FOREST MANAGEMENT THROUGH SIBYLA PROGRAMME SCENARIOS: AN EXAMPLE FROM BULGARIAN FORESTRY PRACTICE

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Abstract

In the context of dynamic socio-economic development and globalization of the economy, modern society places higher requirements for optimal use of the various forest resources. The need to preserve the integrity of forest ecosystems and maintain a sustainable balance between all forest functions implies improvement of the forest management systems. In the forest planning process, it is expedient to prepare scenarios for multifunctional forest management with the help of Sibyla, decision-making support information system partially adapted for use in Bulgaria. Sibyla is a growth simulator that, on the basis of mensuration data, as well as of planned forestry treatments, generated a model development of forest plantations in Jenda State Forestry and Hunting Enterprise in Kardzhali Municipality for a period of 50 years. An analysis of the results has been carried out using the following indicators: total volume of the standing wood, potential yield by wood volume and grade and total biomass production under different forest management regimes in the selected plots. The results obtained provide a good basis for revealing the opportunities for achieving integrated forest management in Jenda State Forestry and Hunting Enterprise in Kardzhali Municipality.

Keywords: *integrated forest management, Sibyla, decision support system, tree growth simulator*

1. INTRODUCTION

Industrial production nowadays is characterized by intense growth, increased use of natural resources, increased globalization and climate changes. These trends objectively place demands on the forestry sector to meet the needs of the society for all the products and services that forests provide. Jenda State Forestry and Hunting Enterprise in Kardzhali Municipality is situated in the southeastern part of Bulgaria (Fig. 1). The area it occupies is 28,426.5 ha. It is located in the Eastern Rhodopes at an altitude of 225-1034 m. Geomorphologically it is very diverse and is characterized by pronounced segmentation due to its mountainous terrain. The hydrographic network is highly developed and the Arda River flows from the west with two large dams built on it: Kardzhali Dam and Studen Kladenets Dam. The climate is continental Mediterranean. In the area of Jenda Enterprise the following naturally growing tree species are found: beech, sessile oak, Hungarian oak, eastern hornbeam, Austrian pine and others. The species form pure and mixed broadleaved as well as mixed broadleaved-coniferous stands. Plantations of Austrian pine, Scots pine, spruce, Douglas fir, red oak and others have been successfully established. There are also diverse shrub and herbaceous species: rosehip, hazel, lilac, nettle, fern, strawberry, geranium, chamomile, sumac, hellebore, thyme. The territory is inhabited by red deer, fallow deer, mouflon and wild boar. There are six protected natural sites and three protected areas in the Jenda Enterprise. An illustration of the rich cultural and historical past of this Rhodopean region are the megalithic Thracian sanctuary Perperikon, the medieval fortress Monyak and other ancient finds. The exceptional landscapes, the richness of flora and fauna, as well as the unique archaeological heritage are important prerequisites for attractive tourist activities. The territory of the Enterprise is suitable for achieving sustainable forest management as an integrated system of resources of material and non-material nature.



Fig. 1. Scenery of the territory of Jenda State Forestry and Hunting Enterprise

2. MATERIALS AND METHODS

With the help of Sibyla decision-making support information system partially adapted for use in Bulgaria, the possible scenarios for the development of the forest plantations have been generated for a period of 50 years. Sibyla, a single tree based simulator, is a software package, kindly provided to us for non-commercial use by our colleagues from the Technical University in Zvolen, Slovakia, who have developed it and continue to develop and improve it continuously [4, 6] (Fig. 2).



Fig. 2. Modules in SIBYLA for systematization of soil-climatic data and morphological characteristics of the selected forest plantations, as well as for generating the results of the simulations.

Sibyla is a growth simulator that, on the basis of mensuration data and planned of forestry activities, generates models of development of forest plantations for a predetermined period of time (at least 1 year), with the growth models being based on tree diameter and height [7]. The parameters used are: CO_2 and NO_x, air concentration, soil moisture and nutrient content, mean temperature during the growing season, annual air temperature amplitude, rainfall during the vegetation period and duration of vegetation period and etc. The site potential determines and interpolates certain growth ranges. The tree crown parameters (diameter, area, shape and surface) are obtained from the tree heights and stems

diameters. Tree mortality in the plantations as a result of self-thinning, as well as other possible causes (windthrow, snowfall, frost, bark beetles, insects, fungi, air pollution, fires, extreme dry conditions and illegal felling) are also taken into account. The model is based on heuristic and stochastic methods. It is also influenced by the predefined specific forestry activities scheduled for implementation at specific time of the simulation period. Such activities may include understory, upperstory or mixed thinnings, as well as different types of regeneration harvests. The model can generate forecasts for the future tree structure, as well as to calculate average and standard deviations. Differences between scenarios can be statistically tested [2, 5]. Sibyla contains a set of mathematical models and algorithms that are transformed into integrated software. A tree with the lowest growth for one year is the base. The model is based on changing diameters and tree height, tree mortality and illegal logging. For each scenario, forest growth is simulated in the application of various forest management plans over a period of 50 years. Tables are compiled to present the data of different scenarios in accordance with the individual ecosystem services in the studied forest area are presented in [6].

3. RESULTS

In this study, the capacity of forest plantations to produce woody biomass and other ecosystem services has been assessed on the basis of actual data obtained from the forest inventory in the surveyed site and from the forest management plans made for different regeneration methods. The assessment has been made for a representative sample of forest plantations due to technical constraints on the volume of input information in one session of the program. The representative sample consists of the largest plots containing all studied parameters which are needed as input information for performing the simulations [6] (Table 1). The representative sample includes 450 forest plots. These plots have been selected on the basis of age class and average diameter class, sampling the ones with the largest area.

Abbreviation	Parameter	Metrics
species	Tree species abbreviation based on tree species code list	code
d	Tree species mean diameter in cm	cm
Vha	Tree species stand volume per hectare in m^3	m^3
h	Tree species mean height in m	m
t	Mean age of tree species in years	age
percentage	Proportion of a tree species from the number of trees in per cent	%
nutrient	Soil nutrient supply (relative value in the range from 0 to 1)	code
season	Number of days of the vegetation period (days with daily mean temperature above 10 °C)	count
amplitude	Annual temperature amplitude (the different between annual minimum and maximum temperature in °C)	°C
temperature	Daily mean temperature in vegetation period in °C (April to September)	°C
moisture	Soil moisture (relative value in the range from 0 to 1)	code
rainfall	Rainfall during the growing season (April to September)	mm

Table 1. Output data needed to perform the simulations

As a result of the simulations, forecasts for the future stand tree structure have been generated. Figure 3 shows generated forecasts for the future structure of a mixed coniferous stand and Figure 4 - generated forecasts for the future structure of a mixed coniferous-broadleaved stand.

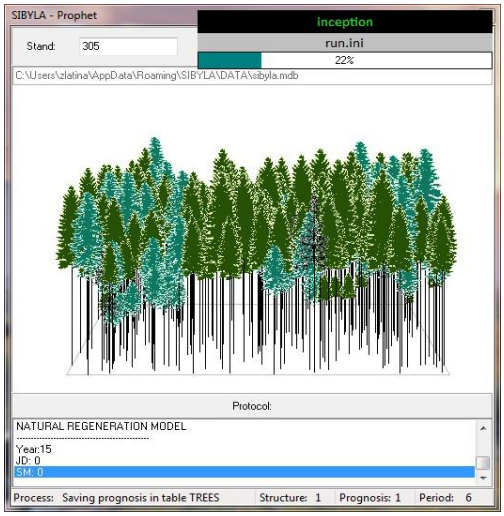


Fig. 3. Mixed coniferous stand

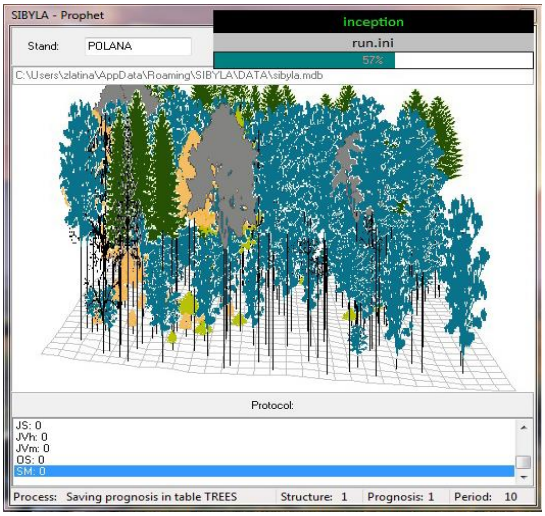


Fig. 4. Mixed coniferous-broadleaved stand

The potential of the forest plantations included in the sample has been analysed in four groups. For each group, eleven simulations of varying degrees of intensity and different management methods have been made. They include:

- the most restricted human intervention in the forest, which resembles the regime of biosphere reserves (not even the dead trees in the forest are removed);
- the same, but dead and dry trees are removed, which simulates salvage harvests;
- understory thinnings reducing stocking to 0.7 for all forest plantations;
- mixed thinnings removing 15% of the growing stock of all forest plantations;
- maximum yield (allowable cut) applying the target diameter method, with simulations for 18, 24, 30, 36, 42, 48 and 54 cm diameter.

Figures 5 and 6 show the dynamics of the total growing stock (m^3) and yield (m^3) for the whole territory for the different management methods for a period of 50 years.

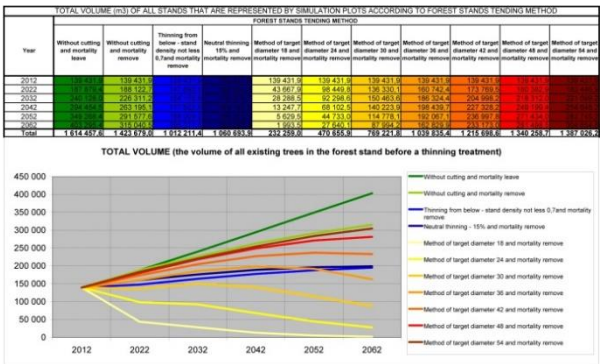


Fig. 5. Dynamics of total growing stock (m^3)

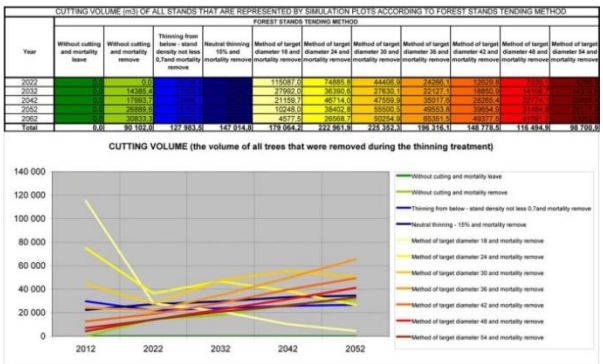


Fig. 6. Dynamics of yield (m^3)

The diversity of forest ecosystems depends on the combinations of abiotic, biotic and anthropogenic factors and impacts. The impact of the selected forest management methods has also been simulated with SIBYLA and included in the analysis. For this analysis, the representative sample of plantations has been used again, taking into account the information on plantations' species diversity. The analysis

has been carried out using the principles of the rare-fraction method [8] so that the number of species is related to the area of the forest plots, and the models of diversity are generated for three moments of the simulation (at the beginning, in the middle and at the end) over a period of 50 years. Two indices have been used to assess the structural diversity: the aggregation index R [1] (Fig. 7) and the differentiation index TM [3] (Fig. 8 and 9). The R index describes the horizontal distribution of trees, using the ratio of the average distance between the central tree and its adjacent trees with the expected distance between them being chosen randomly depending on the stand structure. The R index can theoretically have values between 0-2.1491. Index values above 1 show a tendency for even distribution, and values below 1 - a tendency for tree crowding. An important parameter of structural diversity is the differentiation of trees in the plantation. It can be assessed using various morphological features of the trees (stem diameter, area, height and crown volume or other easily measurable parameters). The TM differentiation index has values between 0-1. For tree plantations with small tree diameter variation, the value of the TM index is close to 0. Conversely, in forests with high variability in tree diameters, the value of this index is close to 1. For a better interpretation of the index, it is suggested to use the following differentiation scale: small (0.0-0.3), medium (0.3-0.5), strong (0.5-0.7) and very strong (0.7-1.0) differentiation.

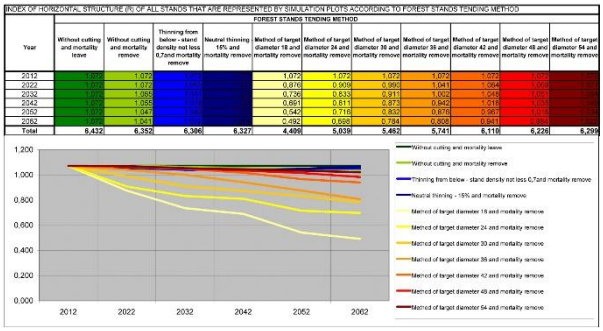


Fig. 7. Dynamics of the horizontal structure index (R) depending on management methods.

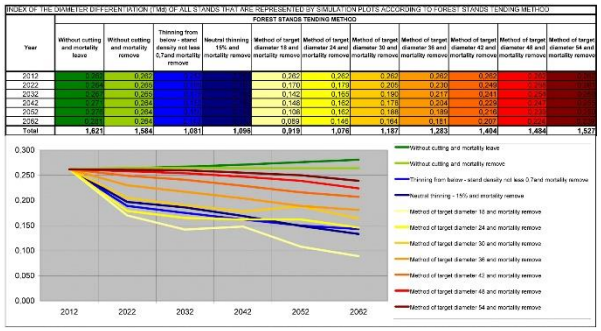


Fig. 8. Dynamics of the diameter differentiation index (TMd) depending on management methods.

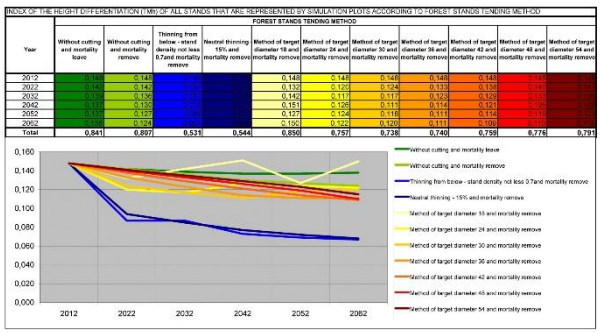


Fig. 9. Dynamics of the height differentiation index (TMh) depending on management methods.

The total diversity (Fig. 10) accounts for the above-mentioned components of diversity: stand species diversity, diversity of the stand vertical structure, diversity of the spatial tree distribution and tree crowns diversity.

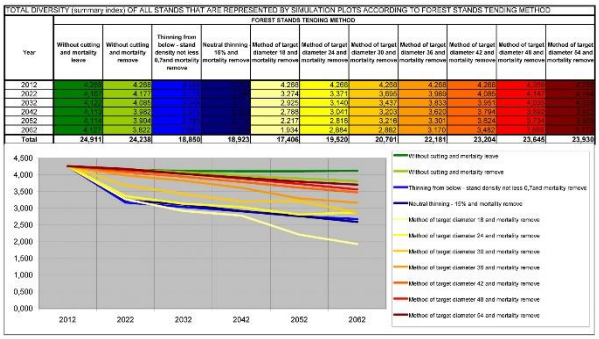


Fig. 10. Dynamics of the total diversity index depending on management methods.

The dynamics of total biomass production (Fig. 11) expressed in dry matter (t) of the entire tree (including roots, stumps, tree trunks, branches, bark and leaves or needles) has also been included in the simulations.

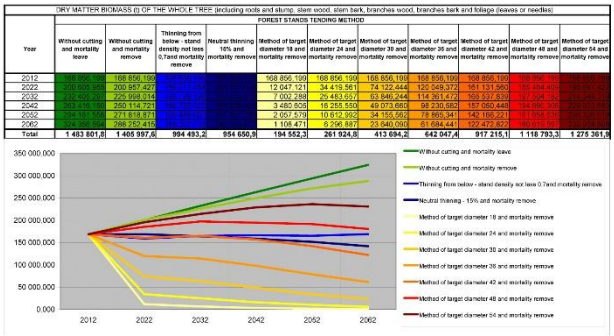


Fig. 11. Dynamics of total biomass production (t).

4. CONCLUSIONS

The figures show that total biomass and carbon production and the aggregate index of diversity are in positive correlation with each other and in negative correlation with yield (allowable cut) volume. This is not surprising and is completely logical, and have been shown by past forestry practice.

Regarding the forest management the following trends have been identified:

- The model excluding any management but including removal of dry and fallen trees shows clearly visible increases in all qualitative and quantitative parameters of ecosystem services.
- In models simulating salvage harvests, the increase is slightly less than in the previous model.
- In the models incorporating understory and mixed thinnings, the parameter values remain almost constant over the years and the x-axis is almost horizontal.
- With using the model of the target diameter method at 18 cm, maximum yield is obtained but all other quantitative and qualitative parameters of ecosystem services are dramatically reduced. Such forestry practices can largely be characterized as final felling.

- When using the same method with a gradual increase of the target diameter, the values become closer to those of the models incorporating understory and mixed thinnings with varying degree of intensity, and final harvests are generally conducted at the end of the 50-year-long period.

The results obtained from the simulations have been analyzed and provide a good basis for the successful implementation of the Sibyla information system to support management decision-making not only in Jenda State Forestry and Hunting Enterprise in Kardzhali Municipality but also in all territorial divisions of the Bulgarian forestry sector. The results show a better balance between the potential of forests and the demand for products and services from them. Conditions are created to better satisfy the diverse public needs of available forest products and services. To increase the efficiency of developed forest management plans, it is appropriate to draw up various scenarios. The possibility of choosing among different options for forest management can serve as a starting point for the development of forest management plans in the municipality of Kardzhali, ensuring the sustainability of the achievement of the set goals.

ACKNOWLEDGMENTS

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