Decision Support System for predicting co-natural forest stand development

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Abstract

There is a long tradition of co-natural forest management in Slovenia. Since the end of the second world war clear cuttings are forbidden and site specific, environmentally oriented forest management is applied in our concept of work. Researchers, scientists and field workers are aware of the importance to preserve the only renewable natural resource – forest. They take great effort in finding new directions and developing modern tools for keeping diverse and healthy forest. Our forest management system is based on forest management, silviculture and operational planning. Planning process and forest information system are closely related. The input data for planning process are provided by forest inventory and mainly these data are used in decision making process.

A Decision Support System (DSS) for predicting forest stand development using different management scenario is represented. Computer supported DSS provides prediction of stand structure and cutting volumes by using different production periods and different thinning operation intensity in forest planning process. Co-natural development is provided by goal function which is determined with potential natural structure of tree volumes defined by site requirements (vegetation association). A step of ten year time period is used for predicting stand dynamic. Output data on stand structure, cutting volumes compared with model optimal situation are provided. We calculated the difference between actual and potential natural stand structure. Index of co-natural stand structure based on difference was used to determine thinning intensity for next prediction period and also for evaluating success of management scenario. DSS provides data which could be used in all three components of our planning process. Its application is not limited by area, but only by availability and accuracy of input data. DSS was tested using real data and results are represented for mountain forests in model forest enterprise unit (cca. 5 000 ha) for a time period of one hundred years.

Keywords: computer model, forest stand development, forest planning, decision support system, production period, prediction, scenario

1 Introduction

Slovenian forests have always been under strong influence of human needs concerning wood extraction and lately also under strong influences of industrial emissions which have impact on natural environment. Forest and human must and should live together and therefore it is not possible to avoid some consequences which are shown as changes in forest structures caused due to reactions of human impacts on forests. Most obvious changes caused by human management activities are changes in tree species, social stage and age structure of forest stands.

At the beginning there was a silvicultural uncontrolled process of wood extraction, forced only by current needs and extraction possibilities. Later, when wood shortage occurred, a man had to think of sustained wood production. In different stages of history silviculture treatments had various aims. The influence of human activities was so huge that nowadays we could not find forests with purely natural development with primary association and selection of plant and animal species.

On the basis of research results concerning vegetation succession during time period and data for past forest management activities it is possible to reconstruct an image of potential vegetation type - that is forest stand structure, tree and plant species which are mostly adopted to micro and macro requirements on each specific forest site. Site requirements are defined by ecological influence factors (floor, climatic, relief and other conditions). Plant and animal species with their structures defined by potential forest vegetation type represent optimal combination with self controlled mechanism for sustained providing various functions of forests and there is no need for human interference. There are cases where production potential of wood in potential vegetation type structures is lower than the production of managed forest in pure commercial manner. Precondition for sustained "overproduction" of wood is caring out forest management activities which accelerate human desired components in natural developments of forest stand structures.

Nowadays computer equipment and information systems enable objective predicting in future development of various systems. We have to know the most important influential factors, their values, form and direction of correlation between each factor and system development. A lot of scientific researches and operational uses in form of decision support systems (DSS) and other computer models are present in today forestry (Siitonen 1994, Petrařš 1994, Bevins 1994). A range of forest estate modeling application has also been reviewed (Manley 1998). At the beginning we should provide input data on initial stand structures in defined computer databases, choose desired goal (aim) and incorporate in model algorithm natural trend of forest (stand) development (Fig. 1).

The representation of DSS which could be used for evaluating different forest management activities follows. Basic characteristic are written in following lines:

- Predicting future forest stand structures for time period of one hundred years
- On each step management strategies are defined by difference to potential optimal stand structures.
- There is no human planting of these new plant species which are part of relevant potential vegetation type.
- Forest management activities are predicted using an internal 10-year step to determine log volumes in thinning and final cutting operations.
- Basic cell of simulation is a forest section which is the smallest unit in our forest inventory.
- Successfulness of scenario is measured by index of co-natural stand structure derived by difference between actual and potential optimal stand structure.
- Growing stock compared to model on each time step, is a growing stock of tree species related to the share of forest association and seral stage in each forest section.

DSS is a collection of computer procedures written in program language FoxPro™ and additional modules for enabling link to geographic information system (GIS) analyses (IDRISI™). The structure and the form of input data are the same as those in computer databases of Slovenian forest inventory (Mikulič 1990).

2 Method

2.1 An analyses of actual and the definition of desired goal forest stand structure

The accuracy of every forest scenario modeling depends on reliability in initial information concerning stand structures. Accurate input data on tree volumes, age classes, spatial distribution and areas have to be disposed. Actual values of studied variables must be so precise and complete that they could be used for input data in model with desired accuracy of output data.

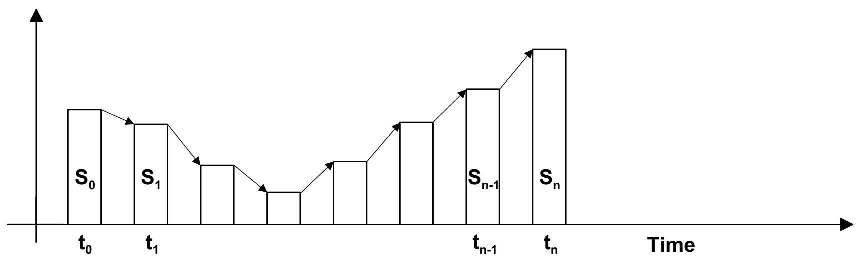


Figure 1. Projection of initial structure (S_0) into new structure (S_n) depends on intermediate structures sequences, natural trend in forest development and forest management activities, defined by desired management strategies (→).

All results shown in paper are derived by a model study in forest management unit Jezersko which comprises about 5000 ha forest land for the time period from 1990 to 2080. The management unit is divided into 225 forest sections and 197 of them are forests with wood yield. The rest 28 sections are forests with protective or other special functions where no wood yield is planned. The average area of forest section is 23,96 ha.

Goal (desired) structure of tree species growing stock was defined by site conditions (potential forest association) – that is potential vegetation type. For each forest association an optimal share of tree species growing stock was provided. Tree growing stock structure on estate (forest management unit) level was calculated using weighted share of tree species in forest association (Table 1, Table 2). Weights are provided by the sum of forest association areas. In calculation different optimal tree volumes for different forest association are taken.

2.2 A simulation of growing stock dynamics in forest stands by tree species

We used sinus function (*sin (age)*) for the approximation of growing stock development. Final cut was simulated in three sequential ten year steps. In the first and the second step we took 40 %, and in the last third step all (100 %) tree growing stock (Fig. 2).

Prediction of future growing stock by tree species was calculated from actual stand data (forest inventory), actual wood increment for different diameter compartments and predicted cuttings (thinning and final cuttings). Calculation was made for every ten year step consequent from results of prior step.

Seral stage distributions are stabile during simulation - prognosis based on assumption that initial (actual) relation of forest seral stages continuosly changes from young to old stages. There are five different classes in structure of tree diameter

Table 1. Structure tree species growing stock in forest management unit Jezersko (forest inventory data).

Tree species	% GS*
Spruce	67.89
Fir	2.34
Larch	9.90
Other softwood	0.8
Beech	17.9
Oak	0.02
Other hardwood	1.14

* growing stock

Table 2. Model goal structure of tree species growing stock defined by area of forest associations.

Tree species	% GS*
Spruce	6.3
Fir	16.9
Larch	0.2
Other softwood	0.4
Beech	70.1
Oak	1.5
Other hardwood	4.6

* growing stock

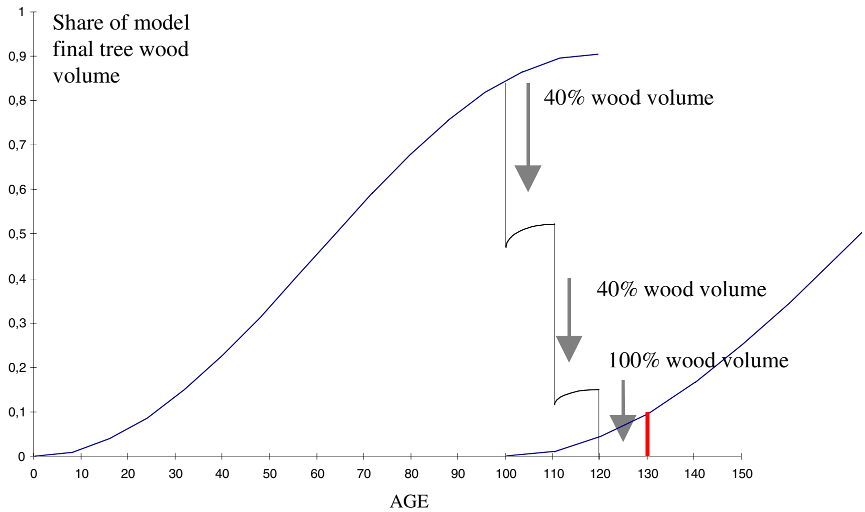
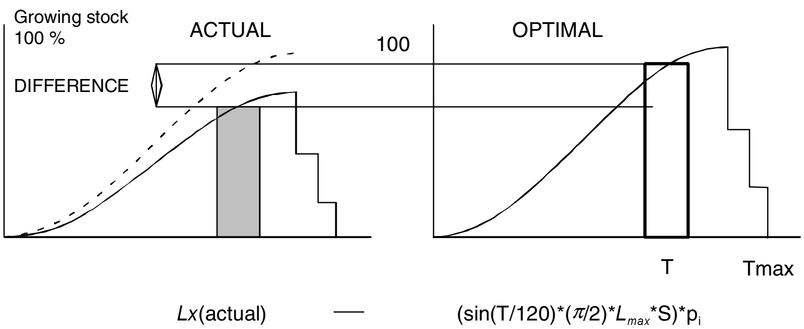


Figure 2. Model for approximation of growth stand growing stock for predicting co-natural forest stand development.

$D = \Sigma(f_i - (\sin(T/T_{max}) * (\pi/2) * L_{max} * S) * p_i) * DGZ$



D..........Sum of growing stock differences between actual and model optimal values

π..........3,14...(pi)

L_{max}.......final stand growing stock taken from yield tables by age *Tmax* (m^3/ha)

S..........share of tree species in growing stock defined site spesific by forest association

DGZ.....share of forest section area defined for specific forest association

f_i...........growing stock for specific seral stage

p_i...........area of seral stage i

Lx.........growing stock (m^3/ha) tree species in forest section

T...........age of trees in seral stage (forest inventory data)

Figure 3. The calculation procedure of sum of growing stock differences by tree species between actual and model optimal values.

related to tree age: young growth (younger than 25 years), early I (from 25 to 50), early II (50 to 80 year), mature (80 to production age – 20 years) and old growth, (production age – 20 years to production age)

2.3 A procedure for comparison of actual and optimal growing stock structure

Every step (ten year) in prognosis had a comparison between actual and potential optimal growing stock. Growing stock was compared to those of model optimal values by the same age. For every forest association in forest section a sum of absolute difference in m^3 was calculated. Absolute difference was used for deriving index of co-natural stand structure.

4.4 A method for determination of index of co-natural stand structure.

Forest section comprises mostly three forest associations. The procedure for comparison of actual and optimal growing stock structure repeats for every tree species three times (three forest associations) (Fig. 4).

2.5 Assuming various management scenarios

We analyzed different management scenarios for approaching desired forest stand structures. Scenario was

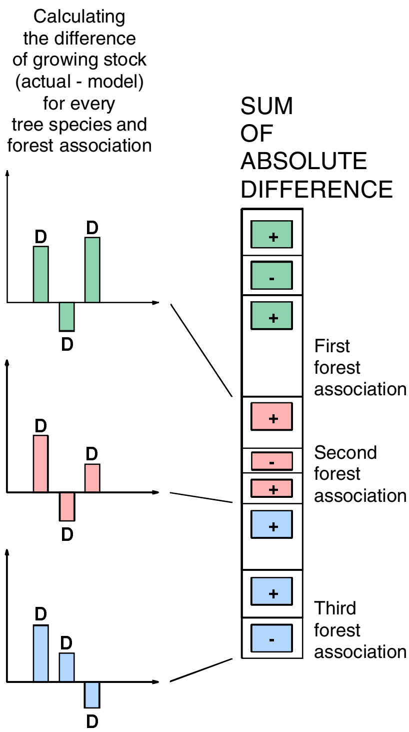


Figure 4. Procedure for summing differences between actual and model growing stock by tree species and forest associations.

determined by three different thinning intensity and also application of three different production periods (Table 3). Yields (harvest volumes) by thinning operation are determined in relation to difference between actual and optimal growing stock of tree species (Fig. 5). Different production ages (120, 140 and 160 years) were applied for scenarios (Fig. 6).

Yields determination for thinning operations is related to difference D (Fig. 3) between actual and optimal growing stock of tree species for forest association. Independent variable

Table 3. Scenarios for predicting forest stand structure development related to different production period and thinning intensity.

Thinning intensity	120 years	140 years	160 years
Low	Scenario 1	Scenario 2	Scenario 3
Medium	Scenario 4	Scenario 5	Scenario 6
High	Scenario 7	Scenario 8	Scenario 9

(*Ddv*) is share which represents difference (*D*) in comparison to final optimal stand growing stock (*KLZ*)

$$Ddv = D/KLZ * 100$$

Concerning *Ddv* value, we determined wood volumes for thinning operations which are measured with a share of actual increment of tree species (*i*) as it is shown in Fig 5.

Procedure of harvest volume determination for thinning operation has three typical intervals related to *Ddv* value:

I. In case of shortage (*Ddv*<0) there is no wood supply from thinning operations.
II. In case of equal actual and optimal wood volumes there is an advance determined share of current wood increment (*Ddv*=0).
III. In case of surplus (*Ddv*>0) there is linear increase of harvested wood.

Harvesting volumes for final cutting are provided by model approximation, (Fig. 2) where in three subsequent ten year periods all volumes are cut regardless to difference in growing stock structures.

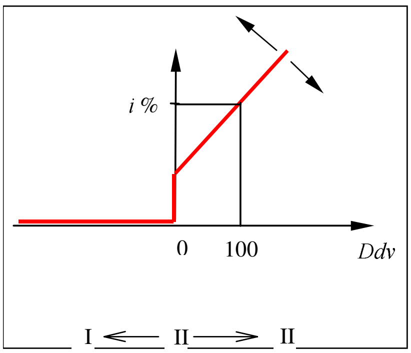


Figure 5. Harvest volume determination for thinning operations related to degree of structure changes in growing stock by tree species (*Ddv*).

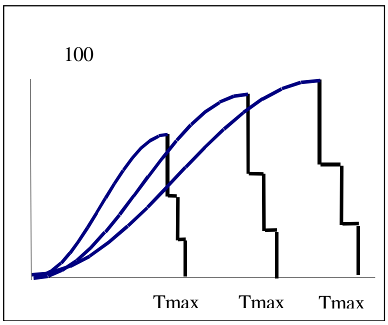


Figure 6. Different production periods (T_{max}) for alternative forest management scenario.

3 Results

DSS enables prediction of growing stock, harvest volumes and approximation of co-natural stand development for different forest estate and management activities. Quantitative data for management scenario (Table 4) are derived from voluminous databases which could be used for prediction of future conditions in various forest estate levels. Data for higher estate levels are derived by analysis from data on basic level of simulation represented by forest section.

Scenarios with different production age have most significant differences in prediction results. It can be be concluded from fig. 7 that today average production age is approximately 140 years. Short production ages (120 years) would decrease, longer (160 years) would increase today average growing stock.

Model optimal growing stocks are lover than predicted. The situation can be explained by tree species, because today dominant spruce has a higher growing stock than more site convenient beech (Tables 1 in 2).

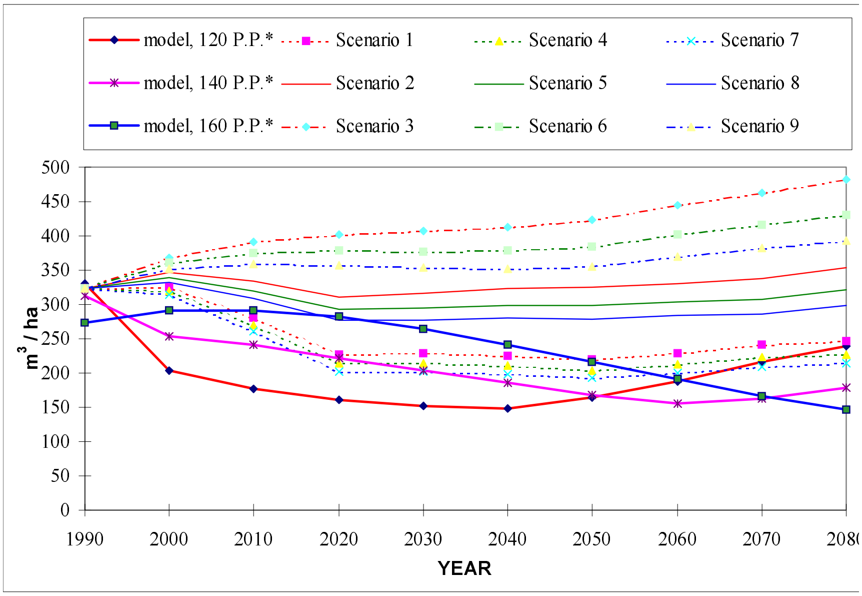
Index of co-natural stand structure showing co-natural development of growing stock was also observed. We derived index by dividing the sum of absolute differences (*D*) in volume structures (Fig. 4) with actual optimal growing stock in forest section. Average values for forest management estate index of co-natural stand structure comprises Table 5.

Best results concerning adoption to site requirements were achieved by scenario seven (120 year production with high intensity of thinning operations). Results were expected because shorter production period operates with lover average growing stock, which corresponds to model optimal requirements. Approaching natural stand development is worst by longer production period. Even by using high intensity of thinning op-

Table 4. Today value (1990) and prediction of average growing stock (m^3/ha) for different forest management scenarios and model optimal values defined by forest association (level of forest management unit).

Year	120 years				140 years				160 years			
	Model	Sc*1	Sc*4	Sc*7	Model	Sc*2	Sc*5	Sc*8	Model	Sc*3	Sc*6	Sc*9
1990	331	323	323	323	312	323	323	323	273	323	323	323
2000	203	325	319	314	254	346	339	332	291	369	360	352
2010	176	280	270	260	241	334	320	308	291	392	375	359
2020	160	227	214	202	222	311	293	277	282	402	379	358
2030	152	229	215	202	204	316	294	276	264	407	378	353
2040	149	226	211	198	185	323	299	280	241	413	379	351
2050	164	219	204	192	168	324	299	279	216	422	385	355
2060	188	229	213	201	155	331	304	284	191	444	402	370
2070	216	241	223	210	162	337	308	286	166	463	416	381
2080	240	246	227	214	178	353	321	298	147	483	431	393
Average	198	255	242	232	208	330	310	295	236	412	383	360

*Scenario



*year production period

Figure 7. Potential optimal and prediction of growing stock structure (m^3/ha) in forest management unit for time period from 1990 to 2080.

Table 5. Prediction for index of co-natural stand structure for different scenario in forest management.

Year	120 years production period			140 years production period			160 years production period		
	Sc*1	Sc*4	Sc*7	Sc*2	Sc*5	Sc*8	Sc*3	Sc*6	Sc*9
1990	1.74	1.74	1.74	1.85	1.85	1.85	2.04	2.04	2.04
2000	2.44	2.41	2.39	2.11	2.09	2.06	1.98	1.95	1.92
2010	2.40	2.35	2.29	2.07	2.02	1.97	1.89	1.83	1.77
2020	2.09	2.01	1.93	2.19	2.10	2.03	1.99	1.90	1.83
2030	2.11	2.00	1.91	2.30	2.19	2.12	2.21	2.10	2.01
2040	2.42	2.27	2.15	2.62	2.46	2.34	2.67	2.53	2.41
2050	2.52	2.37	2.25	2.47	2.29	2.15	2.79	2.60	2.44
2060	2.09	1.96	1.86	2.87	2.62	2.45	3.21	2.95	2.76
2070	1.87	1.74	1.65	3.63	3.38	3.17	3.27	2.96	2.73
2080	1.63	1.52	1.45	2.96	2.70	2.50	4.17	3.71	3.37
Average	2.13	2.04	1.96	2.51	2.37	2.26	2.62	2.46	2.33

*Scenario

eration a gap to natural stand structure grows rapidly. It is not possible to avoid planting new (site convenient) tree species.

4 Discussion

In the paper part of DSS is represented which predicts growing stock, harvesting volumes and co-natural stand development for future. Results can be used in ecological and economical analyses. Economical part includes mainly relations in cash flow, ecological viewpoint maintains non-timber function of forests (protection, hydrological, climatic, recreation, tourist, aesthetic and other social benefit functions) which have important influence on successfulness of management activities. Management plans and forest operations should give both sides equal attention because consequences of management activities have in most cases opposite reactions (results).

Primary purpose of DSS is supporting forest management planning on different level of forest estate. Input data are provided by national wide forest inventory. Predictions for forest stand development are made using real (field) data. It is also possible to provide national wide prediction on future values for some macroeconomics interesting data related with forestry. Rather than predict what will happen, we are able to predict what can happen under specific assumptions. Forest service has a computer database with primary data for over million hectare forests in Slovenia, divided in 80,000 forest sections (basic data cells). Comprehensive and valuable data provided by forest service could be, through DSS, better (objectively) included in forest management planning process. National wide results could be implemented in investment strategy in wood processing industry (potential future wood supply) and also for maintaining forest communication network. Development strategy of DSS is modular oriented. Parallel to forest stand dynamics, we work on module for economic assessment different management scenario concerning silvicultural treatment and production period. Cash flow using different working method in forest operation, skidding means, quantity and quality of harvested volumes can be compared.

Data processing possibilities are almost unlimited. Every important decision should be supported by objective calculations including also ecological and economical viewpoint for alternative possibilities.

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