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SD MODEL OF EVEN-AGED FOREST

SUSTAV DINAMIČKI MODEL REGULARNE ŠUME

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A basic requirement in today's forest resources management is an ongoing production of all forest utilities with preserving the forest ecosystems stability. Considering the even-aged forest management, this requirement will be assured by achieving compositions of normal and stable forests based on normal age class order.

Faced with natural systems governed by intricate relationships in time and space, we have chosen a system-dynamic modelling as our work method, and projected a simulation model of even-aged forest management process by applying the method of age class distribution.

After simulating suitable scenarios, we focused our research on the future development of age class distribution per area and growing stock on the management unit "Lacic Glozdje", within the pedunculate oak management class.

The simulation research proved that even-aged forest management, defined by the intensity of regeneration felling (i.e. by the method of calculating the felling area of the major harvest cut) and the length of rotation, is a powerful factor affecting the future behavior (i.e. the change of age class distribution, felling areas growing stock and values) of a closed even-aged forest system.

Key words: sustainable management, even-aged forest, system dynamics, age class distribution

INTRODUCTION
UVOD

When men realized that timber was not an inexhaustible resource, he started to manage forests on the principle of sustainable forestry. Sustainability is possible to achieve by applying different methods, going through various development phases (Morecroft 1992). Sustainable revenue has been a traditional feature of forest theory and practice (Klepac 1965). The work principle in forest management is such that it enables continuing annual yields, preserving and protecting the productive capabilities of the forest (Kuik & Salomon 1994).

Sustainable management of forest resources today has a much wider concept than continuous yields of timber. The preservation of the forest resources for production of generally useful forest functions and genetic potentials is far more important.

Continuing yields of similar revenues do not necessarily mean sustainable forest management (Gane 1992a,b, Geus 1992). The right way is the search for economic progress that will not damage the welfare of future generations (Vennix 1992).

The basic principle of sustainable revenues present in the traditional theory and practice, and all legislation on forest management, should acquire a dynamic and progressive character (Meštrović 1978, 1980). A composition of stable forest of even-aged stands based on a normal age class distribution is a prerequisite.

A basic requirement faced by forest resource managers is continuing production of forest utilities with preservation of the forest ecosystem stability. Forest is a dynamic natural system governed by complex cause-consequence relations in time and space. A system of dynamic modelling may be a powerful support in deciding and planning forest management (Čavlović 1996).

Based on the created dynamic simulation model of the even-aged management process, applying the method of age class distribution and the done simulation of the suitable scenarios, the research focused on the future development of the age class distributions per area and growing stock within the pedunculate oak management class in the Management unit "Josip Kozarac". Having achieved a considerable success today, the simulation model may process all assumed future changes, that will affect the given forest assets. It is an intelligent support in forest management, appropriate for both short-term and long-term planning of physical, economic and financial elements.

MODEL PRESENTATION
PRIKAZ MODELA

The system dynamic simulation model of the even-aged forest management process presents a real forest as a closed system for achieving balance. It tries to encompass and describe all effective factors within and out of the system (biological disturbances, management practices), that may affect the time of achieving the normal age class distributions.

A forest of even-aged stands can be presented as a system consisting of two basic parts. The first, smaller in area, consisting of mature stands in which regeneration felling is carried out, and yield of the main revenue is realized. The second part of the forest are stands where tending is done through intermediate cuts, and the yield of the previous revenue is realized. Between the two parts, continuous flows of the stands are going on. The regeneration cuts reduce the mature stand area, increasing the areas with intermediate cut stands. Over time, the stands nearest the mature ones, pass into the mature stand forest parts, enhancing their area.

This dynamic system can be presented with the following verbal model:

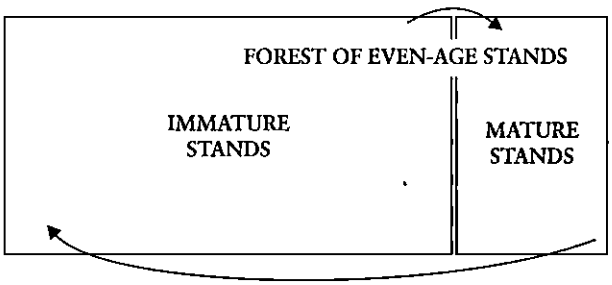


Figure 1. Model of forest of even-aged stands
Slika 1. Model regularne šume

With higher intensity of regeneration felling (ha/year) the young stand area will grow, which means a positive (+) direction of influence. The bigger immature stand area, the higher transition intensity (ha/year) of the stands toward the parts of mature stands, which means a positive (+) direction of influence. Likewise, the higher intensity of stands transition, the smaller the immature stands area, which means the negative (-) direction of influence. The global indication of the causal relationship is negative (-), and the feedback loop's (FBL) polarity is negative. A higher intensity of stand transition from the immature stands parts will cause an increase in the mature stands area. The bigger mature stands area, the higher intensity of regeneration felling, i.e. a positive (+) direction of influence. The area of mature stands ready for felling will decrease with the rise in the regeneration felling intensity. This means a negative direction of influence. The global indication of the causal relationship is negative (-), and the feedback loop's polarity is negative (Fig. 2).

The normal state of forest of even-aged stands is based on a series of stands of various ages. Therefore, forest of even-aged stands should be presented as a system composed of a series of age classes, independent of their number or width. This even-aged forest model can be expanded and represented with the following verbal model:

The transition of stands into a first age class (ha/year) depends on the regeneration felling policy (major harvest cut). Over time, regeneration can be constant or variable.

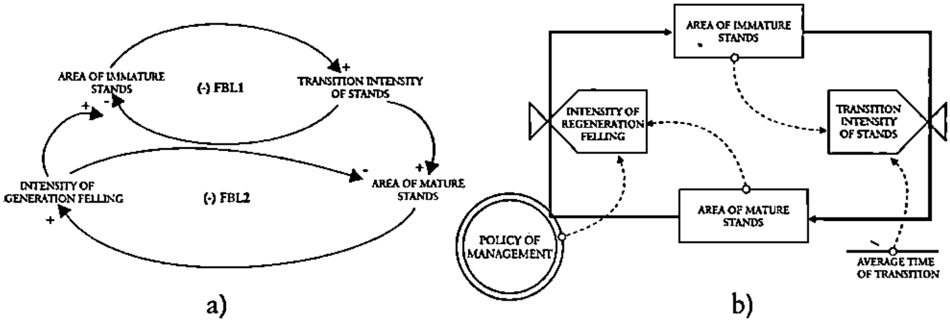


Figure 2. a) Structural model of forest of even-aged stands
b) Elementary diagram of flows

Slika 2. a) Strukturni model sustava regularne šume
b) Elementarni dijagram tokova

The more intensive the regeneration, the bigger area in the first age class will be, which means a positive (+) direction of influence. The bigger area in the first age class is, the more stands area will move from the first into the second age class (hectare annually), which again denotes a positive (+) direction of influence. At the same time, the stands area in the first age class will be smaller as more stands area move from the first into the second age class, which is a negative (-) direction of influence. A more intensive transition of stands area from the first into the second age class will lead to an increased stands area in the second age class (a positive (+) direction of influence), which will in turn cause a bigger stands area to pass from the second into the third age class (again a positive (+) direction of influence). With a more intensive transition of stands area from the second into the third age classes, the stands area in the second age class will be smaller (a negative (-) direction of influence).

The series of influences continue in the same manner and its length depends on the number of age classes, that is, on the rotation.

The stands area in the last age class will be bigger if the transition of stands from the penultimate age class is faster (positive (+) direction of influence); it will be smaller if felling intensity in the last age class is higher (negative (-) direction of influence).

This verbal model of an even-aged forest dynamic system can be presented with the extended influence diagram and an elementary diagram with flows (Čavlović 1996).

The functioning model of the even-aged forest management process consists of the state variables connected by processes into a dynamic system where there are causal relationships and the feedback loop's. The state elements are the areas of the individual age classes in each time section, i.e. in each interaction period the changes in the individual flows are summed.

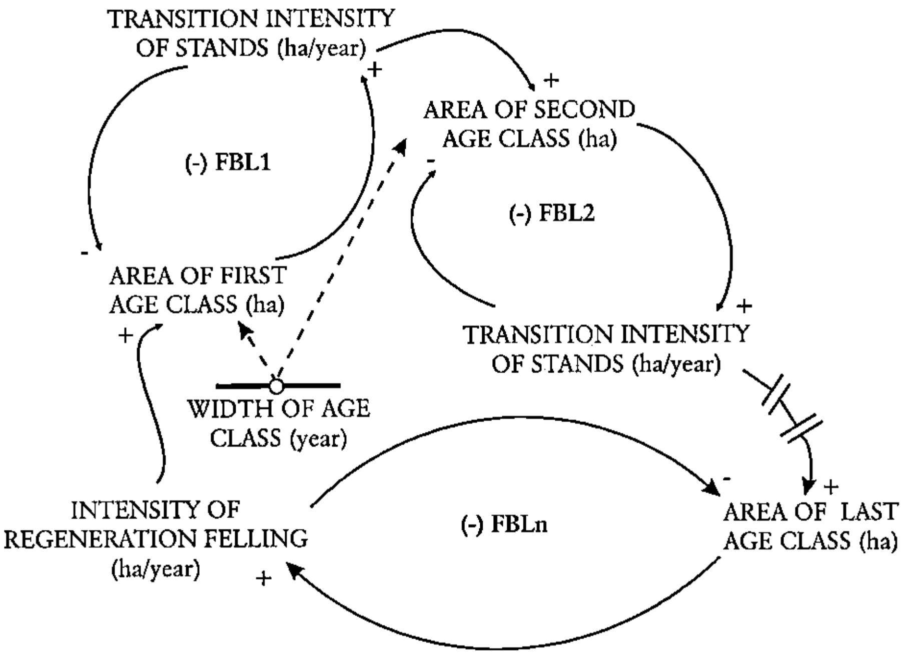


Figure 3. Extended structural model of forest of even-aged stands
Slika 3. Prošireni strukturni model sustava regularne šume

The state variables are calculated using the following formula:

$$\text{New state} = \text{old state} + \int_{t_0}^{t_1} (\text{input changes} + \text{output changes})\, dt \qquad (1)$$

The equation of the state in the DYNAMO simulation language:

$$L\ L.K = L.J + (DT) \times (RA.JK - RS.JK) \qquad (2)$$

The presented model of the even-aged forest management process is a closed system with a self-regulating character. Its behavior will depend on external impacts that can be defined by control equations. In the mentioned model, the regeneration felling policy, which decides on the regeneration felling practice, has been taken as a powerful control mechanism on which the behavior of the given even-aged forest will depend over a long time period. With defining the felling policies and rotation length, the system dynamic simulation may investigate the most suitable management of the real forest under particular conditions.

The methodology consists of the DYNAMO (DYNAmic MOdeling) simulation language, programming and computer simulation in BASIC-version, use of the SYSDYNS (system dynamic software package), and the DYNAMO language in BASIC enabling computer simulation (Forrester 1992, Munitić 1990).

THE OBJECT AND AIM OF SIMULATION RESEARCH
PREDMET I CILJ SIMULACIJSKOG ISTRAŽIVANJA

The simulation research was targeted at the management class of pedunculate oak in the management unit "Lacic Gložđe". The management class consists of pedunculate oak stands in the first quality site class. The total area of the management class is 3,223.88 ha, the total growing stock is 989,057 m^3 and the measured annual increment is 29,409 m^3 (10.20 m^3/ha). Compared to the normal age class distribution, there are a surplus of midle aged understocked stands and deficite of mature and young stands. (Table 1, Figure 4, 5)

Table 1. Data of real forest of even-aged stands (Management class of pedunculate oak-Management unit "Lacić Gložđe").
Tablica 1. Podaci stvarne regularne šume (Uređajni razred hrasta lužnjaka-Gospodarska jedinica Lacić Gložđe)

	AGE CLASS							Total
	0-20	21-40	41-60	61-80	81-100	101-120	121-140	
	years							
Actual area (ha)	353.24	59.64	591.24	783.46	1325.82	110.48		3223.88
Normal area (ha)	460.55	460.55	460.55	460.55	460.55	460.55	460.55	3223.88
Actual growing (m^3)	-	12,167	157,861	241,306	532,980	44,744		989,057
stock (m^3/ha)	-	204	267	308	402	405		307
Norm. growing (m^3)	-	65,859	129,875	184,681	220,603	244,552	259,290	1,104,859
stock (m^3/ha)	-	143	282	401	479	531	563	343

Figure 4. Real and normal age class distributions per area
Slika 4. Stvarna i normalna dobna struktura po površini

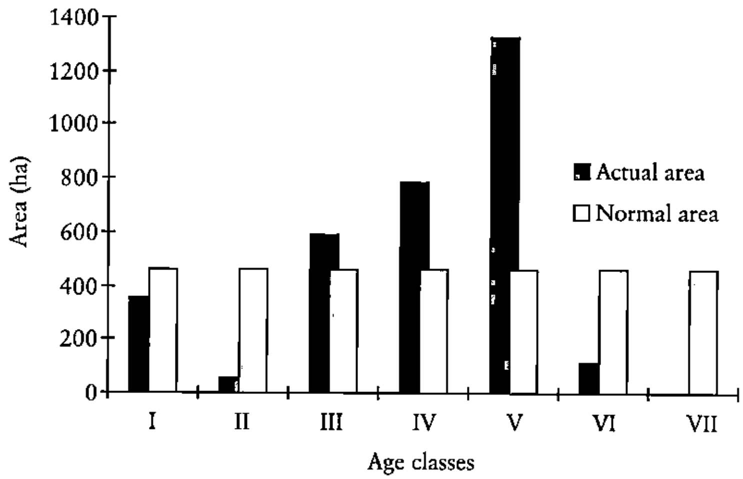
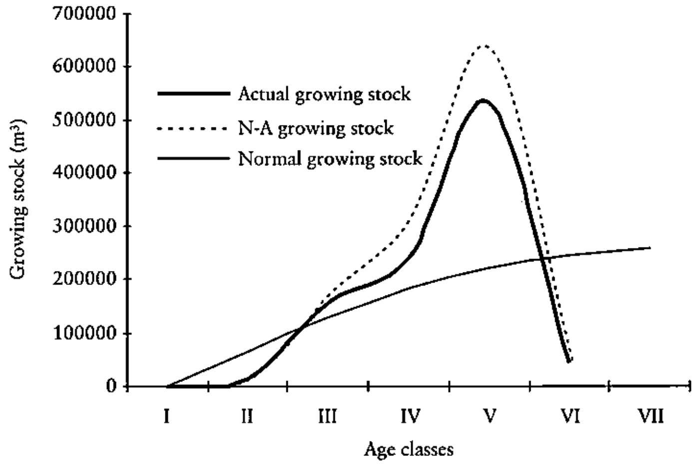


Figure 5. Real and normal age class distributions per growing stock
Slika 5. Stvarna i normalna dobna struktura po drvnoj zalihi



N-A growing stock (g.s. based on the real age class distribut. per area and normal stocked stands)

The surveyed and classified data present the initial states in the course of simulation research on the behaviour of the given even-aged forest system.

The aim of the research was to estimate:

- future development of age class distribution per area and growing stock;
- time needed to equilize age class areas;
- trends in the total growing stock and annual felling and intermediate cut within the defined management requirements;

THE RESULTS OF SIMULATION RESEARCH
REZULTATI SIMULACIJSKOG ISTRAŽIVANJA

THE DEVELOPMENT OF AGE CLASS DISTRIBUTION
KRETANJE RAZMJERA DOBNIH RAZREDA

The simulation was conducted on the sample of actual age-class data (area, actual growing stock per hectare and achievement of a normal growing stock per hectare).

The management policy scenario was based on a 140-year rotation period, according to which regeneration felling is carried out in mature stands in an area representing the rth part of the total forest area. In the course of the simulation period, no changes in the total forest area have occurred, neither by increasing it through afforestation, nor by reducing it, so that the felling intensity has remained constant for the whole simulation period (Eq. 3).

$$IRF = \frac{A}{r} = constant \qquad (3)$$

where IRF - intensity of regeneration felling (ha/year)
A - total (unchangeable) forest area (ha)
r - rotation in years

With regard to the rotation length, a model was studied within the defined scenario according to the dynamics of the age class distribution behaviour along a particular time axis. In connection with trends in the age class distribution (Fig 6), there was a specific flow of the total growing stock and annual cuts (Fig 7).

Figure 6. Trends area of age classes
Slika 6. Kretanje površine dobnih razreda

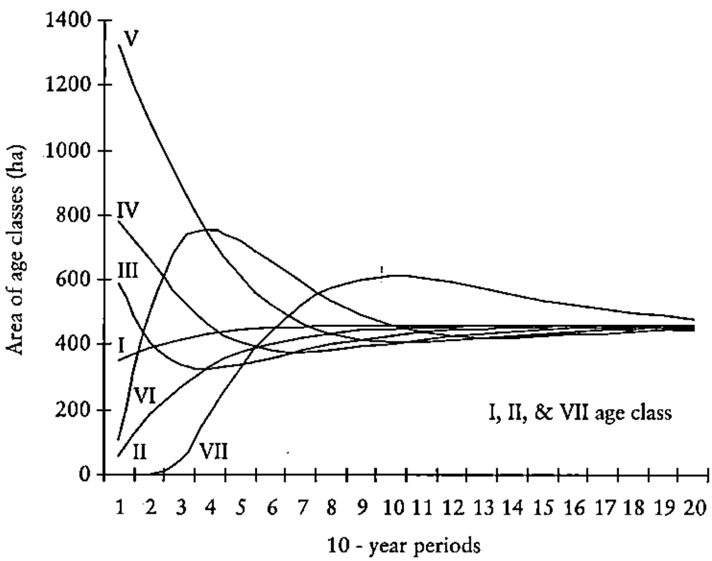


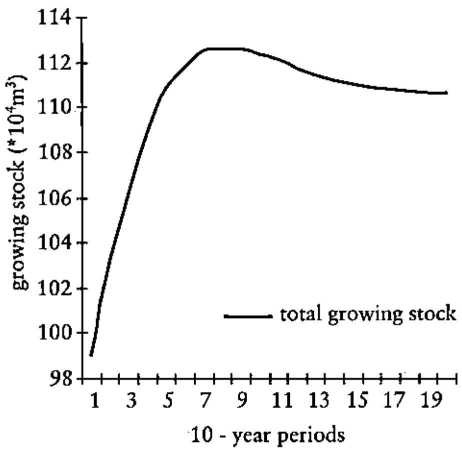
Figure 6 shows the development of age class distribution over a period of 200 years. As can be seen, the age class distribution did not achieve a normal age class structure within the mentioned period.

The greatest changes occurred in area trends of the three last age classes. There is considerable between the last age class distribution and other age classes. The amounts and intensities of these changes over time, particularly of the first and last age class are significant for long-term even-aged forest management.

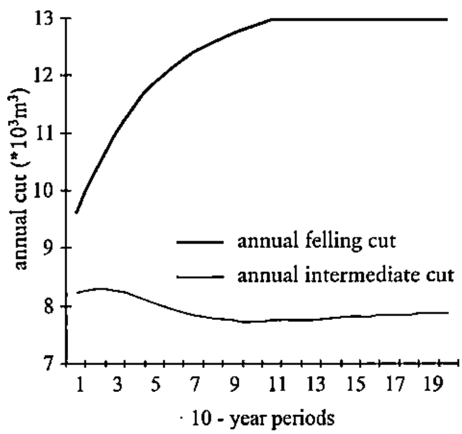
Trends in the total growing stock are the consequence of trends in age class distributions and of the achievement of normal stand stocking. Changes in the trends

Figure 7. Trends of a) total growing stock
b) annual cuts

Slika 7. Kretanje a) ukupne drvne zalihe
b) godišnje sječe



a)



b)

of growing stock and annual cuts were more intensive in the first part of the simulation period which was characterized by equilization.

CONCLUSION
ZAKLJUČAK

Model-building and simulation supported by system dynamics may illustrate complex forestry systems such as those of the even-aged forests managed by the method of age class distribution. Computer simulation models may simulate the behavior of actual even-aged forest systems within a particular period for determining their future development. The method is an integral support to the process of management and planning in forestry, both at local and higher management levels.

According to the assumed management, the initial state of the age class distribution, and the state of the increment and growing stock in any real forest of even-aged stands, the suggested ongoing simulation model can determine the future development of the age class distribution and the flow of the cut and growing stock.

System dynamic modelling makes it possible to build into the simulation model future assumptions of the changes that may affect forest resource management of a particular region. According to the obtained behavior dynamics in the studied system, as response to the simulated scenario, a long-term planning of physical, economic and financial elements is possible:

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SUSTAV DINAMIČKI MODEL REGULARNE ŠUME

SAŽETAK

Temeljni je zahtjev koji se danas postavlja pri gospodarenju šumskim resursima trajna proizvodnja svih koristi od šume uz očuvanje stabilnosti šumskih ekosustava. Razmatrajući gospodarenje regularnim šumama, taj će zahtjev biti osiguran postizanjem strukture normalnih i stabilnih šuma koja se zasniva na normalnom razmjeru dobnih razreda. Kako je riječ o prirodnim sustavima u kojima vladaju vrlo složeni odnosi u vremenu i prostoru, za metodu je rada upotrijebljen sustav dinamičko modeliranje, pri čemu je projektiran simulacijski model procesa gospodarenja regularnom šumom uz primjenu metode razmjera dobnih razreda.

Nakon simuliranja odgovarajućih scenarija istraživanje je usmjereno na budući razvoj razmjera dobnih razreda po površini i drvnoj zalihi u gospodarskoj jedinici Lacić Gložđe unutar uređajnoga razreda hrasta lužnjaka.

Simulacijskim je istraživanjem utvrđeno da su pri uređivanju regularnih šuma određivanje intenziteta oplodne sječe (način određivanja površinskoga etata glavnoga prihoda) te duljina ophodnje vrlo značajni čimbenici koji utječu na buduće ponašanje zatvorenoga sustava regularne šume (promjene u kretanju razmjera dobnih razreda, površinskoga etata glavnoga prihoda, drvne zalihe, vrijednosti šume).

Ključne riječi: potrajno gospodarenje, regularna šuma, sustavna dinamika, razmjer dobnih razreda