Original scientific paper

Economic Consequences of Different Management Approaches to Even-Aged Silver Fir Forests

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Abstract

Economic analysis of even-aged fir stand management was illustrated using the example of the forests of the Croatian Dinaric region, as well as their transformation into more stable uneven-aged structures. Two scenarios (even-aged, uneven-aged) were simulated against the backdrop of the existing forest stand structure of future forest stand management during a 140-year period using forest growth modeling software MOSES version 3.0 in order to identify economic differences amongst different scenarios both at stand level and at forest level. The research included forest management analysis throughout the transformation period and subsequently the continuation of balanced state forest management. Moreover, the research also provided the opportunity of forest purchase within the price range from 1000 to 12,500 EUR/ha, amid assumed fluctuation of selling prices of timber assortments throughout the simulation period. Discount rates from 1% to 5% were used during the economic analysis. The research findings showed that, according to harvesting costs, Net Present Value and Internal Rate of Return, uneven-aged forest management system, including the transformation period, achieved superior economic results, albeit at discount rates that exceeded 1.24%. The conclusion was reached that, according to all economic criteria, uneven-aged mixed silver fir-beech management system is preferred compared with the pure even-aged silver fir management.

Keywords: silver fir, management transformation, cost control, NPV, IRR

1. Introduction

Silver fir (*Abies alba* Mill.) in the Dinaric region primarily includes Slovenia, Croatia and Bosnia and Herzegovina, as well as to a lesser extent Albania, Montenegro and Serbia (Bončina 2011). The notion of uneven-aged management in Croatia normally refers to silver fir (Matić et al. 1996). This management system is normally adopted in fir-dominated Dinaric mountain forests (Bončina 2011). During the last several decades such forests have been characterised by processes of growing stock of large trees, difficulties in regeneration and gradual silver fir dieback, which were recorded in Croatia (Čavlović et al. 2006, Teslak et al. 2016), Bosnia and Herzegovina (Keren et al. 2014), Slovenia (Bončina et al. 2002, Ficko et al. 2011) and other Central European countries.

Silver fir forests in Croatia account for 12% in the total forest area (Čavlović 2010), in which uneven-aged management is dominant (Čavlović et al. 2006). Several types of them are present depending on the soil type, altitude, bioclimatic zone and consequently the plant community. In Croatia, pure even-aged forest stands are to be found only in several localities of silver fir forests in the Pannonian and Dinaric regions. The previously mentioned forests within the Pannonian Region are to be found in the western part of Papuk mountain (Šafar and Hajdin 1954, Božić et al. 2011), whereas in the Dinaric region they are located in the lower parts of Velebit and Mala Kapela mountain by the rivers of Gacka and Lika (Vukelić 2000). It is important to highlight that their origin has thus far remained unknown, yet it can be assumed that they were formed through artificial regeneration. Rare cases of successful even-aged silver fir forest management, i.e. in the Italian Alps, have been recorded to date (Bottalico et al. 2014).

During the past 100-odd years, several silver fir forest management systems were adopted in the Dinaric

Mountain Region, from even-aged to uneven-aged and plenter (or selection) systems and »freestyle forest« management (Bončina 2011). There are both advantages and disadvantages to even-aged and uneven-aged management systems, yet the general trend in forestry, both in Europe and throughout the world, is to emphasise the advantages of the management system referred to as natural or close-to-nature forest management system (McMahon 1999, O'Hara 2001, Macdonald et al. 2010, Davies and Kerr 2011, Knoke 2012). Uneven-aged forest management system is considered as a close-to-nature forest management system due to its features of maintenance of continuous cover stands (Franklin 1989, Mlinšek 1996, Koch and Skovsgaard 1999) primarily for shade tolerant species, yet this is true only in case of observation of small size stands.

There are multiple justifications for the transformation of even-aged coniferous stands into uneven-aged or selection i.e. plenter forests (Hanewinkel 2001). In addition to higher silvicultural and management possibilities (Kenk and Guehne 2001, Malcolm et al. 2001, Schütz 2001, Remeš 2006, Božić et al. 2011), as well as economic potential of uneven-aged forests (Knoke and Plusczyk 2001, Hanewinkel 2002, Price 2002), there is an increasing need for transformation due to a large number of the demands placed by the society upon forests (Salim and Ullsten 1999, Buongiorno 2001, O'Hara 2001). In the context of changing importance of forests and the demands placed upon forests, forest management systems with a rising number of features of adaptability and dynamism are becoming increasingly prominent, whilst the rigid pre-defined framework over a long period is slowly being abandoned.

Forest management system transformation is considered an immense turning point, which is also evident in economic consequences (Davies and Kerr 2015), and hence the only task of forest economics is to analyse forest management transformation processes. Hanewinkel (2002) stated that this type of analysis can be conducted only in silver fir or spruce forests, due to the fact that in such forests both forest management systems can be applied. The same author analyses the European references which, whilst comparing even and uneven-aged management of spruce-fir forests, from an economic standpoint clearly gives precedence to uneven-aged management system, whereas the even-aged forest management system is considered more adequate only in rare cases. This is due to a large quantity of valuable logs, a smaller risk of natural disasters, smaller forest management costs (Hanewinkel 2002), as well as regeneration, which is cost free in case of natural uneven-aged forest management (Navarro 2003, Davies and Kerr 2015).

It is a fact that, upon transformation of artificially grown forests, regeneration costs play an important role concerning the economic effects (Davies and Kerr 2015). Knoke and Plusczyk (2001) compared even-aged and uneven-aged forest management (including the transformation) of spruce stands. The uneven-aged forest transformation process in the previously described case (Knoke and Plusczyk 2001) provides a smaller amount of financial revenue, albeit it is a constant financial revenue, as well as a higher NPV. A similar conclusion was also reached by Pukkala et al. (2010) on spruce stands in Finland. However, transformation into uneven-aged forests is not always the best scenario from an economic standpoint and the specific situation needs to be considered (volume, increment, regeneration, intensity of previous forest gap dynamics, etc.) and cost-effectiveness needs to be analysed (Price 2012).

In cases of balanced even or uneven-aged stands, the transformation is never recommended from an economic standpoint (Price 2012) and the same applies to cases in which the age of even-aged stands is close to financial maturity (Knoke 2012). Moreover, silvicultural treatments of transformation and discount rates can affect the economic result in such proportions that a specific management system is more adequate or less favourable in relation to another, as was shown by, for instance, Price (2002). According to Hanewinkel (2001), the most economically cost-effective is transformation through cutting in circular gaps and the gradual expansion of these gaps, whilst Price and Price (2006) showed the cutting of the biggest trees in the stand as more advantageous. Macdonald et al. (2010) concluded that transformation of coniferous forests through clearcutting in circular gaps initiates the creation of side branches that reduce the financial value of timber assortments.

Even-aged silver fir forests in the Dinaric region in Croatia are considered specific in relation to the dominant approach of a combination of single stem and group selection silvicultural systems. An additional feature of such forests is unbalanced age-class structure with prevalent rate of mature (100-year) stands, which results in decision-making dilemmas concerning the future forest management. Starting from the previously mentioned facts and the above-mentioned published research studies, economic analysis can be conducted through application of even-aged forest management and transformation of even-aged to uneven-aged management, which was considered an interesting and significant research task. Hence, two research hypotheses were formulated:

Table 1 Structural elements of the sampled stand (source: Beljan 2015)

DBH, cm	Silver fir			Common beech			Other hardwoods			Σ		
	Stand density pcs./ha	Basal area m^2/ha	Growing stock m^3/ha	Stand density pcs./ha	Basal area m^2/ha	Growing stock m^3/ha	Stand density pcs./ha	Basal area m^2/ha	Growing stock m^3/ha	Stand density pcs./ha	Basal area m^2/ha	Growing stock m^3/ha
10.0–19.9	66	1.21	7.58	9	0.13	0.81	2	0.02	0.15	77	1.36	8.54
20.0–29.9	56	2.88	31.16	2	0.08	0.92	2	0.07	0.62	60	3.03	32.70
30.0–39.9	78	7.78	104.11	1	0.05	0.63	1	0.04	0.37	80	7.87	105.11
40.0–49.9	93	14.70	213.47	1	0.07	1.09	1	0.10	1.44	95	14.87	216.00
50.0–59.9	52	11.92	179.13	–	–	–	–	–	–	52	11.92	179.13
60.0–69.9	11	3.52	52.98	–	–	–	–	–	–	11	3.52	52.98
70.0–79.9	2	0.52	7.94	–	–	–	–	–	–	2	0.52	7.94
Σ	358	42.53	596.37	13	0.33	3.45	6	0.23	2.58	377	43.09	602.40

⇒ a period of transformation from even-aged into uneven-aged stand structure would result in superior economic effects compared with effects of establishment of even-aged balanced age-class forest

⇒ management of an established balanced uneven-aged fir-beech forest would be more economically effective in relation to management of establishment of balanced even-aged pure silver fir forest.

For that purpose the objective of this paper was to use a specific example of an even-aged fir forest in order to simultaneously conduct a research and an economic analysis of the two scenarios: even-aged and uneven-aged forest management, to be implemented in the future both at stand and forest level.

2. Material and methods

2.1 Research area and data collection

The research was conducted in the Dinaric region covered by beech-fir forests in the Republic of Croatia in the forest of pure silver fir (*Abies alba* Mill.) on even-aged stands. Coverage area of the pure (>90% of total volume) silver fir forest (management unit Škamnica 44°58′N, 15°08′E) was 567.33 ha. The stands in this specific forest were extremely similar in terms of age, growing stock, basal area and mean annual volume increment. The altitude ranged between 430 and 828 m a.s.l. The soil types were primarily limestone and dolomite. According to Köppen's classification, the climate was of *Cfwbx* type, i.e. it was classified as moderately warm rainy climate. The average annual air temperature was 9.3 °C.

From a total of 33 stands, one specific stand was selected in order to conduct a field measurement. First, a group of stands was defined, in which intermediate cut had just been performed and where the rate of silver fir exceeded 90% (18 stands). Out of these 18 stands, the sample stand intended for field measurement was selected by random sampling. Terrain survey in the selected stand, covering an area of 22.21 ha, was conducted in the year 2013 (Table 1). A total of 20 circular plots with 40-metres in diameter were placed within a 100-meter square net oriented towards four cardinal directions. All the trees with DBH exceeding 10 cm were measured. For every tree, its species, the specific position in the three-dimensional space, DBH, and absolute height were determined according to Čavlović and Božić (2008).

2.2 Simulation of stand growth and management scenarios

A virtual square shaped stand (173.2x173.2 m) was designed (Beljan et al. 2016) based on both measured and assessed data of the observed stand (Table 1). This virtual stand was integrated into a single-tree growth computer programme for stand growth simulation model MOSES version 3.0 (Pretzsch et al. 2002, Steinmetz 2003, Hasenauer 2006, Mikac et al. 2013) as the initial state for the simulation of management scenarios. Three assumptions were made:

⇒ the stand structure represented 10% of the forest where cut had just been performed (past management characterised by 10-year cutting cycles and some kind of intermediate cut)

⇒ the first 10-year period of stand growth simulation was without cut

⇒ the use of the same initial state for other nine tenths of the forest (groups of stands) where stand growth simulation was to start sequentially during the following 2–10 years.

Stand growth and future management were simulated for both even-aged and uneven-aged management scenarios and also at both stand and forest level.

2.2.1 Even-aged management scenario

Even-aged management scenario and the theoretical even-aged forest were defined by the forest area of 567.33 ha, rotation, theoretical number and area of compartments/sub-compartments, regeneration period and prescribing and scheduling both intermediate and regeneration cut (Table 2). It is necessary to distinguish »free« simulation period (without cutting, year 2013–2022) and simulation period of management (with cutting, from the year 2023 to the future).

Stand level growth simulation of the sub-compartment (stand) 1*a* in which the regeneration would be the first to begin, taking place »on time« (at the age of 100). Stand growth simulation of other stands in the compartment 1 (*b* up to *j*) would be similar, albeit with a shift of 1 year and sequentially the prolongation of regeneration would start. Concerning the stands within other compartments (2–11), the management (cutting) would start in 2023 (*a* stands). In that case, an intermediate cut in 10-year cycle would be simulated until the start of the regeneration in several stands depending on their belonging to several compartments (stands belonging to compartment 11 were scheduled for regeneration last (cut stand age of 220 years)). Stand growth simulations of all 110 stands arranged in the previously described way presented the even-aged forest management scenario.

Table 2 Description of elements whereon even-aged management scenario and theoretical even-aged forest were defined

Element of even-aged management/forest		Explanation
Forest area	567.33 ha	Forest area of stands in forest where the rate of silver fir exceeds 90%
Rotation	120 yrs.	In the past, according to Meštrović (2001), 120-year rotation was the most frequently used system of silver fir even-aged management in Croatia
Regeneration period	20 yrs.	20 yr. regeneration period by 3 cuts; theoretically first (preparatory) at the age of 100 yr., second (regeneration) at the age of 110 yr. and after 10 yrs. the final cut. New stand growth cycle begins with regeneration (second) cut in the middle of the regeneration period
Sub-compartment (stand)	110 pcs. (5.15 ha)	In case of 120-yr rotation and 20-yr regeneration period 50% of youngest and oldest age class area overlap, in which case theoretical forest is comprised of 110 stands (Nenadić 1929)
Compartment	11 pcs. (51.5 ha)	110 stands are arranged within 11 compartments (each compartment divided into 10 stands, a up to j); stands of compartment 1 would be regenerated first (felling age of 120 yrs), whilst stands of compartment 11 would be regenerated last (felling age of 220 yrs)
Start of simulation	yr 2013 up to yr. 2022	a stands of all compartments in 2013, … , j stands of all compartments in 2022
Start of management (cut)	yr 2023 up to yr. 2032	a stands of all compartments in 2023 (1a regeneration, 2–11a intermediate cut), … , j stands of all compartments in 2032
Intermediate/thinning cut	10 yr. cycle	Intermediate cut in stands during period between start of management and first regeneration; thinning in new cycle growth stands (first at the age of 30 yr, last at the age of 90 yr); cut amount estimates according to Matić (1989) as quotient of stand volume and stand age in decades (i.e.: V=675 m^3/ha, age=170 y; cut volume=675 m^3/ha /17=40 m^3/ha)
Regeneration felling	20 yr. period	Start first in stand 1a (preparatory in 2023, regeneration in 2033, final in 2043) and last starts after 110 years in stand 11j (preparatory in 2133, regeneration in 2143, final in 2153); estimation of felling amount: one third of current stand volume for preparatory, one half of current stand volume (accumulated last 10-y increment included) for regeneration cut, total remaining stand volume (accumulated last 10-y increment included) for final cut

2.2.2 Uneven-aged management scenario

Theoretical uneven-aged forest and management scenario was defined by the same forest area of 567.33 ha, selection cut cycle of 10 years, theoretical number of 10 stands (compartments 1–10) each covering an area of 56.73 ha and achievement of balanced selection stand structure with aimed silver fir/beach proportion of 80% vs. 20%.

The management scenario was based on stand level simulation of compartment 1, where simulation started in 2013, whilst the transformation (1^{th} cut) would begin in 2023. Stand growth simulation of other stands (compartments 2 up to 10) was similar, but with a shift of 1 year (the assumption was made that those stands would have similar structure at the commencement of the simulation in 2014 lasting up to 2022 (state just after the cut) and the transformation would start in 2024 lasting up to 2032 (state just before the cut) similarly as compartment 1).

The estimate of the cut for each cut cycle was based on theoretical rate of current annual volume increment standing at 2.5% (10-year cut intensity of 25%) according to Klepac (1961). The commencement of stand transformation to uneven-aged structure was simulated by establishment of 5 initial regeneration gaps by cutting of all trees in circle diameter of 20–25 m on the »virtual« stand research object covering an area of 3 ha (1.7 gaps per ha). The other segment of the performed cut was implemented on the remaining stand area as thinning. Concerning the following cut cycles, the enlargement of the initial gaps by cut of circle-marginal trees, establishment of new regeneration gaps and thinning were simulated.

2.3 Economic analysis of silvicultural treatments

2.3.1 Cash flow

Cash flow of each specific scenario was estimated based on i) the results of simulation of forest management using the forest growth modelling software MOSES, ii) timber assortment tables, iii) simulated selling price, iv) cost in compliance with the Croatian Forest Law (OG, 140/2005), v) estimated through expenses arising from wood harvesting. Simulation of the future selling prices of beech and fir assortments was taken from earlier study of Beljan et al. (2017). A simulation of timber prices on the market was made based on the collected data on achieved selling prices for the surveyed forest using Monte Carlo methodology (Beljan et al. 2017).

On the other hand, costs (both indirect and direct) are revaluation expressed by consumption of production elements. Indirect costs include administrative costs which, for even-aged silver fir forests stand at 22.09 EUR/ha (Beljan 2015). According to available calculations, average direct costs of wood harvesting (1997–2013), in relation to the selling price achieved, stand at 1:0.654 (±0.08) (Beljan 2015). In other words, wood harvesting costs per 1 Euro of generated revenue stand at 0.65 Euro ± 8 Euro cents. This ratio was also projected in the future. The costs also include the share of 5% of the selling price of stumpage, which, according to the National Forest Law (OG, 140/2005) is collected from legal entities involved in forestry.

Purchase of (investment in) both the forest and land within the price range between 1000 and 12,500 EUR/ha was analysed for the purpose of this research.

2.3.2 Assessment of economic returns and profitability

Economic analysis encompasses the period commencing from 2013 (actual situation in the field) up to 140 years in the future for an even-aged scenario and 120 years for uneven-aged scenario. Subsequently, the cash flow is continuous and in balanced structure theory it is assumed to be for an unlimited period of time.

The comparison of economic effectiveness amongst specific scenarios focused on net present value (NPV) (Klemperer 2003) for unlimited time period according to the Faustmann (1968) concept and internal rate of return (Damodaran 2002). Interest rates ranging from 1% to 5% were used concerning economic analysis features, with 2% taken as a reference value.

According to Knoke and Plusczyk (2001), net present value $J_{\text{even-age}}$ for an unlimited time period of the even-aged scenario was calculated by the following mathematical expression:

$$J_{\text{even-age}} = \Sigma \frac{1}{\left(1,0r\right)^{t}} \times R\left[v\left(t\right)\right] + \\ + \left[\left(\frac{1}{\left(1,0r\right)^{T}-1}\sum_{t=0}^{T}\left(1,0r\right)^{T-t} \times R_{s}\left[v\left(t\right)\right]\right) \times \frac{1}{\left(1,0r\right)^{t}}\right] \quad (1)$$

here:

$R[v(t)]$ profit during the current rotation
$R_s[v(t)]$ profit during the upcoming rotation
t time of the current rotation
T time of the upcoming rotation
r discount rate.

The first part of the mathematical expression (before the square bracket) referred to NPV (of the current rotation). From the commencement of the simulation to the final felling, all the profits (*R[v(t)]*) were discounted to the start through the discount rate (*r*). In this way the analysis of only a segment of the rotation was included (e.g., from 100 to 220 years of age, depending on the felling age in a specific compartment according to Table 2. The second part of the mathematical expression referred to NPV of the entire upcoming rotation shown over an unlimited time period. Irrespective of the fact that the time of the regeneration felling determined the commencement of production of a new stand, all the revenues and expenditures were capitalised/discounted according to the time of seeding felling (Nenadić 1922) and hence the factor $1.0r^{u}-1$ (Navarro 2003) was used.

Net present value $J_{\text{uneven-age}}$ of uneven-aged scenario over an unlimited time period was described through the expression according to Knoke and Plusczyk (2001):

$$J_{\text{uneven-age}}=\sum_{t}\frac{1}{\left(1,0r\right)^{t}}\times R\left[v\left(t\right)\right]+$$

$$+\left[\left(\frac{1}{\left(1,0r\right)^{cc}-1}\times R_{s}\left[v\left(t\right)\right]\right)\times\frac{1}{\left(1,0r\right)^{t}}\right] \qquad (2)$$

Where:

R[v(t)] profit during transformation

R_s*[v(t)]* profit after transformation

t time of transformation

cc time after transformation

r discount rate.

The first part of the mathematical expression (before the square bracket) discounted the profit throughout the duration of the transformation. Following the establishment of the uneven-aged structure, a continuation of forest management was expected upon equal net circulating capital generated every (*cc*) year, according to Navarro (2003) shown over an unlimited period of time.

3. Results

3.1 Growth data

A comparison of dynamics in growing stock at the level of stand and forest showed the fundamental difference between scenarios (Fig. 1). In Fig. 1, the scenario for an even-aged management system was presented through a sub-compartment (stand) 1*a*, whilst the uneven-aged scenario was presented through a compartment 1. The end of the simulation at the stand level (sub-compartment 1*a*) was defined by the time of the final felling of the even-aged scenario and, from the temporal aspect, it matched the previously established balanced selection stand structure) (compartment 1). It is important to emphasize the fact that fluctuations in growing stock of the uneven-aged scenario within the theoretical values occurred 30 years prior to the even-aged scenario.

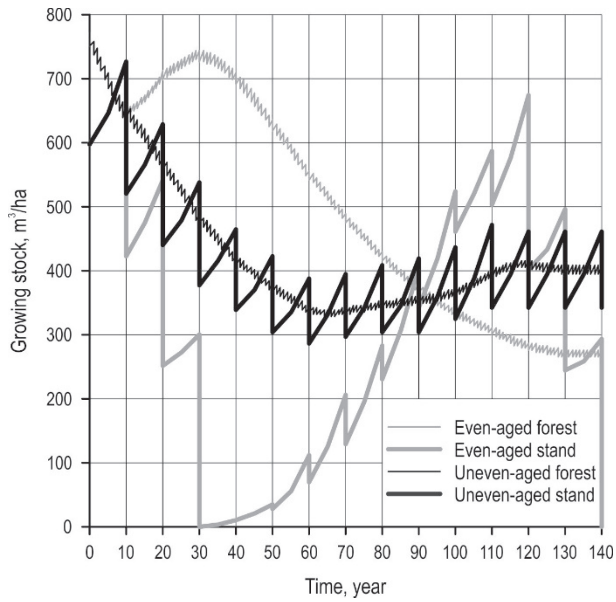

Fig. 1 Comparison of dynamics in growing stock at stand level. During the first decade, the dynamics of fluctuations in growing stock was equal at both levels

The development of growing stock at forest level is primarily conditioned by the features of the specific scenario. A rise in average growing stock at forest level up to a remarkable 750 m^3/ha (Fig. 1) was shown in case of the scenario for the even-aged management system, due to the extension of the felling age up to 220 years old. The uneven-aged scenario continuously reduced the growing stock to the minimum amount after 65 years of simulation, when a gradual increase in growing stock and the establishment of balanced selection stand structure commenced.

3.1.1 Even-aged management scenario

At the beginning of the analysed time period, the growing stock both at stand and forest level was above the optimal level (Table 1), for details see (Čavlović 2013) and (Beljan 2015). Simulation at forest level in even-aged management scenario included individual

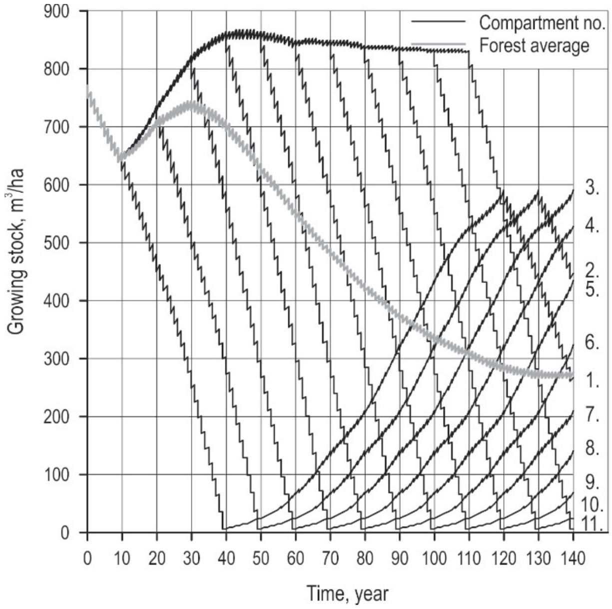

Fig. 2 Dynamics of growing stock in even-aged scenario divided into compartments (a compartment is comprised of ten stands/sub-compartments) at forest level. The growing stock for individual compartment is the average of its 10 sub-compartments

simulations of each sub-compartment (110 pieces) distributed in 11 compartments shown in Fig. 2. The growing stock in a specific year for an individual compartment was the average of all sub-compartments of the corresponding compartment (Fig. 2).

A balanced even-aged forest structure was expected to be established after 140 years. It would include all age classes, whilst the forest would comprise 110 even-aged stands, where under the tree tops of the old stand there would be a new one (for instance, under 120-year old stand there would be a young – 10-year old stand). Growing stock per hectare at forest level corresponded to half the stock of the 3rd compartment, which had the highest growing stock amongst all the compartments (Fig. 2). This was also an indicator of a balanced even-aged forest structure.

3.1.2 Uneven-aged management scenario

This scenario includes a transformation of the management system from even-aged into uneven-aged. Tree felling into 5 gaps of the radius from 25 m to 30 m was simulated over the surface represented by the virtual object of the research (3 ha). Not all the trees within the gap intended for forest regeneration were cut, but due to the seeding of the soil with seeds several trees were left. The cutting in first cutting cycles was spatially concentrated for the opening of the gaps intended for regeneration. Through subsequent cutting cycles, the gaps intended for regeneration were concentrically expanded through cutting of the circle-marginal trees, whilst selection cutting was performed throughout the remainder of the stand. This procedure was repeated until the entire stand was regenerated and the uneven-aged structure established after 110 years at stand level, i.e. after 120 years at forest level (Fig. 3). A gradual decrease in the proportion of silver fir in the growing stock enabled its substantial regeneration. It is important to highlight that this also resulted in beech regeneration which, at the beginning of the simulation, covered only 3.45 m^3/ha (Table 1), whilst after 70 years it achieved the desired growing stock.

Simulation at forest level was the average of simulations of all the stands distributed into 10 compartments (Fig. 3). The dynamics of growing stock at that level followed the trend of individual stand and decreased from the commencement of the simulation period. That happened during the first 60 years of simulation, after which the increase in growing stock started and it lasted until 120th year of the simulation, when the uneven-aged structure at forest level was established (Fig. 3). The same picture shows that the balanced uneven-aged forest was gradually achieved; first, in the compartment No. 1 and in all the subsequent compartments upon one-year interval. Analogous to the indicator of normality for even-aged management scenario, growing stock at forest level corresponded to half the growing stock between two cutting cycles (uneven-aged forest management).

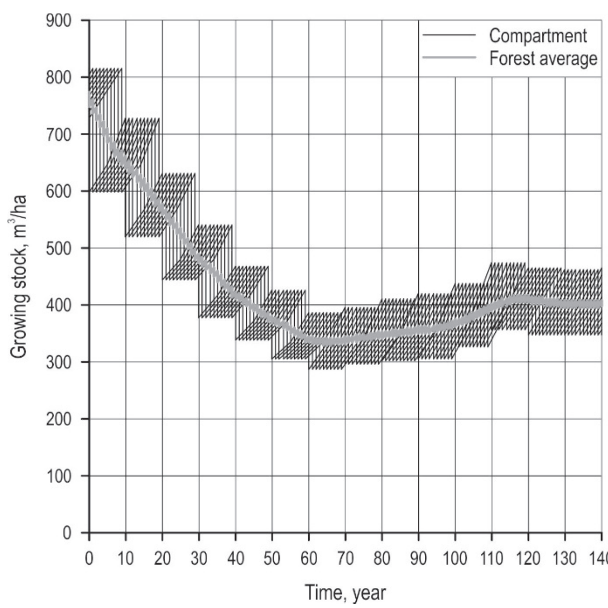

Fig. 3 Development of growing stock of uneven-aged scenario at both stand and forest level

3.2 Economic analysis

3.2.1 Cash flow

Cash flow can be observed both at stand and at forest level, albeit the forest level covers a significantly larger area. At forest level, revenue and cost were present every year and their sum was comprised of revenue and cost of all the stands in annual yield area (Fig. 4). Revenue and cost are closely connected. In the event of higher revenues, the expenditures will also be higher, yet disproportionately, as shown in Fig. 4. Cash flow of both scenarios was not even roughly identical throughout the period.

The scenario for even-aged management of different felling-age (Table 2) prescribed for a specific compartment resulted in different dimensions of trees and hence in different revenue. During the first decade, the cash flow was roughly identical due to the fact that every year 1/10 of the forest area was cut with equal intensity (Fig. 4). During the subsequent 20 years, both revenues and costs dropped drastically, due to the fact that the felling age regularly exceeded 120-year rotation. Throughout that period (10–30 years of simulation) annual surface of final cut stood at 8.55 ha (the area covered by one sub-compartment). In other words, most of the yield was achieved by the intermediate yield – with an inferior financial result. After that, every year the final felling was achieved over an equal area covering 8.55 ha, yet every subsequent year it was performed in the sub-compartment that was 1 year older and hence its financial value was also higher. The older the stand, the higher its financial value, yet up to a point which occurred in this specific situation after 50 years of simulation. Fig. 4 also shows the previously mentioned recurrent drop in revenue and cost. The decrease in cash flow was the result of lower revenue from stands, which were considerably old and had an increased share of dead trees and wood of inferior value. As the end of the simulation approached, cash flow showed a deceasing number of fluctuations and eventually, expectedly, it entirely harmonised.

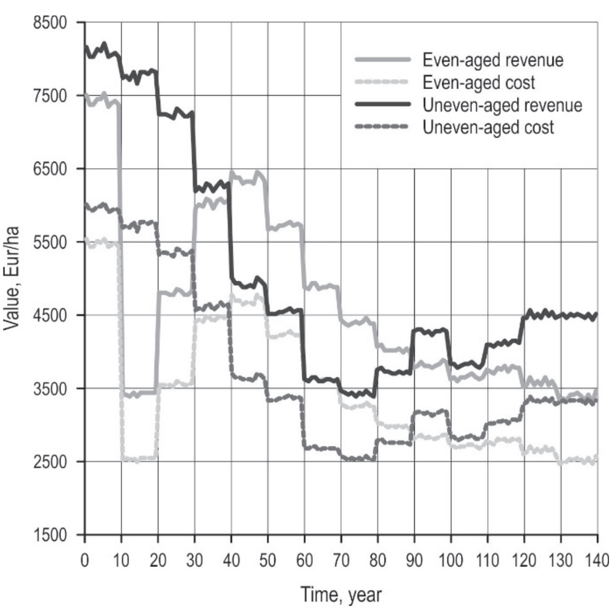

Fig. 4 Cash flow of forest management in both scenarios at forest level. Investment costs of both forest and land purchase have not been shown

Cash flow in case of uneven-aged management scenario assumed entirely different attributes (Fig. 4). The sum of revenues and costs of all the stands in a specific year is considered the cash flow at forest level. At the commencement of the projection period, the revenue from beech could not be expected due to the fact that its share was too insignificant. Nevertheless, the first revenue was generated in that aspect after 40 years of simulation of uneven-aged forest management. On the other hand, cash flow from silver fir at the commencement of the projection period showed the highest amounts due to a more intensive cutting of accumulated growing stock (Fig. 4). Summary cash flow (silver fir and common beech) recorded the lowest values between the 60th and the 80th year of the simulation, as a direct consequence of inevitable reduction in growing stock, as shown in Fig. 3. It is also important to highlight that both revenues and costs at the commencement of the simulation were almost double compared with those at the end – when the balanced uneven-aged forest structure has been established. Another objective was met in this scenario, i.e. the forest can be provided with such features that it can generate equal profit throughout the year without any time limits.

3.2.2 Economic consequences

Net present value over an unlimited time period was shown as a specific crossword, from the values for different costs of purchase of (investment in) a forest can be read (Table 3). Cases regarded as unprofitable from an economic standpoint have been shaded in grey. Following the comparison amongst different NPV scenarios, shown in Table 3, it was evident that even-aged scenario was more adequate throughout an entire range of investment costs, albeit only at discount rate of 1%. Break-even point for uneven-aged transformation scenario was given when an interest rate of 1.24% was applied, irrespective of the proportion of investment costs. In other words, uneven-aged scenario was more adequate when discount rate that exceeded 1.24% was applied.

Table 3 Net present value [EUR/ha] upon application of different purchase prices and discount rates

Investment EUR/ha	Interest rate, %									
	1		2		3		4		5	
	EA*	UA**	EA*	UA**	EA*	UA**	EA*	UA**	EA*	UA**
1000	11,286	9368	6077	6153	4071	4600	2982	3599	2300	2903
2500	9786	7868	4577	4653	2571	3100	1482	2099	800	1403
5000	7286	5368	2077	2153	71	600	–1018	–401	–1700	–1097
7500	4785	2868	–423	–347	–2429	–1900	–3519	–2901	–4201	–3597
10,000	2285	368	–2923	–2847	–4929	–4400	–6019	–5401	–6701	–6097
12,500	–215	–2132	–5423	–5347	–7429	–6900	–8519	–7901	–9201	–8597

*even-aged management scenario, **uneven-aged management scenario

Comparison at forest level (Table 3) provided an approximate overview of the economic features of forest management, as opposed to the analysis at stand level (Fig. 5). At stand level and at reference discount rate of 2%, the dependence of NPV on investment costs and the management system were shown. Absolutely expectedly, higher values of NPV were achieved by stands purchased at lower prices, which would be cut in the forthcoming future. NPV of even-aged scenario was higher in relation to the uneven-aged scenario in all the compartments management with felling age that ranges from 120 to 170 years old (Table 2, Fig. 5). Irrespective of the fact that at discount rate of 2% and investment of 7500 EUR/ha NPV at forest level were negative for both scenarios (Table 3), a proportion of stands still achieved a positive NPV (Fig. 5). An overview of changes in mutual ratio of NPV at other discount rates would be identical to the overview presented in Fig. 5, yet the amount of NPV at a higher rate would be lower and vice versa. Management in compartments, whose turn for cutting is earlier, will be more profitable compared with the compartments in which cutting occurs later and which can have a negative NPV (Fig. 5).

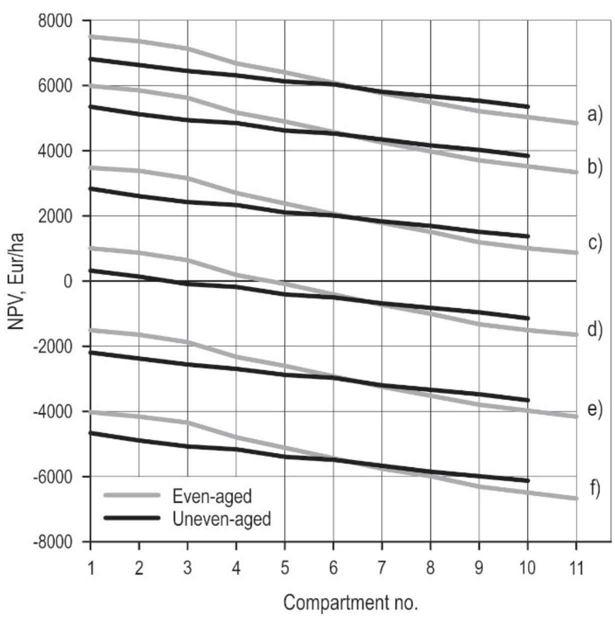

Fig. 5 Comparison amongst NPV at stand level at reference discount rate of 2% and investment cost of a) 1000, b) 2500, c) 5000, d) 7500, e) 10,000, f) 12,000 EUR/ha. Due to the features of a specific management scenario the forest has been divided into 10 or 11 compartments. A specific compartment comprises 10 stands and hence values for each stand have been provided in the graph

Internal rate of return (IRR) fluctuated substantially, depending on the levels of the investment cost (Table 4). Initially, upon the lowest investment cost, IRR may appear to be unrealistically high, yet in case of the opportunity of investment in such forests at that price, IRR would be identical to the values shown in Table 4. On the other hand, the highest investment cost resulted in a considerably low IRR. From this table, it is important to highlight that IRRs in uneven-aged scenario are higher (in most cases) compared with those in even-aged scenario, whilst the interval of fluctuations of IRR (min-max) was shorter upon higher investment costs.

The applied discount rate has the greatest impact on economic comparison between the two scenarios. It is extremely important to make a comparison between the scenarios at identical discount rate. Table 3 shows the impact of different rates on NPV, which will

Table 4 Comparison of internal rate of return (IRR) both at forest and stand level for a period of 140 years

Investment cost EUR/ha	Internal rate of return, %					
	Even-aged			Uneven-aged		
	Forest level	Stand Min.	Stand Max.	Forest level	Stand Min.	Stand Max.
1000	25.4	24.9	28.7	27.3	12.2	>150
2500	7.0	5.8	10.6	8.8	6.0	26.0
5000	3.1	2.4	4.6	3.6	2.8	4.8
7500	1.9	1.5	2.4	1.8	1.5	2.2
10,000	1.3	1.0	1.5	1.1	0.9	1.2
12,500	1.0	0.8	1.1	0.7	0.7	0.8

regularly be lower at a higher discount rate and it is likely that NPV can also be negative in case high discount rate is applied (Table 3, Fig. 5). The highest discount rate that can be applied in order for NPV to equal zero has been shown for different investment amounts in Table 4 (column Forest level). Each discount rate inferior in relation to that provided therein will achieve a positive NPV. Consequently, it is evident that low discount rates positively affected even-aged scenario. Comparison between the two scenarios showed that the difference in NPV was not constant, i.e. it was less evident at higher rates (Table 3).

The results presented thus far show management until the establishment of balanced even-aged i.e. uneven-aged forest and subsequently management through theoretical balanced forest. Nevertheless, upon comparison of management only in balanced forests, the comparison was slightly different. Even-aged balanced forest achieved constant average annual yield of 10.72 m^3/ha, whilst uneven-aged that of 11.72 m^3/ha (the difference of 8.5%). Upon ignoring the fluctuations in price, it stood at 106.39 EUR/ha for even-aged, or 127.98 EUR/ha for uneven-aged scenario (the difference of 16.86%).

4. Discussion

4.1 Forest planning

The main directions of future forest management need to be analysed against the backdrop of the current state of affairs in even-aged silver fir forests in the Dinaric Region. Two scenarios (both even-aged and uneven-aged scenario) which can be implemented in practice have been analysed. Even-aged scenario implies the continuation of the currently implemented forest management, whereas uneven-aged is considered as a turning point in forest management, which requires a transformation during the first phase.

The scenario for the even-aged management system is a kind of imitation of the management system applied thus far in such forests. During the period in which pure silver fir forests in the Croatian Dinaric region were managed exclusively through even-aged management system, the rotation period of 120 (100) years with a regeneration period of 20 (10) years and regeneration felling applied twice (Meštrović 2001) was resorted to. Due to ecological characteristics, the scenario with the rotation period of 120 years, regeneration period of 20 years and regeneration felling applied 3 times was analysed.

On the other hand, the scenario for uneven-aged forest management implied a transformation from even-aged to uneven-aged forest. This process requires a change in the stand structure from homogeneous even-aged into a more complex uneven-aged (O'Hara 2001, Pommerening 2006). Several factors played a crucial role in a successful transformation. Most authors (Hanewinkel and Pretzsch 2000, Malcolm et al. 2001, Schütz 2001, Mason and Kerr 2004, Čavlović and Božić 2007, Francetić 2010, Božić et al. 2011, Knoke 2012) agree that regeneration (both natural or artificial) plays the most important role. Even-aged stand can establish the uneven-aged structure by a natural process through natural disasters (Koop 1989, Peterken 1996), yet upon implementation of silvicultural measures the process is considerably shortened (Schütz 2001). The ideal timing for the commencement of the transformation is up to one half of the prescribed rotation period of even-aged forest management (Schütz 2001, Knoke 2012) and the process should commence after the full seed yield (Malcolm et al. 2001). Hence, in this research the places in the virtual forest which were naturally regenerated were used as centres of regeneration nuclei (gaps). In addition, this was supported by the fact that clearcutting in small gaps and their gradual expansion through cutting of the circle-marginal trees were the most adequate for pure coniferous stands (Hanewinkel and Pretzsch 2000, Hanewinkel 2001) both from the silvicultural (Malcolm et al. 2001) and economic standpoint (Hanewinkel 2001). In the previously mentioned forest, the height of the mean basal-area tree was 27.2 m (Beljan 2015). Consequently, according to Malcolm et al. (2001), the diameter of the circle-shaped regeneration patch ranged between 25 m and 30 m, depending on the characteristics of the terrain and the arrangement of the trees in the area covered by the virtual stand.

4.2 Economic analysis and cost control in forest management

Economic comparison between two main forest management systems can be made only with silver fir or spruce forests, since they enable the application of both systems (Hanewinkel 2002) and transformation from even-aged into uneven-aged management system and vice versa. The economic feature of the transformation can be analysed both at stand level (Buongiorno 2001, Hanewinkel 2001, Knoke et al. 2001, Knoke and Plusczyk 2001) and at forest level (Buongiorno and Gilles (1987), Price and Price (2006)). However, the conclusion on the economic result of forest management needs to be made exclusively at forest level and, if possible, at normal balanced forest level. It is important to point out that the comparison at stand level depends on the selection of stands for the purpose of comparison. The selection of different stands would result in a different comparison. In this specific research, there was a total of 1000 different combinations of stands for comparison and hence caution needs to be exercised during the interpretation of results at this level and consequently comparison at forest level is required. Although a wide range of potential buying prices of forest was examined, IRR results can seem unrealistic. Analysed purchase prices ranging from 1 EUR/ha to 12,500 EUR/ha are hypothetical. So the investor's ability to negotiate prices is crucial for economic results. If an investor can make an agreement and invest (buy) a forest for 1 EUR/ha, IRR will be 150% because standing timber is around 600 m^3/ha. Other analysed buying prices (like 5000 or 7000 EUR/ha) will result in IRR as in similar research. In other words, all possibilities have been examined, the worst and the best ones.

Transformation from the even-aged into uneven-aged management system is considered as a kind of turning point in forest management, which also affects the economic aspect. It is financially unprofitable to commence the process of transformation in the event when even-aged stand is »close« to financial maturity (Knoke 2012), which was also the case in this research. However, Knoke (2012) reached this conclusion based on the analysis conducted at stand level. The characteristics of the object of research determine which management system is more cost-effective. In case of the Croatian Dinaric region, clearcutting in small gaps is the only logical option since the piled up and homogeneous standing timber make difficulties in natural regeneration. Nevertheless, in that case it is possible to reduce the value of timber assortments due to the growth of side branches on the remaining trees located on the edge of the circular patch (Macdonald et al. 2010) and increase harvesting costs. Both the economic and ecological justification of the transformation of forest management system from pure stands into mixed is relative (Knoke et al. 2005). However, an advantage to mixed stands is certainly the reduction of risk spread between two or more forest tree species (Bauhus et al. 2017). In case of the existence of a balanced even-aged or uneven-aged forest, transformation is never recommended from the economic standpoint (Price 2012). Silvicultural characteristics, primarily the age class ratio in case of even-aged management and tree age structure of all the stands in uneven-aged management, are the factors that define the cost-effectiveness of transformation. In other words, each forest, due to its specific features, requires a special analysis (Price 2012). Natural regeneration is the most important economic factor in this process (Davies and Kerr 2011), since it represents the creation of capital that is a gift of nature (Navarro 2003). Irrespective of the fact that, from silvicultural standpoint, both management systems can be applied, it is clear that, from the economic aspect, a balanced uneven-aged forest has a higher financial impact.

Both cash flows (Fig. 4) give the impression that simulations take the forest into a direction in which the profit will be reduced. It is important to highlight that a unique method has been presented, in which a normal balanced forest can be established generating optimal profits that will be continuous in theory. Otherwise, huge profits from the forest can be short-term and without the perspectives of financial gains in the long-term future.

As is the case with other types of decisions, the same applies to economic decisions, which are normally made against the backdrop of risk and uncertainty and this is particularly evident in long-term projects, as is the case in forestry. Most economic studies on forest management ignore the uncertainty of the future cash flows (Knoke et al. 2005), whereas in this research risk was considered as an integral part of economic analysis. In addition to the potential risk from natural disasters, it is also necessary to consider the uncertainty of changes in selling prices of timber assortments (Beljan et al. 2017) and timber harvesting costs. Timber assortment production is characterised by long production cycles and it is influenced by natural disaster risks. Forestry investment risk differs from country to country and it is directly affected by the risk carried by a specific country. A country whose economy implies lower risk will also be the one to apply a lower discount rate (Snowdon and Harou 2013). The selected discount rate that is applied in forest management analysis plays a decisive role in achieving good economic results (Klemperer et al. 1994, Price 1997, Brukas et al. 2001, Kanas 2008). Premium of the investment risk in forestry production is extremely low as opposed to other branches of the economy, where both the yield and risk are higher.

5. Conclusions

In the silver fir forests located in the Croatian Dinaric region, which are currently even-aged, both management systems can be applied. Nevertheless, due to their current characteristics, the piled up standing timber into even-aged structure, they are not sustainable over the long term and hence they need to be directed towards the uneven-aged structure through a gradual transformation. The economic effectiveness of the transformation is determined primarily by the current characteristics of a specific forest and it can in some cases be cost-effective over a long period of time. Consequently, it can be concluded that, from the long-run economic perspective, even-aged silver fir forests need to be transformed into balanced uneven-aged forests, which will be continuously providing higher monetary and non-monetary (public benefit function) values. During the transformation process, discount rates of up to 1.24% favourably affect even-aged management, whereas the increasing rates have a positive impact on uneven-aged management. Upon comparative analysis at the level of the established balanced forest, uneven-aged management will achieve a higher Net Present Value irrespective of the discount rate, as a consequence of a higher and financially more valuable forest increment/yield.

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