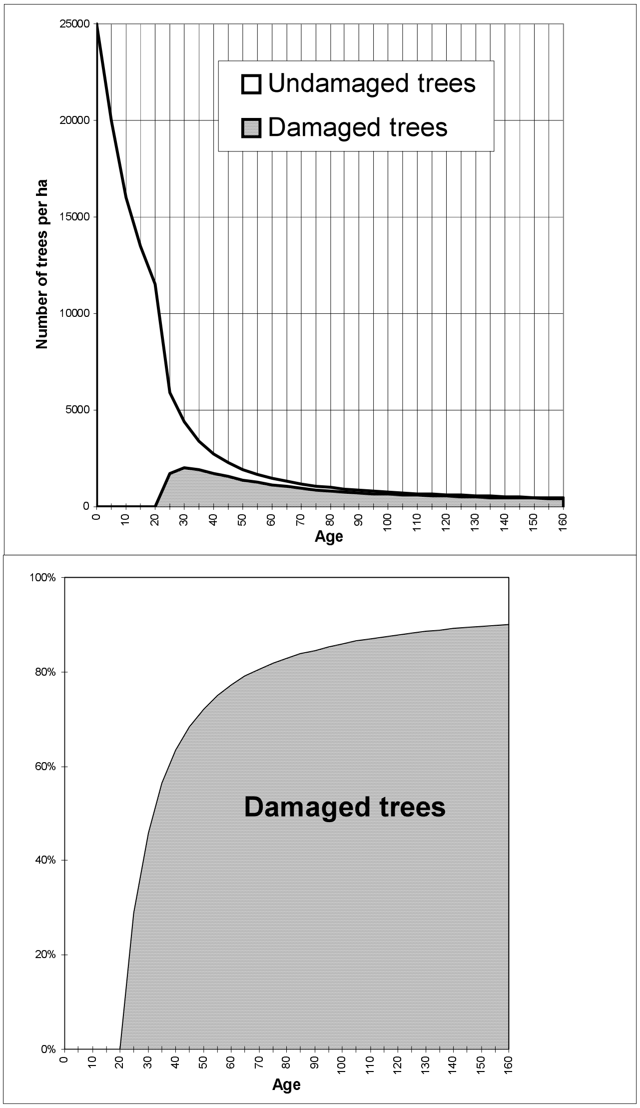

Figure 6. Damaged and undamaged trees in model stand.

mind sustainable forest management which includes the economics too, despite those thinnings should have good influence to the future stand from silvicultural point of view. Once again we have to stress that field observation confirmed a very high share of damaged trees in alpine spruce stands (Košir 1998).

Damages in the stand emerge at every thinning and some of them stay in the stand from the time they occur to the end of rotation period. The influence of such damages on the value of the timber is the greatest. Among the damaged trees the share of new damaged trees is at the end of rotation period very small, while the share of old damages strongly prevails.

3.4 Timber value and operational costs

The theoretical values of timber based on the estimation of assortment structure regarding the tree diameter were calculated for healthy and damaged trees. In calculation of timber value of damaged trees we supposed that beside tree diameter the main influence had the age of the damages. Smaller value of damaged trees had the reason in worse assortment structure and because of higher amount of cutting residues. We represented all those facts in a factor which was used to calculate decreased value of the removed trees in each thinning in dependance to the age (Fig.7).

The operational costs in damaged and in undamaged stand are more or less equal and could be directly compared to the value of the timber removed in thinning. This way, we get the answer to the rationality in different ages (Fig. 8 and 9). The influence of damages to the value of the stand and to the value of removed wood is very high. In the undamaged stand the operational costs would be higher than the timber value up to the age of 75 years, when the positive difference would degresively increase until the end of rotation period or the beginning of new regeneration period. In the damaged stand the value of timber removed in later thinnings is getting smaller. The difference between operational costs and this value is slightly positive only for a short period. Only after the age of 95 the operational costs are smaller than the timber value, and the difference is very small. After 140 years the operational costs again overtake the value of removed trees.

The same relations could be observed in dependance to the tree diameter during the whole rotation period. Difference between operational costs and timber value in the undamaged stand is positive at trees larger than 22 cm, while in damaged stand break-even tree diameter is 30 cm. The difference in the damaged stand is also significantly smaller than in hypothetical undamaged stand. The loss in timber value due to damages in thinnings is very high and puts out the question of raitonality of any thinning in the rotation period.

Sustainability has many parameters and only few of them are recognised in Forest Act and acknowledged in practice. Majority of silvicultural concepts, as well as forest operation practice, has not been adapted to the trends toward complex

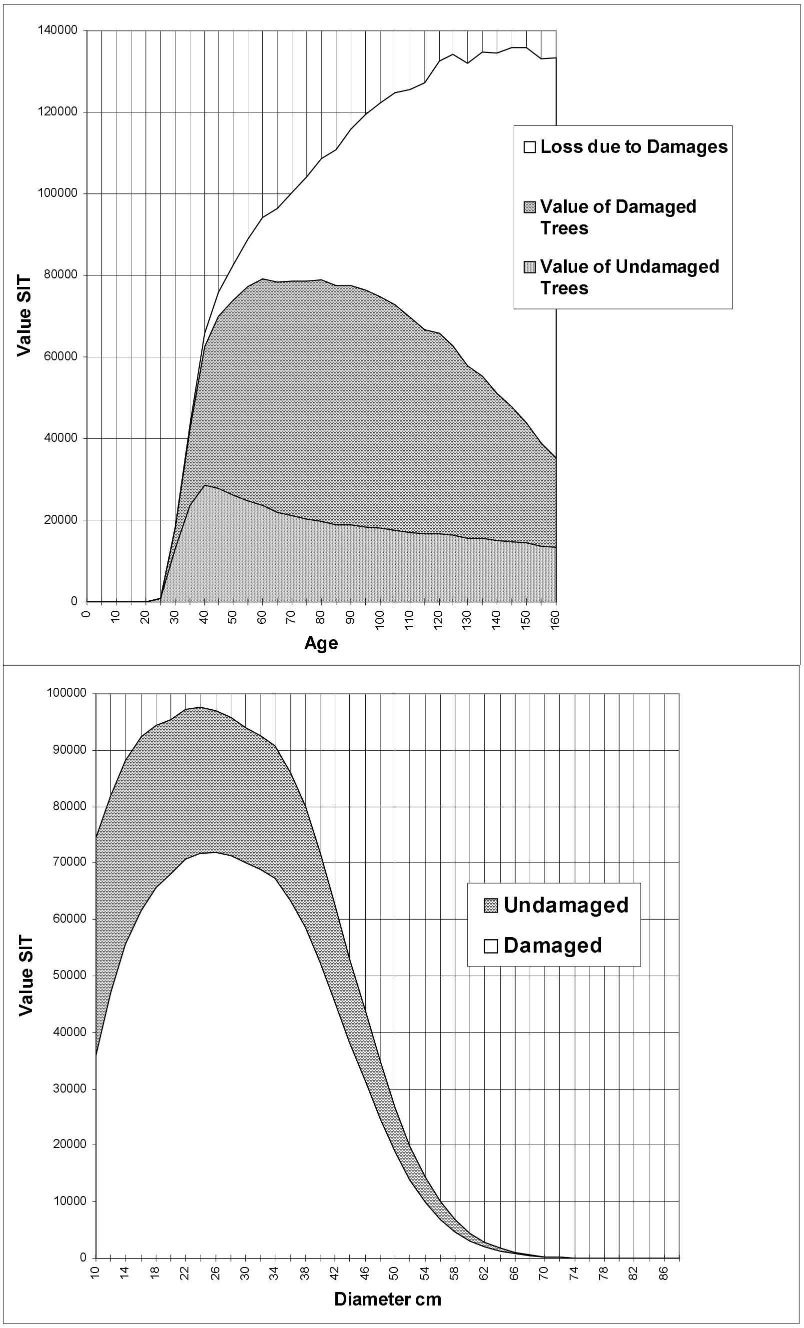

Figure 7. Value of damaged and undamaged part of the stand.

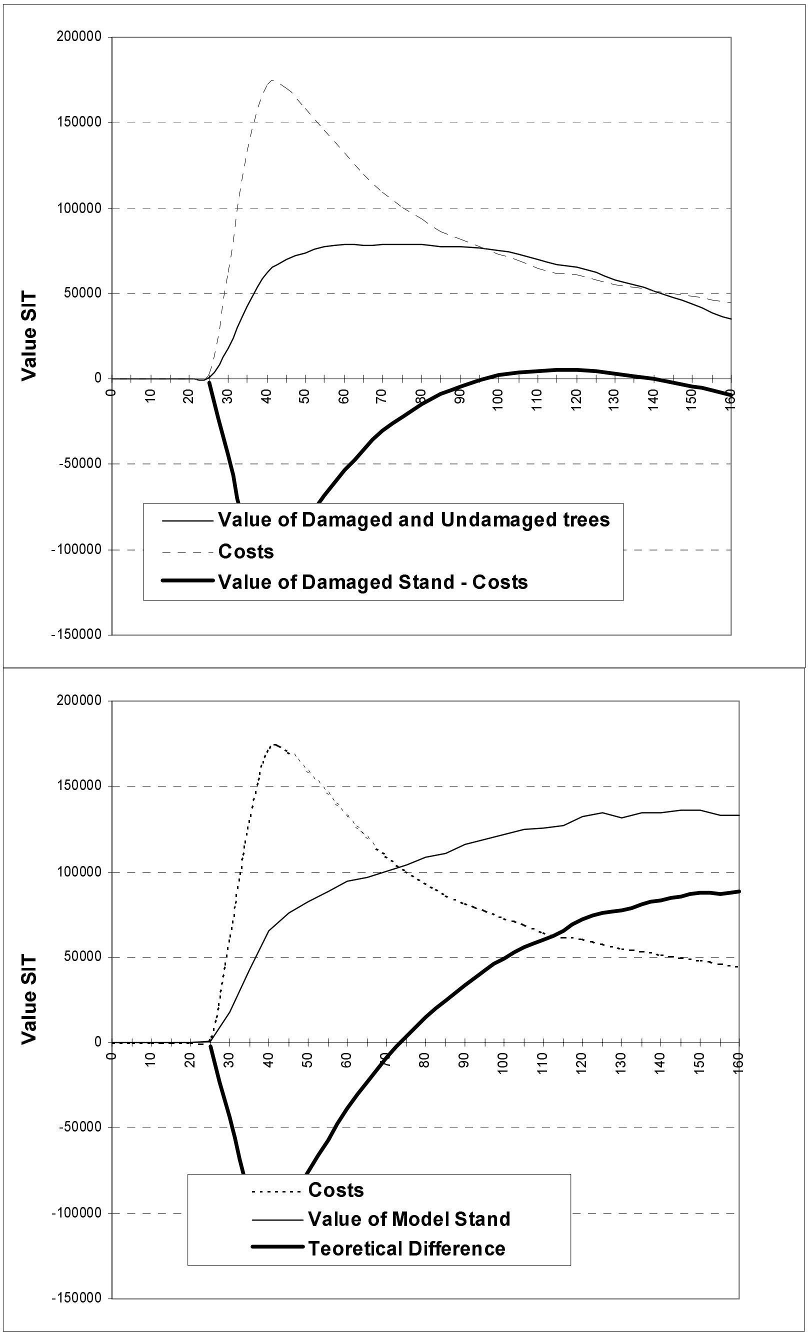

Figure 8. Value of damaged and model stand in comparison with costs during the rotation period.

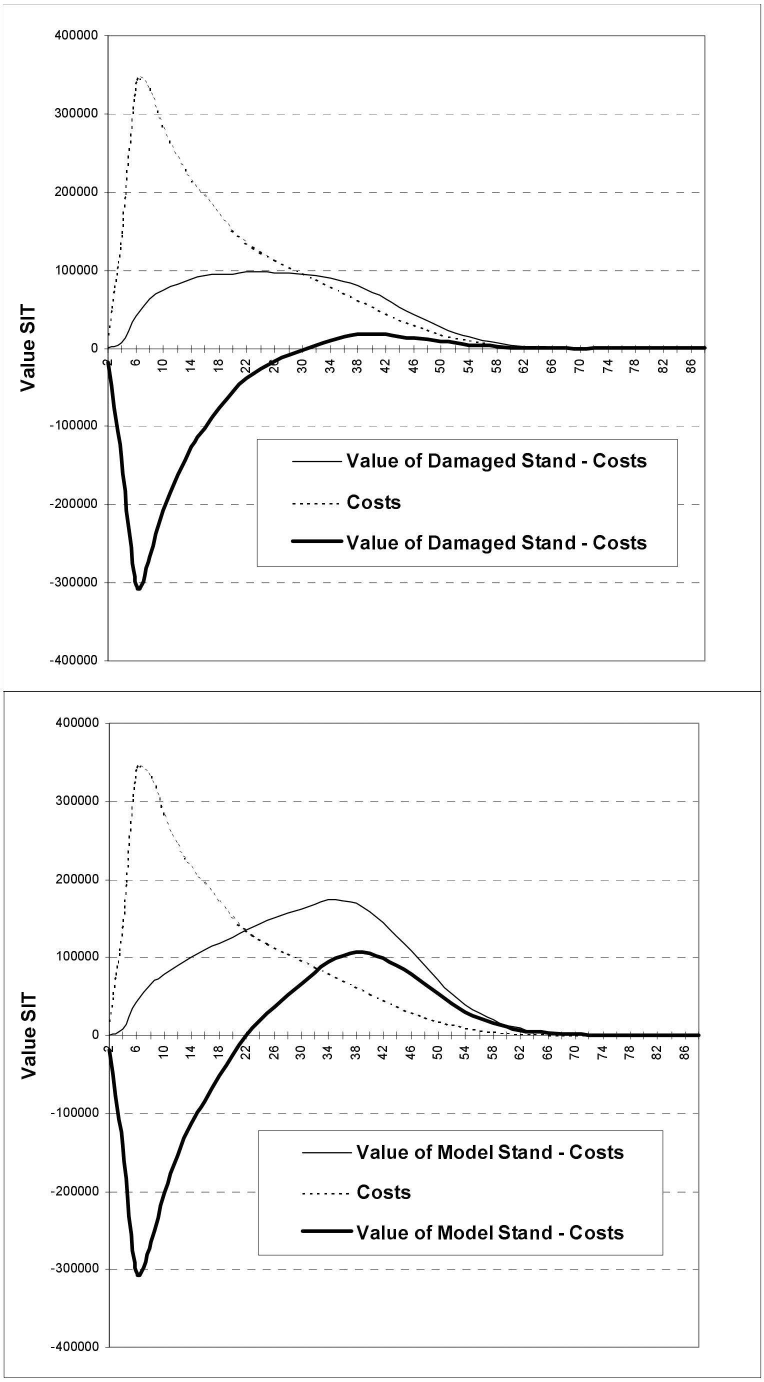

Figure 9. Value of damaged and model stand in comparison with costs in dependance upon tree diameter.

environmentally friendly behaviour that has developed recently. The answer is not in abandoning forest management on vast areas and in more or less rigid restrictions but in changing concepts of forest management on the basis of complex conclusions and applied research results. Forestry has to contribute its share in searching more sustainable way of living with nature and urban environment.

4 Discussion

The model should do the work which is trusted to models: to simplify reality so much to loose nonessential details which are hiding the rules of our interest. In our model some of very important input data which would be the results of research are missing, therefore we had to accept some assumptions and simplifications. Data which could improve the model's results are a better structure of assortments in dependance on the tree diameter and more reliable data of value loss when the tree is damaged at different age. The growth in the model could be improved with knowledge of growth functions for main domestic species where the necessary thinnings would also be included.

The model would show different results if it was applied to beech stand. In any case, the results show that in the conditions of present technology the early thinnings – where too many damage is caused –are not rational. Much more cost effective, as well as energetically more reasonable results we may expect in thinnings up to 26 cm of tree diameter, if we use mechanized felling and forwarding. The results of the model must be however proven with field observations, despite some field research having already confirmed a very high rate of damaged trees at the end of rotation period. It is obvious that such practice should be changed if we wish to switch to sustainable forest management.

The model includes only a few factors which are importand for forest management and have origin in forest itself (tree species, timber volume and it's structure), technology (standard times, energy) and economics (costs and timber value). Factors connected with man and society have not been included in the model, but at this time that was not the intention of the research. Multifunctional role of the forest, restrictions in relation with it and it's impact on forest management, stays a matter of further discussion.

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