

## SOME RESULTS OF FOREST STANDS DEVELOPMENT MODELING ON THE TERRITORY OF YUNDOLA, BULGARIA

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### Abstract

In the scientific frame of INTEGRAL project the analysis of key indicators influenced forest stand development on the territory of Yundola is made. The possible variants of forest stand development during the period of 50 years were outlined by decision support system (DSS) SIBYLA. The received results are analyzed and they are a good basis for a successful DSS Sybila implementation in decision making process in Bulgarian forestry management.

**Key words:** forest and forestry management, modelling, decision support system.

**JEL:** Q01, Q23.

### Introduction

The area is placed in the south-western part of Bulgaria. This region of dramatic physiographic and biologic diversity includes a broad spectrum of vegetation and natural sightseeing and phenomena. It is mainly woodland landscape with forests in all parts of area (about 90%). There are very productive coniferous forests. Agricultural landscapes are presented by meadows located near the village of Yundola and the other surrounding villages. The whole wooded area belongs to the Experimental Forest Department "Yundola" and is managed by the University of Forestry in Sofia as an outdoor classroom and research facility.

The Experimental Forest Department Yundola is located on the boundary between two Bulgarian mountains (Rila and Rodopi) and occupies an area of 5211 hectares. 91% (4750 ha) of that area is covered by forests.

*Description of the site, why it was selected, background on the use of the forests, etc.*

The forests at the case study area are managed continuously by forest management plans that are valid for a decade. Current land use planning is generally consistent with the multipurpose forest management and with the conservation and sustainable development of forest landscapes in the modern socio-economic conditions.

*Description of the main Ecosystem Services in the site, in general, and why they are important*

List of Ecosystems Services relevant for the case study area:

1. *Wood production.* According to statistics from the forest revisions within the territorial scope of the case study area there exists a sustainable timber harvest level for a long time. It is an indicator of proper maintenance and management of forest resources. The most ap-

propriate proxies in this regard which could describe this Ecosystems Service are:

- *Total volume* - the volume ( $m^3$ ) of all existing trees in the forest stand before a thinning treatment;
  - *Cutting volume* - the volume ( $m^3$ ) of all trees that were removed during the thinning treatment;
  - *Standing volume* or *Main crop* - the volume ( $m^3$ ) of all trees that stayed in the forest stand after a thinning treatment;
  - *The quality of wood* - as a percentage in years;
  - *Dry matter biomass* (t) of the whole tree (including roots and stump, stem wood, stem bark, branches wood, branches bark and foliage (leaves or needles));
  - *Carbon content* (t) of all stands.
2. *Diversity.* The largest share of woodland (43% or 2039.6 ha) have the forest stands with a predominant white pine (*Pinus silvestris*, L.). About one third (31%) accounted for the planting of predominant white fir (*Abies alba*, Mill), but just a quarter (25%) cover the plantations with predominant spruce (*Picea excelsa*, A. Dietr). Beech (*Fagus silvatica*, L.) has being the predominant species accounting for only 1%, while other species have a very small percentage. As the predominant tree species in forest stands is identified the species having maximum percentage of participation in the total stock. In forest stands composed of two types at a ratio of 5:5, is adopted as the predominant the one that is written first in taxological description.
3. *Water quality.* A measuring station (Experimental Watershed Study Site) for conducting long-term hydrological, environmental and forestry research is located in the case study area. It gives data for the water quantity. A brief history of hydrological studies and some

of the more significant findings from the hydrological, ecological and silvicultural investigations will be presented. The water quality in the whole region is very high, because of the region's forest cover over 90% and because no industrial pollutants. Unfortunately, any scientific information for the chemical water quality such as concentration of chemical substances, i.e. water concentrations of nitrogen (N), phosphorus (P), methyl mercury (MeHg) and dissolved organic carbon (DOC) etc. wouldn't be collected soon.

4. *Tourism.* This region of dramatic physiographic and biologic diversity includes a broad spectrum of vegetation and natural sightseeing and phenomena. The case study area is placed purely in the optimal hypsometric zone for recreation and tourism, which reaches to 1800-1900 m above sea level under the climatic conditions in Bulgaria. This is a prerequisite for positive development of tourism in this region, such as in altitude there is no need for acclimatization of the body at a long stay in the mountains.
5. *Recreation.* (In this case – to a large extent recreation in the local communities, rather than long distance tourism). Yundola region is a mountain resort with national importance, and has a large recreational potential and is a subject to deep landscape investigations and analyses. Although it is very difficult to find direct numerical measures of recreational value of forest stands, an attempt has been made for their evaluation with quantitative indicators. A parametric recreational evaluation of forest stands defines "recreational index" of forest stands using their wood stock, but not as extreme value in m<sup>3</sup>/ha, but as a function of the most important forestry-taxological indicators that are synthesized in its essence. Recognized as such are: average diameter (d); average height (H); age of the predominant species (A); and completeness (k). Recreational aspect of these indicators is expressed in conventional grade units, and the evaluation itself  $R = f(d, H, A, k)$  is an aggregate quantitative measure formed by their total. It also have been made another similar attempt, but this time the recreational value of forest stands includes two more criteria: slope (I) and walking izohron (l). Then the logical formula acquires the appearance:  $R = f(d, H, A, k, i, l)$ , and the evaluation is called "comprehensive".
6. *Mushrooms and herbs.* The case study area is known for its richness of mushrooms and herbs. The mushroom lovers used to harvest wild mushrooms under appropriate weather

conditions from April to October. The same goes for herbs.

7. *Carbon sequestration.* All analyses concerning to:
  - amount of carbon sequestered in biomass;
  - total C in trees and ground;
  - amount of bioenergy supplied for fossil fuel substitution;
 will be systematized and presented in textual, graphical and tabular form.

#### *Description of the Decision Support System:*

The Decision Support System (DSS) utilized for the analyses is SIBYLA, a Slovak developed software package, kindly provided to us by our colleagues of the Technical University in Zvolen (Fig. 1).



Fig. 1. Logo of SIBILA (*Simulátor biodynamiky lesa*)

The simulator of forest biodynamics (SIBYLA) belongs to the category of tree growth simulators (hereinafter called as a *growth simulator*).

#### SIBYLA (Single tree based simulator)

- The model is single tree based, with smallest growth period 1 year. The growth model is based on change of tree diameters, and tree heights. The exchange of parameters is based on modeling of growth potential. Growth potential is sensitive to site description: CO<sub>2</sub> and NO<sub>x</sub> concentration in the air, soil moisture, soil nutrient content, mean temperature in vegetation period, annual temperature amplitude, precipitations in vegetation period, days of vegetation period. The potential is polymorphical interpolated from growth range. The Korf's function is applied. Increment is consequently derived and modified by tree competition pressure and tree vitality. Competition pressure depends on KKL index by Pretzsch (crown light competition) and vitality depends on crown surface. Crown parameters (diameters, base, shape and surface) are derived from tree heights and diameters. Stand growth is influenced by natural mortality of

trees. Natural mortality depends on differences between current stand basal area and maximal basal area. Maximal basal area depends on upper height of stand. Selection of dead trees is solved by logistic regression depending on tree parameters. Eventually incidental cuttings are possible (by wind, snow, ice, bark beetles, foliage beetles, fungi, air pollution, fire, extreme dry conditions, and illegal cuttings). The model is heuristic and stochastic based. Stand production is influenced also by thinning. The following thinning are possible: from bellow, from above, neutral, crop trees oriented, target diameter oriented, target frequency curve oriented, and clear cutting method.

- The model includes stochastic components: generated residuals of diameter and height increments, tree mortality, and illegal cutting (if they are activated). Generation of tree

coordinates is also stochastic if we use type b) or type c) as input.

- The model can repeat structure generation and prognosis. Different results are produced. Mean values and standard deviations can be calculated. Differences between scenarios and variants can be statistically tested.

The growth simulator SIBYLA has been developed since 2002 within the framework of several foreign and national scientific projects at Technical University Zvolen, Technische Universität München and Georg-August-Universität Göttingen.

SIBYLA is a simulator that strives to imitate the behaviour of trees in the context of forest ecosystems. It consists of the set of mathematical models and algorithms that are transformed into an integrated software package (Fig. 2).

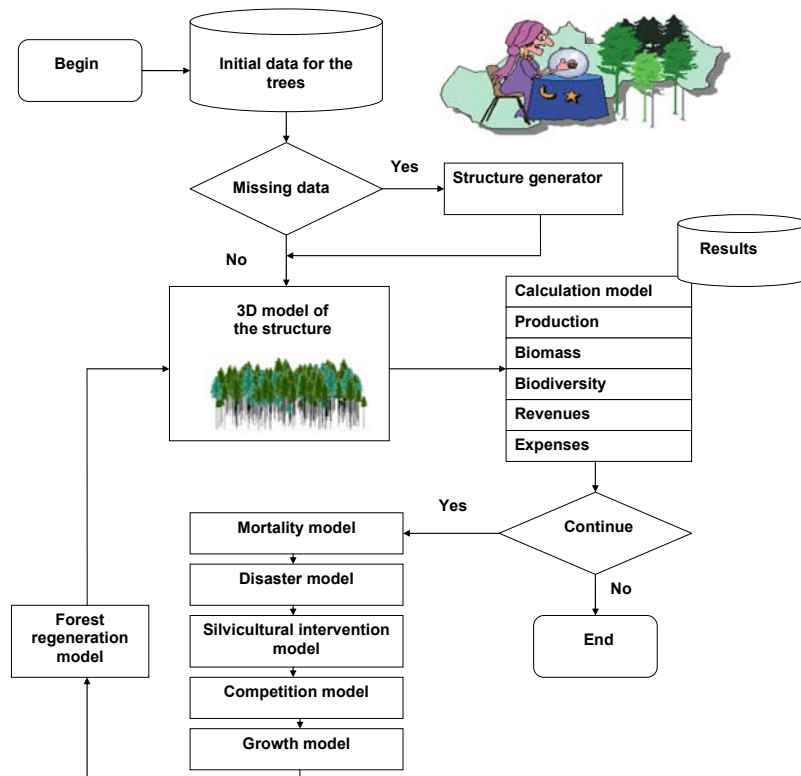


Fig. 2. The architecture of the forest growth simulator SIBYLA

The difference between the growth simulator SIBYLA and a classical forest model (e.g. forest yield tables) can be defined as follows:

Table 1. Compare between SIBYLA simulator and a classical forest model

Growth simulator	Yield tables
imitates forest behaviour	simulates forest development
set of complicated models and algorithms	simple model
many input parameters	limited (simple) input parameters

(continued)

wide range of outputs	outputs oriented at production aspect
stochastic system	deterministic system
complexity and flexibility	simplified and bound to strictly defined initial conception
ecological (site) classification	forest stand classification
inevitably as a computer program	sufficient as tables
difficult to apply	simple to apply
suitable for research and education	suitable for forestry practice
prognostic character	normative character

*SIBYLA is a system, that strives to imitate forest behaviour using the principles of ecosystem and cybernetical modelling.* It utilises a very wide range of input conditions and parameters. It simulates different initial forest stand structures starting from even-aged homogeneous stands (pure plantations) of the type of age classes, through differentiated multistoreyed forest, mixed stands and shelterwood systems, up to selection forests. It is able to simulate a wide range of natural conditions defined by ecological (site) classifications in the form of climate, air, and soil characteristics. In addition, it also offers a quite large operating space to make the interventions of a forest manager in the form of various thinning and felling regimes. And besides, a specific economic environment is accounted for inclusive of applied technological techniques. At the same time, growth simulator provides a user with a great variety of output data. Apart from classical production data it also deals with ecological information, such as biodiversity, biomass, fixation of nutrient elements in trees, oxygen production and carbon dioxide consumption. It also covers an economic aspect in the form of assortment structure of produced wood, forest revenues and management costs. To imitate the real forest as faithfully as possible, *stochastic* principles are applied, i.e. every time the simulation is repeated, the model produces slightly different results.

*YIELD TABLES represent a mathematical model, which today describes forest development by the system of mathematical equations.* It simulates the development of even-aged homogeneous forest stands (pure plantations) at full density and 100% proportion of a particular tree species in relation to age and site. The site is defined by stand class, or also by stand volume level. Yield tables are restricted to only one thinning regime, or eventually to a set of pre-defined variant regimes with no possibility to modify them. The outputs are primarily oriented at production aspect of a forest, while usually they are presented in tabular form. Thanks to the model simplicity and to the restricted range of possible variants of a forest, the model does not have to exist as a computer program. It is mainly

composed of simple growth curves, or eventually of other mensurational relationships. The model is strictly *deterministic*, and hence, its character is often normative. Due to the facts that this model does not require many input parameters and is simply applicable, it is primarily used in the forestry practice.

## Analysis of Ecosystem Services

### 1. Forest Managements Strategies

Numerous investigations have indicated that projected climate change will impact strongly on forest growth and composition. To adapt managed forests to changing environmental conditions it may be necessary to modify traditional forest management strategies. Most of developed to date forest models was initialized with forest inventory data and run using routines devised to simulate three management scenarios:

- maximized timber production;
- climatically well-adapted forest composition, and
- maximized tree species diversity.

The strategies were compared with a baseline scenario of traditional management without any response to climate change. The comparisons were based on simulated wood production and species composition after 30-50-100 and more years of development (Fig. 3-5). The results underline the important influence that management strategies have on forest growth. Forest management may adopt a variety of strategies to respond to the expected changes in climate and socio-economic conditions.

### 2. Ecosystem Service 1 - Wood production

#### 2.1. Data (existing data, metrics and format of the data):

Data from Forest management plan valid to year 2017. Spatial units of forest land - that's mean polygon feature class with detailed attribute data on each unit of forest. Maximal spatial resolution of vector data is in scale 1:10000. From the complex of attribute data has been separated those data (see following table) which were necessary as an input to SYBILA simulations (Table 2).



Fig. 3. Example of schematic 3D visualisation of a simulation plot for 50 year's time horizon

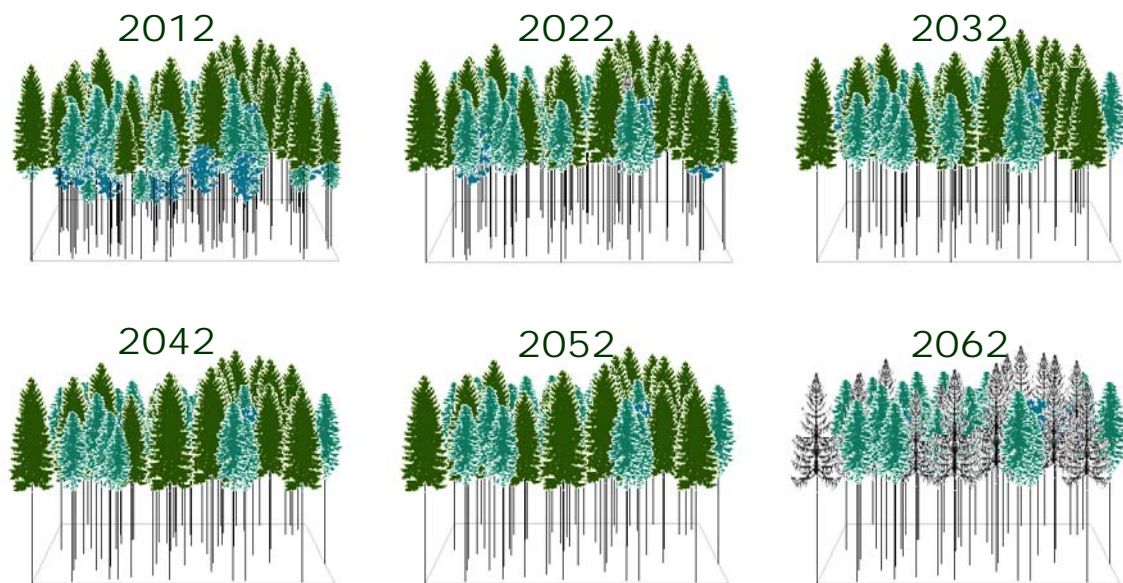


Fig. 4. Example of schematic 3D visualisation of a simulation plot for 50 year's time horizon

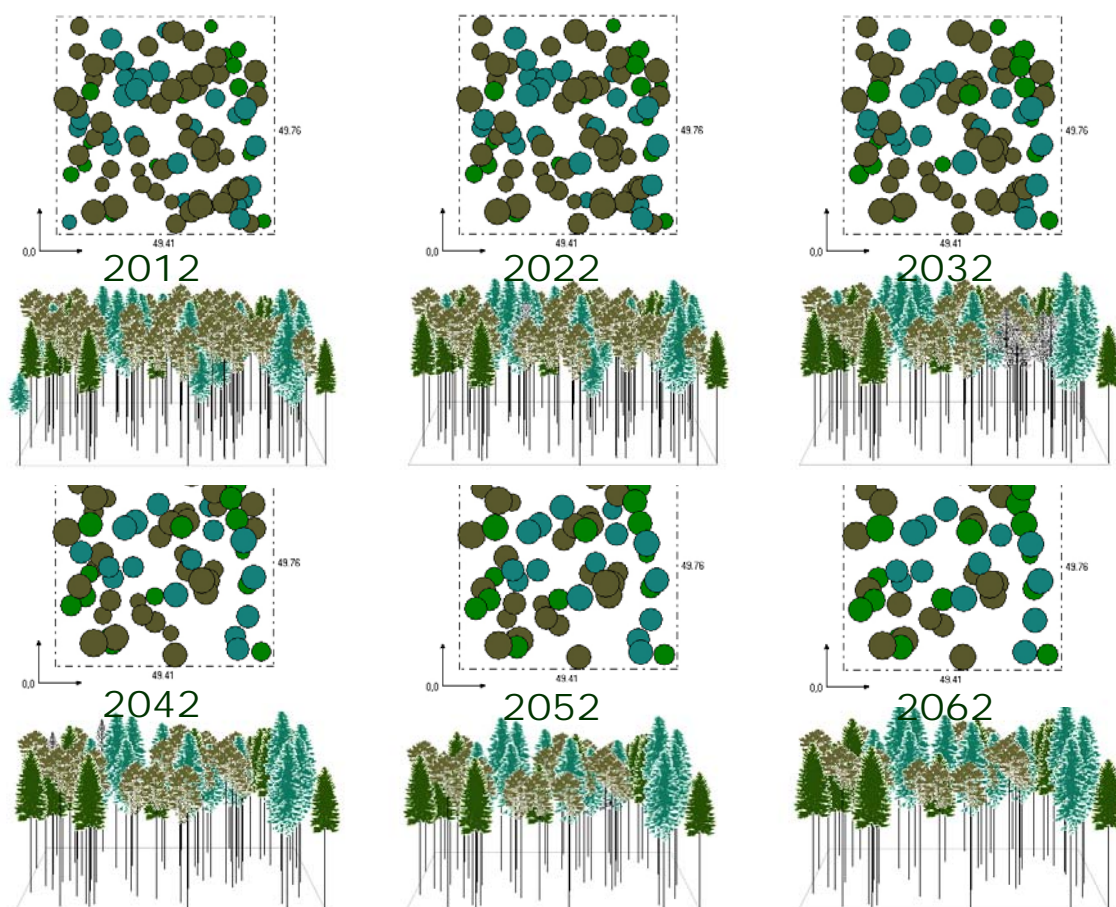


Fig. 5. Example of schematic 3D visualisation of a simulation plot for 50 year's time horizon

Table 2. Attribute data used in SYBILA simulations

Abbreviation	Field content	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 <sup>3</sup>	m <sup>3</sup>
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 difference 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	precipitation amount in vegetation period in mm (from April to September)	mm

## 2.2. Current status of the ES

The forests in Yundola have a timber stock of 1 516 503 m<sup>3</sup> and growth of 40 491 m<sup>3</sup> (Table 3).

Projected annual volume of the timber production of 21 686 m<sup>3</sup> representing 1.43% of the total timber stock. In the previous audit period (the previous decade), this value was 1.15%.

The total timber production is distributed as:

- Large timber – 11 434 m<sup>3</sup>;
- Average timber – 3 800 m<sup>3</sup>;
- Small timber - 659 m<sup>3</sup>;
- Firewood – 3 249 m<sup>3</sup>;
- Brushwood - 256 m<sup>3</sup>.

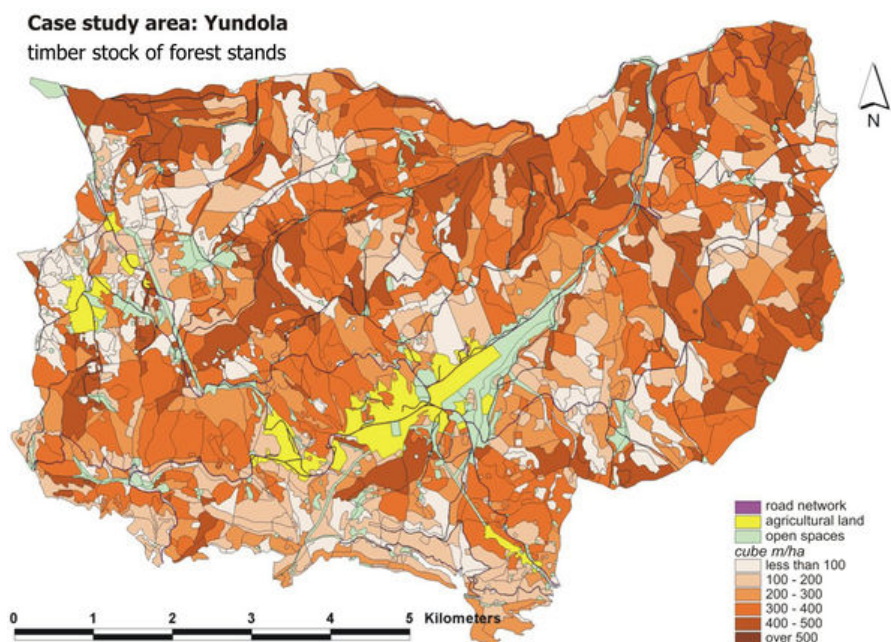


Fig. 6. Forest area classified by timber stock of forest stands

Table 3. Volume of growth by tree species

	Tree species	Volume ( $m^3$ )	%
Coniferous	Subtotal	39 392	97.29%
	<i>Pinus sylvestris</i>	12 652	31.25%
	<i>Picea abies</i>	12 908	31.88%
	<i>Abies alba</i>	13 608	33.61%
	<i>Pinus peuce</i>	172	0.42%
	<i>Pseudotsuga menziesii</i>	30	0.07%
	<i>Larix</i>	8	0.02%
	<i>Pinus cembra</i> var. <i>cembra</i>	6	0.01%
	<i>Picea pungens</i>	6	0.01%
	<i>Cedrus atlantica</i>	1	0.00%
	<i>Pinus ponderosa</i>	1	0.00%
Deciduous	Subtotal	1 099	2.71%
	<i>Fagus sylvatica</i>	969	2.39%
	<i>Quercus petraea</i>	55	0.14%
	<i>Alnus viridis</i>	19	0.05%
	<i>Sorbus aucuparia</i>	19	0.05%
	<i>Populus tremula</i>	22	0.05%
	<i>Betula pendula</i>	9	0.02%
	<i>Salix caprea</i>	0	0.00%
	<i>Robinia pseudoacacia</i>	6	0.01%
<i>Corylus avellana</i>	0	0.00%	
Total		40 491	100.00%

Note: Data from forest management plan has a last revision to 2017.

### 2.3. Potential of the ES

The potential of case study area has been calculated in four sub analyses. For each subanalysis has been made eleven simulations according to different methods of forest stand tending:

- Strict restrictions in forest (Using no cutting model including mortality. Mortality is leave in forest.)
- Extended restrictions in forest (Using cutting model "Without cutting except mortality" for all samples of forest stands)
- Restriction of today in forest area (Using cutting model "Thinning from below - stand density not less 0,7 and mortality remove" for all samples of forest stands)
- Restriction of today in forest area (Using cutting model "Neutral thinning - 15% and

- mortality remove” for all samples of forest stands)
- Maximum harvest (Using cutting model "Method of target diameter 18 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 24 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 30 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 36 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 42 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 48 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 54 and mortality remove")

- Maximum harvest (Using cutting model "Method of target diameter 42 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 48 and mortality remove")
- Maximum harvest (Using cutting model "Method of target diameter 54 and mortality remove")

2.4. Results

The simulations show the following dynamics in the development of ecosystem services within 50 years (Fig. 7-12).

TOTAL VOLUME (m <sup>3</sup> ) OF ALL STANDS THAT ARE REPRESENTED BY SIMULATION PLOTS ACCORDING TO FOREST STANDS TENDING METHOD											
Year	FOREST STANDS TENDING METHOD										
	Without cutting and mortality leave	Without cutting and mortality remove	Thinning from below - stand density not less 0,7and mortality remove	Neutral thinning 15% and mortality remove	Method of target diameter 18 and mortality remove	Method of target diameter 24 and mortality remove	Method of target diameter 30 and mortality remove	Method of target diameter 36 and mortality remove	Method of target diameter 42 and mortality remove	Method of target diameter 48 and mortality remove	Method of target diameter 54 and mortality remove
2012	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4	227 641,4
2022	273 973,1	274 016,3	224 532,8	232 252,2	13 107,0	41 099,1	93 770,1	157 385,3	216 327,7	250 159,9	265 841,5
2032	321 290,0	310 396,6	235 717,4	239 530,5	7 252,1	30 069,0	80 683,6	150 478,5	223 506,9	269 292,1	293 181,2
2042	368 718,8	346 838,7	245 575,3	224 303,2	3 406,6	18 466,3	60 375,6	129 377,0	212 045,7	269 531,6	313 440,5
2052	415 848,8	376 177,3	249 745,0	217 089,5	1 999,0	11 882,5	42 163,1	103 287,3	191 927,9	264 131,0	323 889,2
2062	462 935,0	405 475,0	255 851,5	205 545,9	1 049,3	6 811,2	28 507,7	80 221,6	164 516,3	248 340,0	316 892,5
Total	2 070 509,9	1 840 545,3	1 440 073,4	1 336 839,8	254 455,4	335 969,5	533 141,8	848 391,1	1 235 987,9	1 529 096,0	1 740 674,4

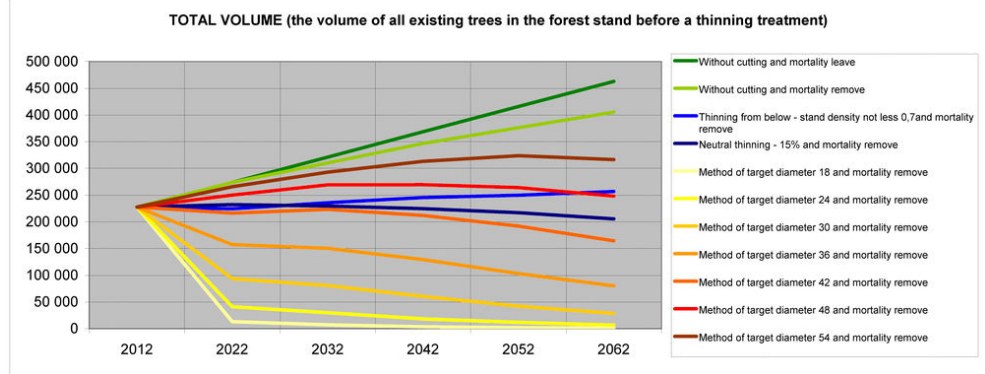


Fig. 8. Total volume (m<sup>3</sup>)

CUTTING VOLUME (m <sup>3</sup> ) OF ALL STANDS THAT ARE REPRESENTED BY SIMULATION PLOTS ACCORDING TO FOREST STANDS TENDING METHOD											
Year	FOREST STANDS TENDING METHOD										
	Without cutting and mortality leave	Without cutting and mortality remove	Thinning from below - stand density not less 0,7and mortality remove	Neutral thinning 15% and mortality remove	Method of target diameter 18 and mortality remove	Method of target diameter 24 and mortality remove	Method of target diameter 30 and mortality remove	Method of target diameter 36 and mortality remove	Method of target diameter 42 and mortality remove	Method of target diameter 48 and mortality remove	Method of target diameter 54 and mortality remove
2022	0,0	0,0	42 212,3	40 859,4	221 136,5	200 880,9	159 468,2	105 879,8	54 573,7	21 462,0	10 141,0
2032	0,0	11 206,2	23 732,1	20 255,9	9 327,9	21 516,0	34 221,1	38 987,4	34 205,9	25 380,5	13 533,2
2042	0,0	11 895,6	22 208,5	19 255,9	5 504,4	17 981,0	36 195,1	47 930,9	49 233,2	46 283,1	24 913,3
2052	0,0	18 963,3	20 379,0	18 270,2	2 376,1	10 676,7	29 634,5	47 401,5	53 180,7	44 426,2	24 915,2
2062	0,0	18 733,7	25 347,9	23 458,8	1 451,6	7 420,4	21 338,1	39 463,6	55 165,5	52 534,3	51 261,2
Total	0,0	60 798,8	151 179,7	196 460,8	239 796,5	258 474,9	280 857,0	279 663,1	246 359,1	190 086,2	137 762,2

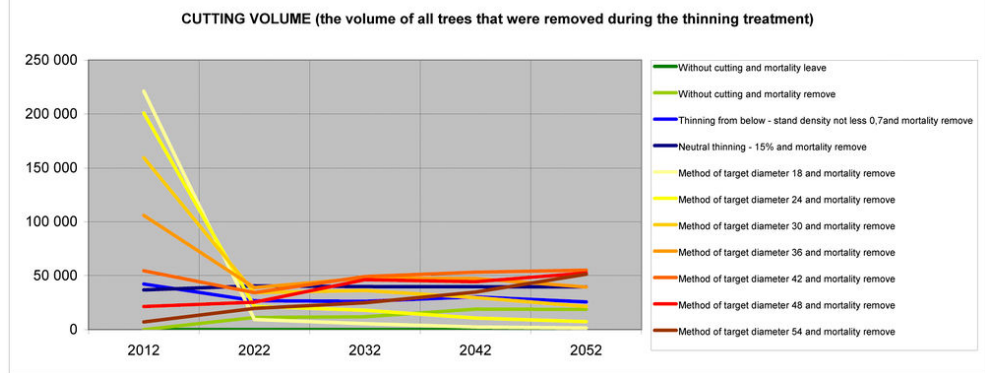


Fig. 9. Cutting volume (m<sup>3</sup>)

SOME RESULTS OF FOREST STANDS DEVELOPMENT MODELING ON THE TERRITORY OF YUNDOLA, BULGARIA

Year	FOREST STANDS TENDING METHOD										
	Without cutting and mortality leave	Without cutting and mortality remove	Thinning from below - stand density not less 0,7and mortality remove	Neutral thinning 15% and mortality remove	Method of target diameter 18 and mortality remove	Method of target diameter 24 and mortality remove	Method of target diameter 30 and mortality remove	Method of target diameter 36 and mortality remove	Method of target diameter 42 and mortality remove	Method of target diameter 48 and mortality remove	Method of target diameter 54 and mortality remove
2017	227 641,4	227 641,4	185 450,1	180 987,5	6 550,2	26 834,9	68 209,6	121 861,9	173 146,3	206 221,0	220 903,8
2022	273 873,0	274 016,3	224 532,8	222 330,3	13 107,0	41 099,1	93 770,1	157 395,3	216 327,7	252 334,5	269 199,3
2027	273 873,0	262 812,4	187 863,5	181 028,8	3 824,3	19 679,1	59 556,4	118 319,3	182 144,6	226 981,7	249 633,1
2032	321 290,2	310 396,6	235 717,4	229 530,3	7 252,1	30 069,0	80 683,6	150 478,5	223 506,9	272 057,4	296 805,5
2037	321 290,2	298 491,2	209 500,5	198 274,2	1 750,8	12 028,4	44 454,7	102 549,2	174 210,9	225 778,5	271 969,1
2042	368 718,8	346 838,7	245 573,3	232 200,2	3 406,6	18 466,3	60 376,6	129 377,0	212 045,7	268 369,9	319 853,2
2047	368 718,8	327 950,6	245 213,4	180 030,2	1 070,7	7 804,1	30 754,1	81 848,6	158 855,2	223 911,0	284 950,4
2052	416 948,5	376 177,3	249 745,0	217 058,5	1 999,0	11 882,5	42 163,1	103 287,3	191 927,9	263 976,6	331 491,2
2057	416 948,5	357 476,7	224 106,4	170 529,0	536,8	4 489,5	20 830,6	63 663,7	136 719,7	211 489,5	280 085,0
2062	469 838,9	405 475,0	265 864,1	209 849,2	1 049,3	6 811,2	28 507,7	80 221,6	164 619,3	247 945,4	329 696,8
Total	1 786 886,6	1 720 196,6	1 298 639,6	1 258 842,2	35 890,9	148 176,9	407 048,9	780 031,3	1 181 382,4	1 451 743,1	1 625 954,5

MAIN CROP (the volume of all trees that stayed in the forest stand after a thinning treatment)

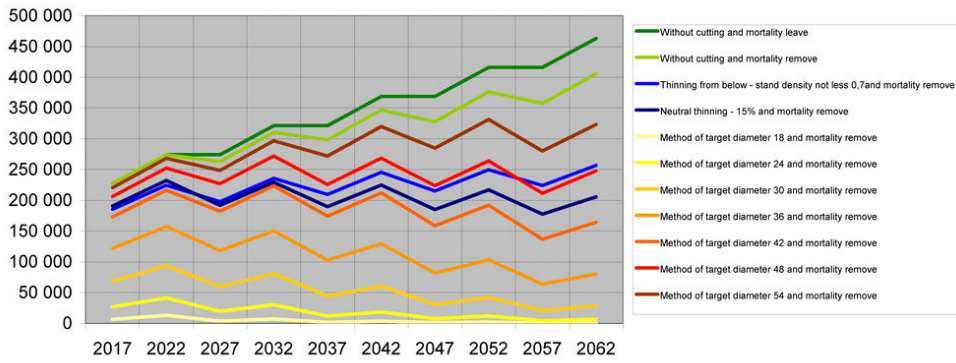
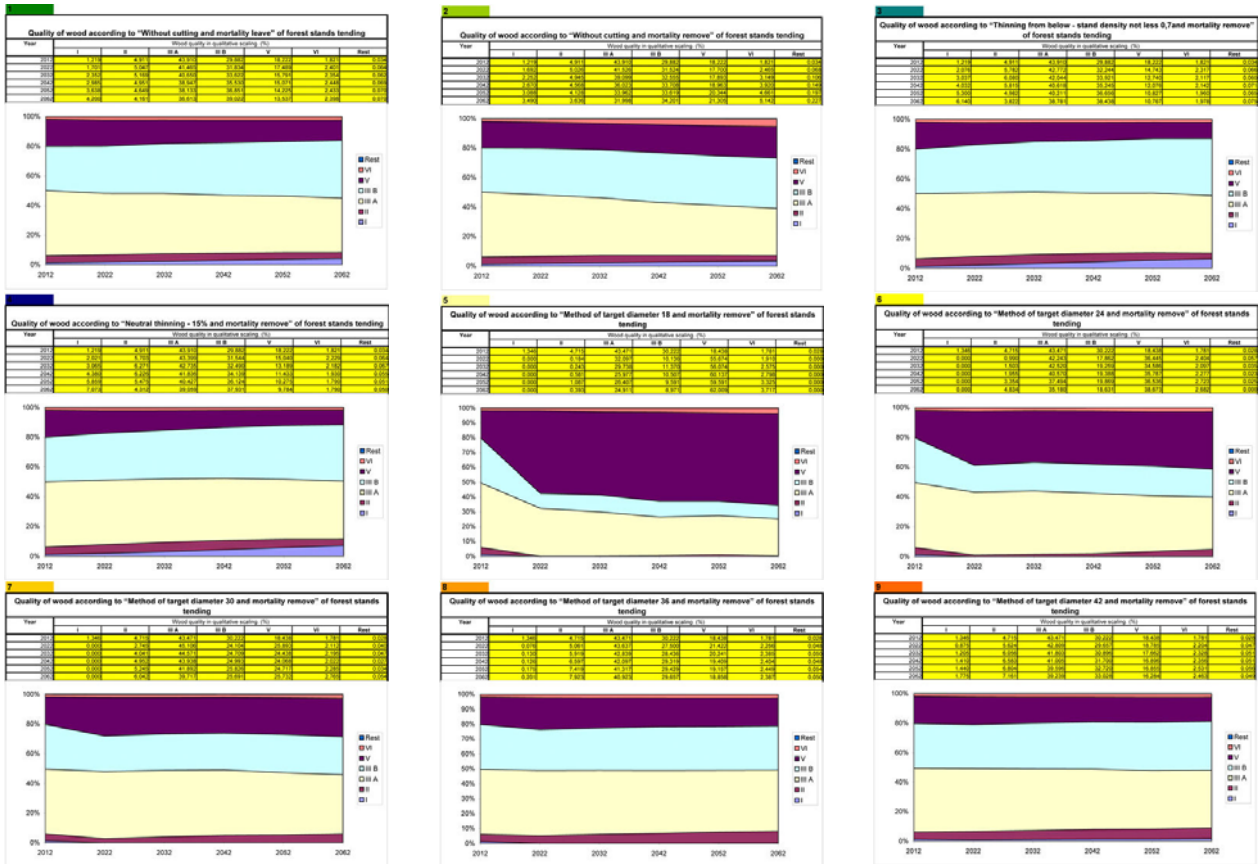


Fig. 9. Main crop (m<sup>3</sup>)



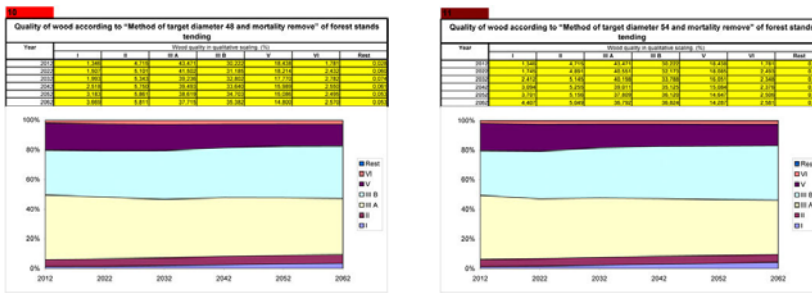


Fig. 10. Quality of wood Representation of quality of wood as a percentage by years

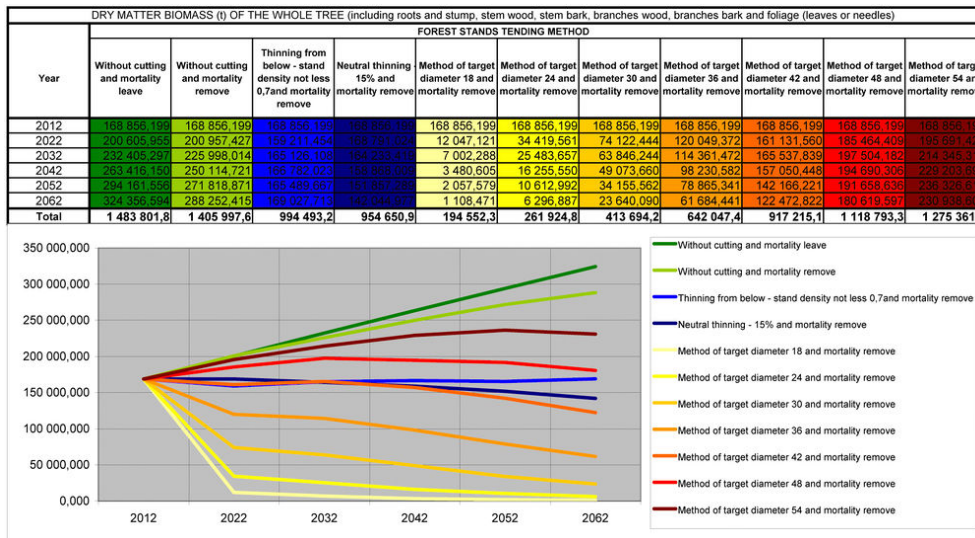


Fig. 11. Biomass production

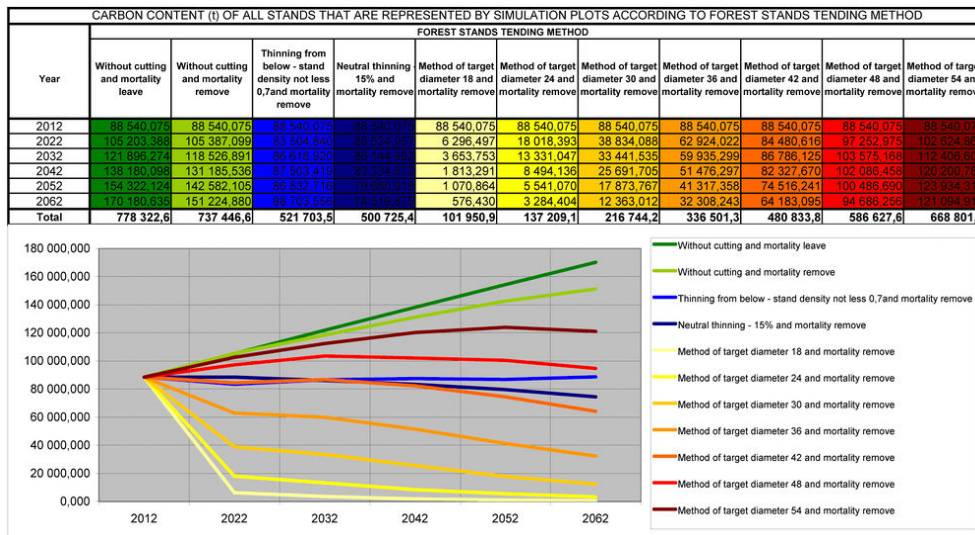


Fig. 12. Carbon production

2.5. Discussion

- Using no cutting model including mortality we observed clearly visible increase of all qualitative and quantitative indices of the Ecosystem Services.
- Using cutting model "Without cutting except mortality" the increase is less than in the previous forest stand tending method.

- Using cutting models "Thinning from below" and "Neutral thinning" the values of the indices remain almost constant over the years and the line graph is almost horizontal. Such forestry practices can largely be treated as intermediate felling.
- Using cutting model "Method of target diameter 18 and mortality remove" we get a

maximum harvest but all of the qualitative and quantitative indices of the Ecosystem Services decrease dramatically. Such forestry practices can largely be treated as a final felling placed as now.

- Using the following cutting models where the diameter of the felling trees gradually increased we observed gradually approach the values obtained in the intermediate fellings in varying degrees of intensity where the final fellings more or less take place at the end of the 50 year period.

### 3. Ecosystem Service 2 - Diversity

#### 3.1. Data (existing data, metrics and format of the data)

The same as at Ecosystem Service 1.

#### 3.2. Current status

##### Potential of the ES

Diversity of forest stands within the case study area has been calculated in four sub analyses illustrating:

- *Index of the diameter differentiation (TMd)* - one of the indexes of the structural diversity which is related to the ratio between the larger and the smaller diameter of all nearest neighbouring trees in the plot as defined by Földner (1995);
- *Index of height differentiation (TMh)* - one of the indexes of the structural diversity which is related to the ratio between the larger and the smaller height of all nearest neighbouring trees in the plot as defined by Földner (1995);
- *Index of horizontal structure (R)* is derived from all distances between two nearest neighbours, number of trees in the plot, plot area, and the perimeter of the plot according

to Clark and Evans (1954). The range of the index is from 0 to 2.15. The value 0 indicates an aggregated structure, i.e. the trees are aggregated in clusters. The value 1 represents a complete random distribution of trees in the plot area (so called Poisson distribution), while the value 2.15 stands for the regular tree distribution in the plot (in hexagonal spacing).

- *Total diversity (summary index)* proposed by Jaehne and Dohrenbusch (1997) is calculated using many relationships. It is the aggregation of partial components of diversity: tree species diversity, diversity of vertical structure, diversity of tree spatial distribution, and diversity of crown differentiation. The input variables are: number of tree species, maximum and minimum tree species proportion, maximum and minimum tree height in the stand, maximum and minimum tree spacing, minimum height to crown base, and minimum and maximum crown diameter. If the final value is equal to or higher than 9, stand structure is very diverse, the values from 8 to 8.9 indicate a diverse structure, index values in the range from 6 to 7.9 mean an uneven structure, an even structure is indicated by the values between 4 and 5.9, and the values below 4 represent a monotonous structure.

For each subanalysis has been made eleven simulations according to different methods of forest stand tending.

#### 3.3. Results

The simulations show the following dynamics in the development of ecosystem services within 50 years (Fig. 13-17).

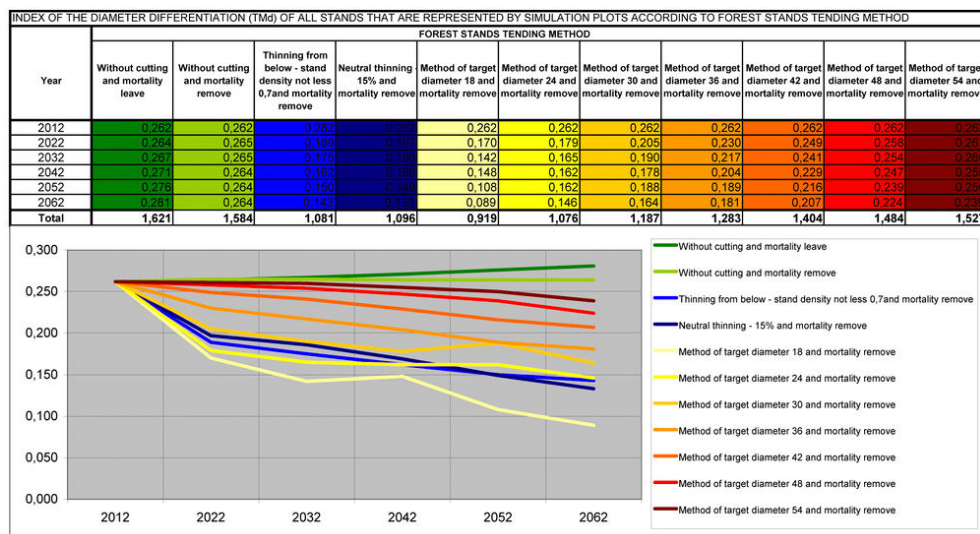


Fig. 13. Index of the diameter differentiation (TMd)

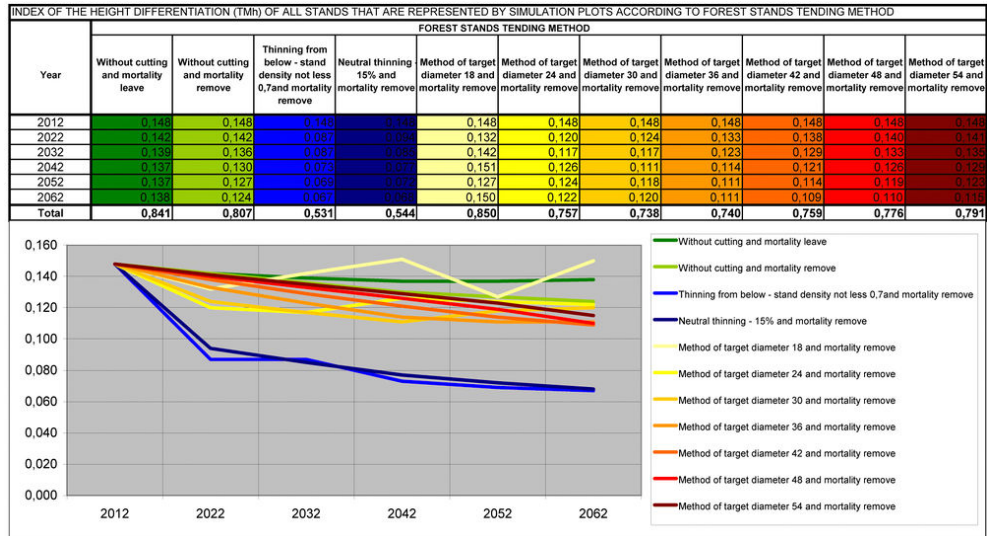


Fig. 14. Index of height differentiation (TMh)

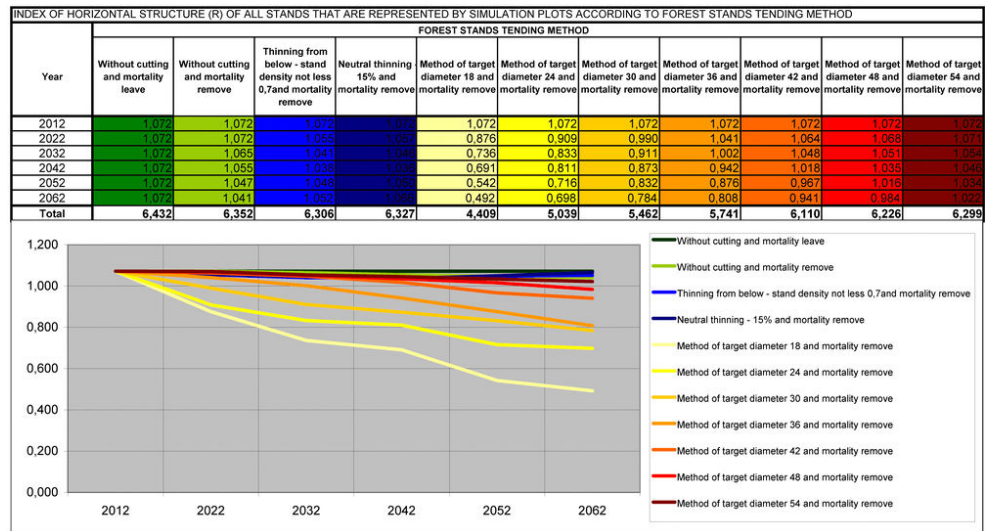


Fig. 15. Index of horizontal structure (R)

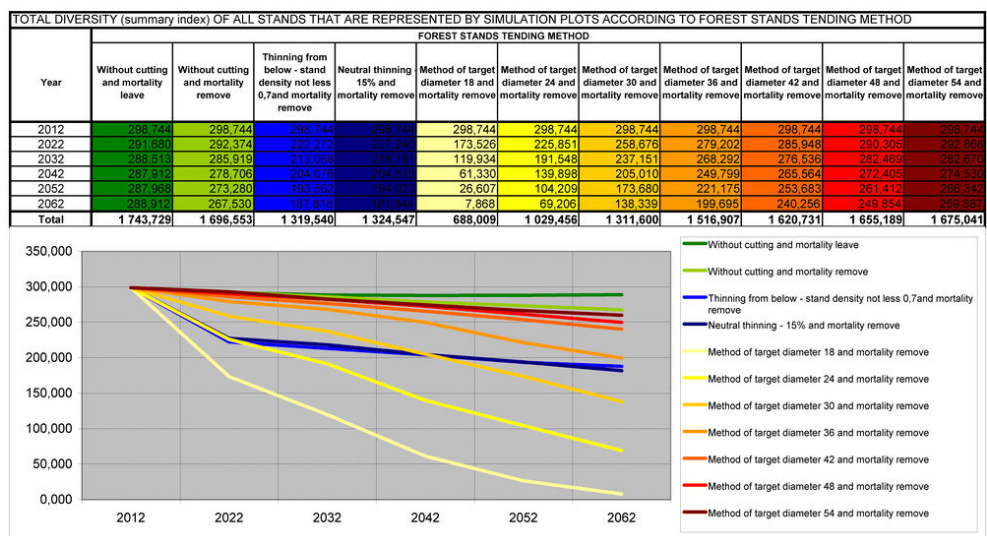


Fig. 16. Total diversity (summary index) as a total value

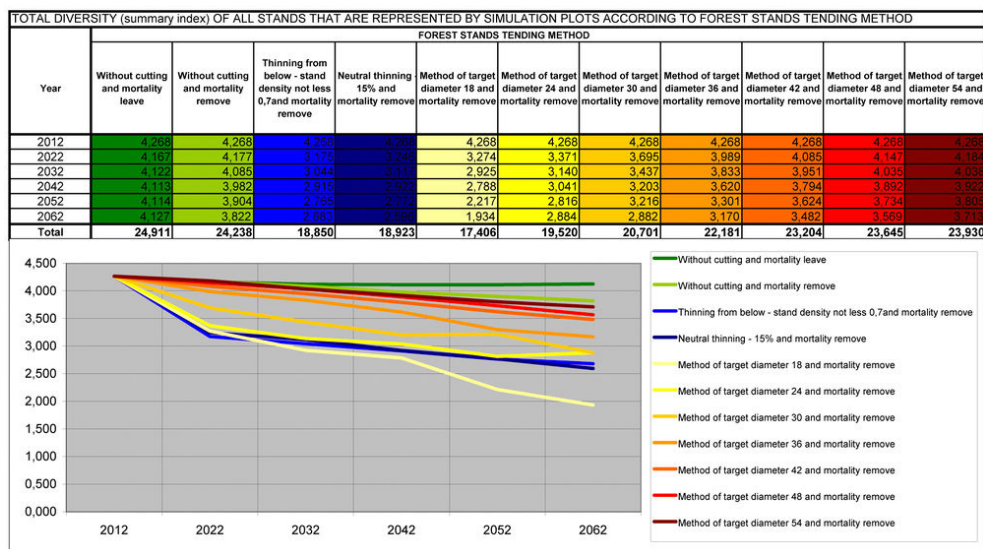


Fig. 17. Total diversity (summary index) as an arithmetic mean value

### 3.4. Discussion

- Using no cutting model including mortality we observed clearly visible increase of all qualitative and quantitative indices of the Ecosystem Services.
- Using cutting model "Without cutting except mortality" the increase is less than in the previous forest stand tending method.
- Using cutting models "Thinning from below" and "Neutral thinning" the values of the indices remain almost constant over the years and the line graph is almost horizontal. Such forestry practices can largely be treated as intermediate felling.
- Using cutting model "Method of target diameter 18 and mortality remove" we get a maximum harvest but all of the qualitative and quantitative indices of the Ecosystem Services decrease dramatically. Such forestry practices can largely be treated as a final felling placed as now.
- Using the following cutting models where the diameter of the felling trees gradually increased we observed gradually approach the values obtained in the intermediate fellings in varying degrees of intensity where the final fellings more or less take place at the end of the 50 year period.

### 4. Ecosystem Service 3 - Water quality

#### 4.1. Data (existing data, metrics and format of the data)

All waterways are part of the catchment of the River Maritsa. In the northeast they flow into Yadenitsa river and in the southwest - into the Chepinska river. Yadenitsa is the largest river in the area and have a constant flow. Its tributaries are three. Some other smaller streams which flow significantly reduces in summer run into them. At the bottom of the dingles Bazenishki and Yundolski are catchments.

The second largest river is the Hot River. It originated from the foot of Black Peak. Its tributaries are five. The slopes to the village of Saint Petka are very steep. Its flow is constant with a slight decrease in summer and autumn.

The springs in the area are many. Some of them dry up during the summer. The presence of relatively well saturated and branched hydrographic network, partly determine predominance of fresh and fresh to moist habitats.

### 5. Synthesis and trade offs between different Ecosystem Services

After recapitulation of the results from the different simulations it is clear that management can greatly affect the state of the case-study area with respect to all Ecosystem Services. There are some definite dependence between the Total volume, Cutting volume, Carbon content, Dry matter biomass and Total diversity (Fig. 18-20).

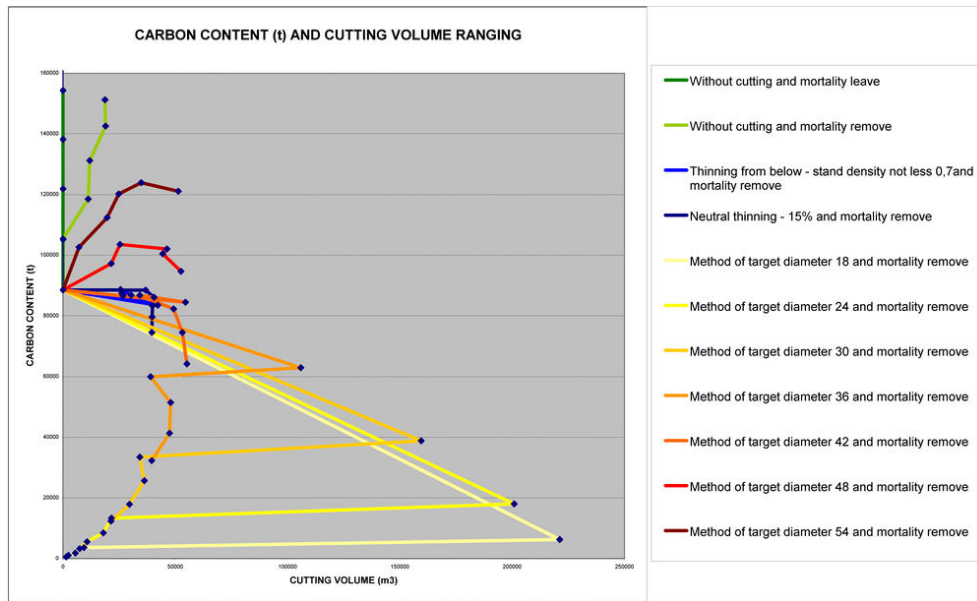


Fig. 18. Carbon content (t) and cutting volume ranging according to forest stands tending method

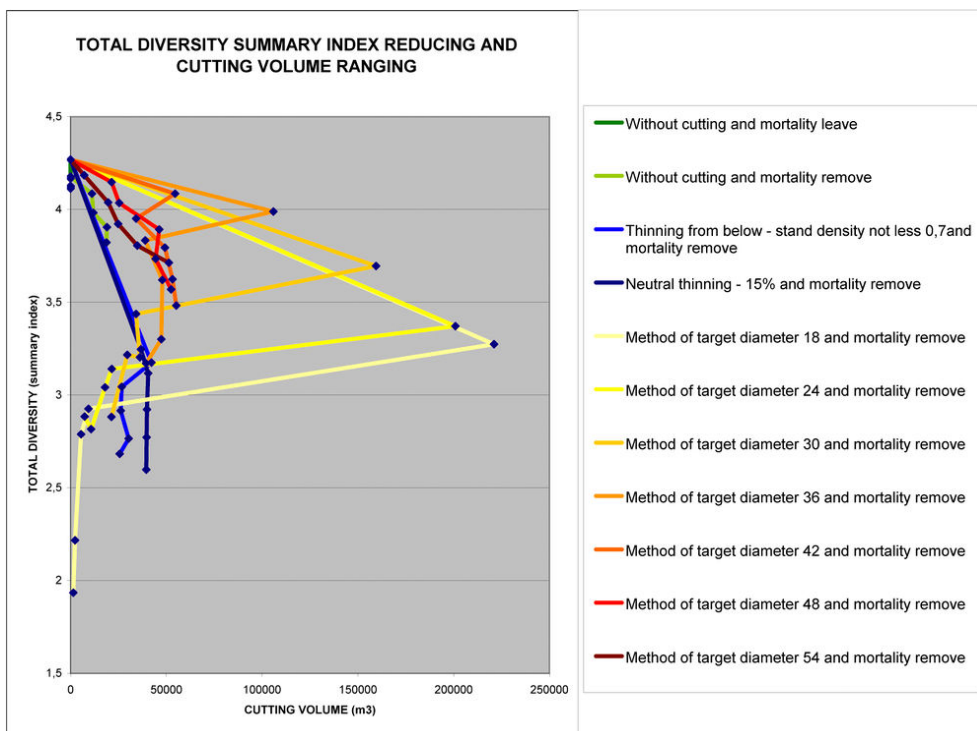


Fig. 19. Total diversity summary index reducing and cutting volume ranging according to forest stands tending method

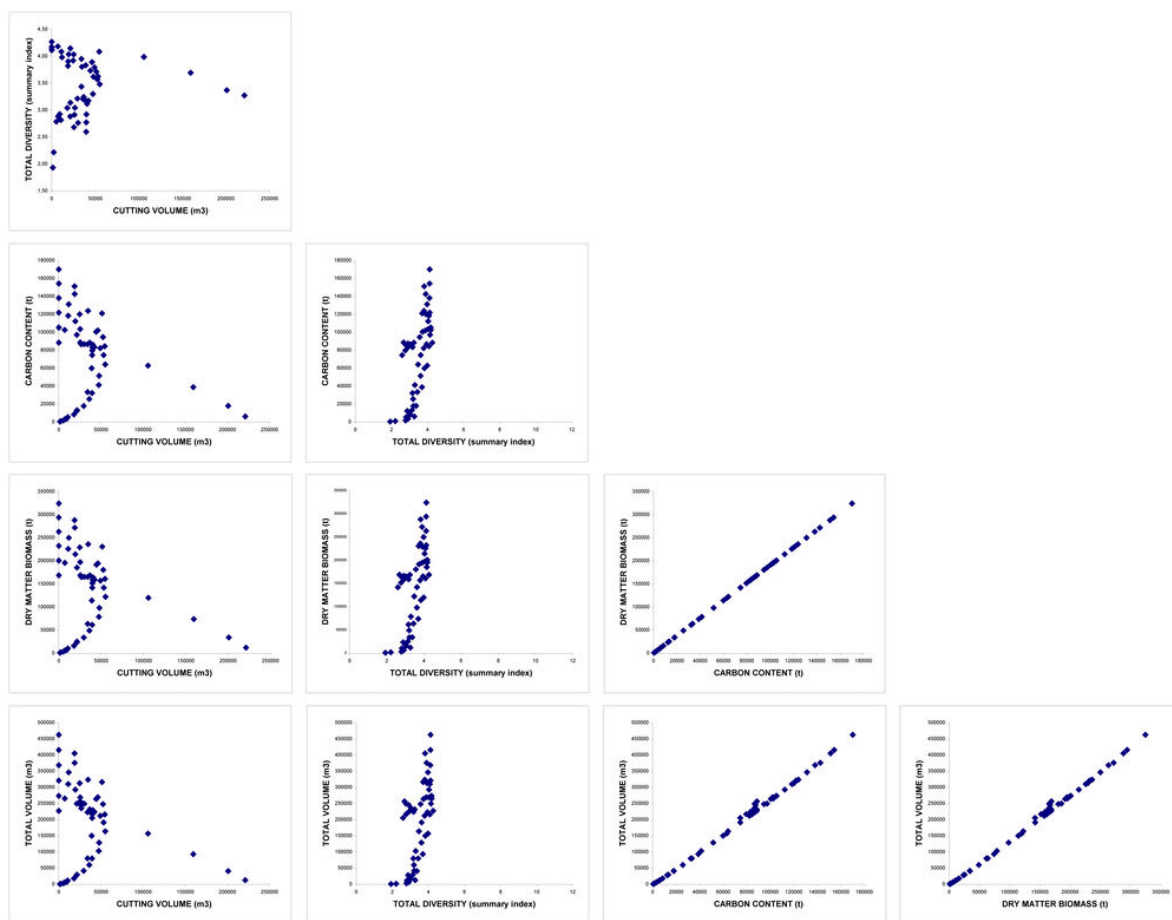


Fig. 20. Pairwise correlation between the Total volume, Cutting volume, Carbon content, Dry matter biomass and Total diversity

These diagrams show that the biomass and carbon and the total diversity are positively correlated with each other and negatively correlated with the cutting volume.

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## **НЯКОИ РЕЗУЛТАТИ ОТ МОДЕЛИРАНЕ НА РАЗВИТИЕТО НА ГОРСКИТЕ НАСАЖДЕНИЯ НА ТЕРИТОРИЯТА НА УОГС ЮНДОЛА**

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### **Резюме**

В рамките на изследването по проект INTEGRAL е направен анализ на изменението на състоянието на ключови индикатори, влияещи върху развитието на горските насаждения на територията на УОГС Юндола. С помощта на Информационна система за подпомагане на вземането на решения (ИСПВР) „СИБИЛА“ са очертани възможните варианти за развитие на горските насаждения за период от 50 години. Получените резултати са анализирани и са добра основа за успешното прилагане на информационната система за подпомагане вземането на управленски решения в условията на българското горско стопанство.

**Ключови думи:** управление на горите и на горското стопанство, моделиране, информационни системи за подпомагане вземането на решения