PERIODICUM BIOLOGORUM
VOL. 115, No 3, 409–420, 2013

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Original scientific paper

Current state and the structural analysis of the mixed even-aged pedunculate oak and common hornbeam forests in Croatia

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Key words: mixed forest stands, pedunculate oak, common hornbeam, stand structural elements, basal area, growth and yield tables

Received May 15, 2013.

Abstract

Background and Purpose: *Mixed forests of pedunculate oak and common hornbeam are among the most important and most recognizable forest ecosystems in Croatia with exceptional ecological, economical and sociological significance. Stand structure of these forests can be very complex, and their development highly dynamic due to the relationships between the add-mixed tree species as well as vertical and horizontal stand structural elements. In the contemporary management of oak-hornbeam forests in Croatia growth and yield tables of domestic authors are used. Aim of this research is to give an overview of the current state of mixed forest stands of pedunculate oak and common hornbeam in Croatia through the analysis of available information on the area extent and basic stand structural features. Furthermore, the information obtained in the research are compared with the data from the growth and yield tables of domestic authors.*

Materials and Methods: *Database used in this research is maintained by the state-owned forest management company Croatian Forests Ltd., and is comprised of the data collected within the regular forest management. In total, 5,060 forest stands (sub-compartments) with total area of 75,948.76 ha from whole area extent of pedunculate oak in Croatia were included in the analysis. Record for each stand included: phytocoenological community, forest area, stand age and age class. Width of the age classes is 20 years. Analyzed stand structural attributes were grouped for each stand by tree species (pedunculate oak, common hornbeam and other species) and as a whole, and included: stand density, basal area, volume, quadratic mean diameter and height. Finally, the shares of pedunculate oak and common hornbeam in the total basal area of each stand were calculated.*

Results and discussion: *Total area of mixed pedunculate oak and common hornbeam forests in Croatia, according to the results of this research, amounts to 98,364.43 ha. Age structure of these forests is irregular, both by area, and by the number of forest stands with stands older than 80 years (5th age class and older) dominate in the total area. Most of the stands (> 68%) grow on 1st site class, i.e. the best site class. Structural elements of forest stands on 1st site class, show a large variation of the analyzed structural elements throughout the development of the stands (2nd to 8th age class). Highest variation is established in the shares of tree species in the total basal area of the stand. These values are under the direct influence of the growth and development of diameters at breast heights of trees of different species and of the corresponding diameter distributions. Basal area shares are also highly influenced by the silvicultural measures applied during the life-time of each* *particular stand. Comparison of actual stand structural attributes with the values indicated as optimal in the growth and yield tables of domestic authors revealed a high degree of discrepancy.*

Conclusion: *As a general conclusion, it can be said that the currently used growth and yield tables only very rarely correspond with the actual state of forest stands in the field. New and improved methods of forest management planning are highly desirable at this moment in Croatian forestry.*

INTRODUCTION

Forest is a complex biological system comprised of organic and inorganic parts of the environment with very dynamic and long life-time. Many interactive processes between plants, animals, microorganisms, soil, climate and water influence the development and growth of forests. Within one lifetime of one even-aged forest stand, three, four or more generations of foresters succeed each other. Therefore, the analysis and planning for the proper management of forests represent vital component of their sustainable development.

According to the actual official Forest Management Plan *(1)*, total area of forests and forest land in Croatia amounts to 2,688,687 ha, representing 47.5% of its the land surface. Basic subdivision of the total area by ownership and land cover types is given in Table 1. With the large land coverage, forests represent a highly significant social, economic and ecological natural resource in Croatia. One of the most important tree species is pedunculate oak (*Quercus robur* L.), with 195,000 ha of total area of pedunculate oak dominated high forests in public ownership and managed by state-owned forest company (Croatian forests Ltd.).

In the current Forest Management Plan *(1)*, and in the practical forest management in Croatia, all of the pedunculate oak forests are grouped in one management class. However, pedunculate oak forests in Croatia could be sub-divided into two distinct ecosystems, or phytocoenological communities: (i) forests of pedunculate oak in the microtopographic depressions and (ii) forests of pedunculate oak and common hornbeam on microtopographic elevations *(2)*. Main features of these two communities, as expressed through phytocoenological parameters can help in the forest management planning under climate change conditions *(3, 4, 5)*.

Out of the two oak forests types, the one with common hornbeam on microtopographic elevations has always been preferred by the forest practitioners. Diameter increment of oak trees in these forests is higher *(6)*, common hornbeam in the understory protects the soil and the trunks of oak trees, thereby making possible to achieve the higher yield of valuable wood in shorter rotation lengths *(7)*. From the stand-point of the ecological stability, forests of peduncualte oak and common hornbeam are also viewed as more stable compared to pure oak forests in microtopographic depression *(2, 8, 9)*.

TABLE 1

Total area of forests and forest land in the Republic of Croatia by ownership and land cover.

Land category	Area, ha
Total area of forests and forest land	2,688,687
Forests and forest land in public ownership	2,106,917
Public forests and forest land managed by Croatian Forests Ltd.	2,018,987
Stocked public forest land managed by Croatian Forests Ltd	1,747,885
Management stocked public forests managed by Croatian Forests Ltd.	1,597,781
Even-aged public forests managed by Croatian Forests Ltd.	1,042,953
High even-aged public forests managed by Croatian Forests Ltd.	690,375
High even-aged pedunculate oak forests managed by Croatian Forests Ltd.	194,569

Due to the all of the above, Rauš *(10)* has stated that the typical forests of pedunculate oak and common hornbeam represents »the pinnacle of the natural development of lowland forest ecosystems, and the forest type to which foresters should always aim«.

Mixed pedunculate oak and hornbeam forests in Croatia are found on microtpographic elevations in lowland floodplains of larger rivers like Sava, Drava, Kupa and Danube, as well as in the valleys of their tributaries *(2)*. According to the National Ecological Network habitats of these forests belong to the unit E.3: Forests of deciduous oaks outside the reach of floods *(11)*.

Depending on the sub-type, apart from pedunculate oak and common hornbeam, a number of other tree species builds this forest type. Stand structure of these forests can be very complex, and their development highly dynamic due to the relationships between the add-mixed tree species and vertical and horizontal stand structural elements. In the contemporary management of oak-hornbeam forests in Croatia growth and yield tables (G&Y tables) of domestic authors are used.

G&Y tables are constructed to portray the development of even-aged forest stand from its establishment trough to the end of the rotation length. They are used to estimate the future yields and to compare the development stage of a real forest stand with the figures in the G&Y table for that forest type as a management goal *(12)*. Comparison of the actual forest stand as derived from measurements with the yield estimated in G&Y tables is very important element of forest management planning process *(13)*.

There are three types of growth and yield tables: optimal, empirical and G&Y tables of variable density. Optimal G&Y tables depict the »optimal« development of the stand structure for even-aged forests on sites for which they were constructed, while the empirical tables give the averaged development of stand structural elements at the specific site. In Croatia, tables of domestic authors are constructed as optimal growth and yield tables.

Aim of this research is to give an overview of the current state of mixed forest stands of pedunculate oak and common hornbeam in Croatia through the analysis of available information on the area extent, phytocoenological attribution and basic stand structural features. Database used in this research is maintained by the state-owned forest management company Croatian Forests Ltd., and is comprised of the data collected in periodical operational forest inventories. Therefore, the analysis is constricted only to forests in public ownership and managed by Croatian Forests Ltd. Moreover, the actual condition of the pedunculate oak and common hornbeam forests is compared to the most used growth and yield tables in Croatia.

MATERIALS AND METHODS

Information on area extent and basic stand structural attributes of the investigated forest stands which were used in this study were derived from the »HS Fond« database, maintained by the state-owned forest management company Croatian Forests Ltd. All the available data records on forest stands from the management class of pedunculate oak forests were extracted from the database. Special attention is given to ensure that the data records extracted are from the actual (up-to-date) forest management plans. State of the forests analyzed corresponds to the state in the year 2010.

From the available data only the stands belonging to the phytocoenological community of pedunculate oak and common hornbeam were retained for further analyses. For some stands (total area of 7,476 ha) there were no information on phytocoenological attribution, and those stands were discarded. Total area of pedunculate oak and common hornbeam forest stands in this stage amounted to 98,364 ha. Stands are grouped in four phytocoenological sub-associations (Table 2) out of which the most prevalent is the typical pedunculate oak and common hornbeam forest, e.g. *Carpino betuli-Quercetum roboris typicum* Rauš 1973. This sub-association accounts for the 87.7% of the total area of pedunculate oak and common hornbeam forests.

TABLE 2

Pedunculate oak and common hornbeam forests in Croatia by phytocoenological sub-associations.

Phytocoenological sub-association	Area	
	ha	%
E 3.1.1. *Carpino-betuli-Quercetum roboris typicum* Rauš 1973	86,255.6	87.7
E 3.1.2. *Carpino-betuli-Quercetum roboris fagetosum* Rauš 1973	8,376.2	8.5
E 3.1.3. *Carpino-betuli-Quercetum roboris quercetosum cerris* Rauš 1969	3,558.2	3.6
E 3.1.4. *Carpino-betuli-Quercetum roboris tilietosum tomentosae* Rauš 1969	174.4	0.2
Total area	98,364.4	100.0

Final database for the analyses was constructed by applying the series of filters to ensure the accuracy and consistency of the data. Filtering was done trough several stages, and all records with erroneous and illogical values were deleted. Also, all records pertaining to the stands of less than 3 ha in size were also deleted *(14)*. Final database consists of records on 5,060 stands (sub-compartments) with the total area of 75,948.76 ha. which amounts to 77.2% of pedunculate oak and common hornbeam stands (Table 2).

Each record of each forest stand analyzed had following general attributes in the database: phytocoenological community, forest area, stand age and age class. Age class is given in the steps of 20 years. Forest stands younger than 20 years were not analyzed due to the fact that they are not measured within the regular forest inventories. Analyzed stand structural attributes were grouped for each stand by tree species (pedunculate oak, common hornbeam and other species) and as a whole, and included: stand density, basal area, volume, quadratic mean diameter and height. Finally, the shares of pedunculate oak and common hornbeam in the total basal area of each stand were calculated.

Stand attributes were analyzed according to stand age. For some comparisons, sub-compartments were grouped into age classes 20 years wide. Development of the total stand basal area, and basal areas of pedunculate oak and common hornbeam over stand age was graphically compared with values from following domestic growth and yield tables: Špiranec *(15)* for pure pedunculate oak stands, Meštrović *(16)* for mixed pedunculate oak and common hornbeam stands and EGT growth and yield tables for the ecological-management forest type II-G-10 *(17)* for mixed pedunculate oak and common hornbeam stands. The term EGT refers to »Ecological and management forest type«, defined in the multidisciplinary project »Typological research and mapping of forests and forest sites in Croatia« *(18)*. This project has set the foundations of the forest classification system in Croatia *(17, 19)*. EGT is the basic unit of the typological forest classification, defined through the set of ecological, biological and management criteria. These three growth and yield tables are the most used today in Croatian forest management. These tables give tabulated values for the optimal, e.g. best possible stand development over the stand age.

We have calculated descriptive statistics on basic stand structural parameters of the forest stands included in the final database (Table 3).

Age structure of the stands was analyzed through the distributions of the number of stands and their area by age classes respectively (Figures 1, 2). Stands of the 5th and higher age-classes (> 80 years of age) prevail in the total number and area of the analyzed stands.

TABLE 3

Descriptive statistics of the basic stand structural parameters of 5,060 stands included in the analyses.

	Number of stands	Mean	Median	Sum	Minimum	Maximum	Standard deviation
Area, ha	5060	15.01	11.90	75,948.76	3.00	86.75	11.02
Stand age, years	5060	92.05	96.00		21	174	28.89
Stand density, N/ha	5060	441.70	376.00	–	36	7920	352.93
Basal area, m^2/ha	5060	27.47	28.19	–	3.56	54.11	5.55
Volume, m^3/ha	5060	381.32	399.00	–	23.37	752.00	117.60

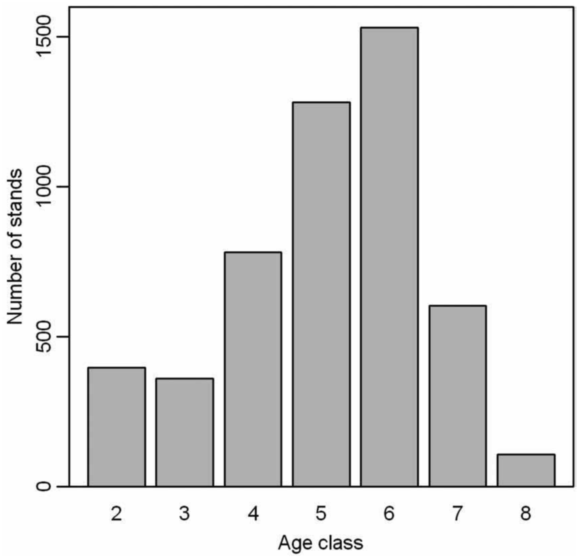


Figure 1. *Distribution of the number of analyzed forest stands by age classes 20 years wide.*

Stands are distributed in the entire natural range of pedunculate oak and common hornbeam forests in Croatia (Figure 3). Research area encompasses 55% of the territory of Croatia with around 66% of its population. There are some significant industrial activities in this area, primarily agriculture, food, textile, wood and metal industry, and some chemical and oil industry. Road and railway infrastructure is well developed, as well as air and river traffic. All these activities exert to some degree the anthropogenic pressure over the forests of the area, mainly through the pollutants in water, soil and air.

For the purpose of the database construction and data manipulation the MS Access software was used. Statistical analyses and figures were done in Statistica 6.0 (StatSoft Ltd., 2001) software package.

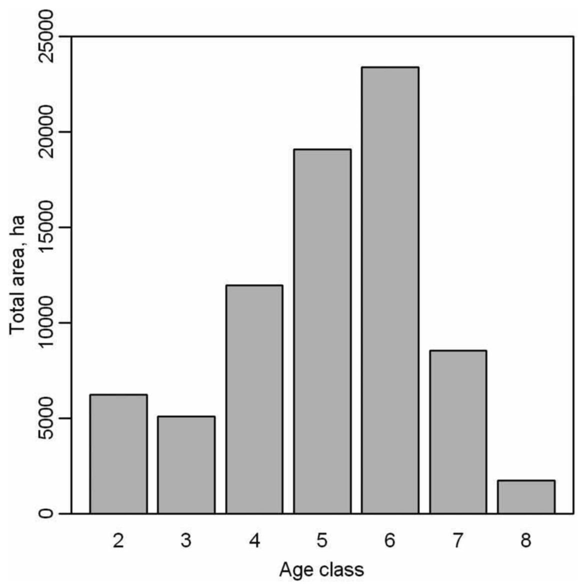


Figure 2. *Distribution of the area of analyzed forest stands by age classes 20 years wide.*

TABLE 4

Structure of stand sample (number and area) over three site classes.

Site class	Number of stands		Area of the stand					
			Mean	Median	Sum	Min	Max	St.Dev.
	n	%	ha					
1st	3,453	68	15.66	12.56	54,078.35	3.00	86.75	11.37
2nd	1,403	28	14.13	11.01	19,823.05	3.01	64.10	10.27
3rd	204	4	10.04	7.79	2,047.36	3.04	56.15	7.76
Total	5,060	100	15.01	11.02	75,948.76	3.00	86.75	11.02

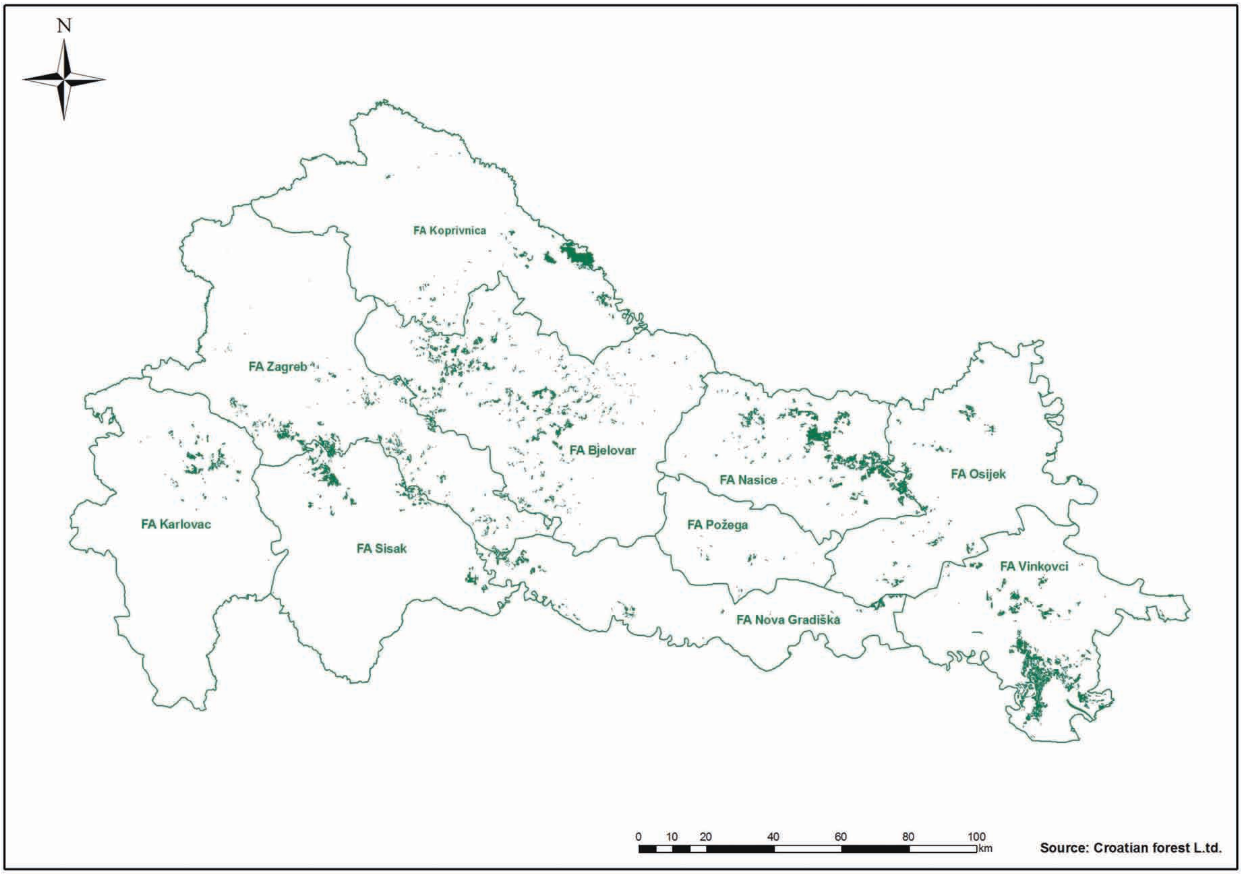


Figure 3. *Spatial distribution of analyzed forest stands of pedunculate oak and common hornbeam in the Northern Croatia.*

RESEARCH RESULTS AND DISCUSSION

Firstly, the stands included in the database were explored according to the quality of the sites on which they were found. Very high share (68%) of analyzed pedunculate oak stands are situated in the best forest sites (1st site class) with total area of 54,078.35 ha (Table 4). Similar result was obtained by Teslak *(20)*, although over smaller area (Management unit »Opeke«), where he analyzed the management class of pedunculate oak. He established the share of oak stands on 1st site class as high as 72% of the area, and stands on 2nd site class on 20% of the area.

Share of stands on three site classes as percentage of the area of each stand age class, are fairly stable and similar trough the whole stand age (Figure 4). Highest area of high-quality sites is currently found in 4th age class (~ 80%) an lowest in the last, 8th age-class (~ 60%). Oak stands on the worst forest sites (3rd site class) are found on under 10% of the area in all age-classes.

Distribution of the number of analyzed stands by age classes and according to site-quality classes again points to the fact that the stands on the best site class are the most prevalent in all age classes (Figure 5).

From Figure 5 (but compare also Figures 1, 2) it can be seen that the age structure of pedunculate oak and common hornbeam stands in Croatia has an irregular shape. Mean stand age over all analyzed stands is 92 years, which indicates the high prevalence of middle-aged mixed

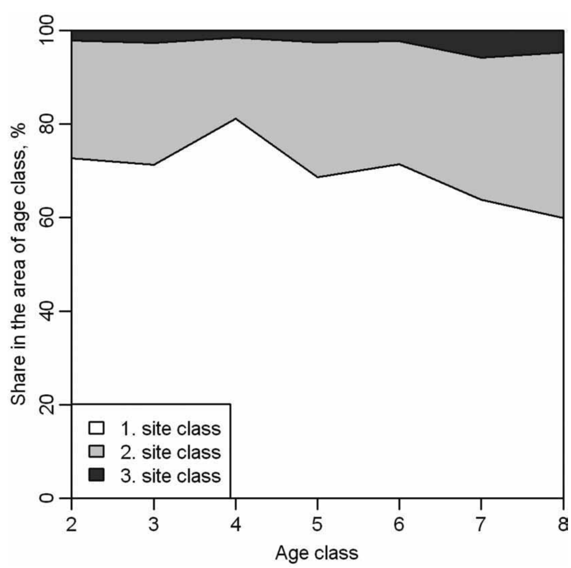


Figure 4. *Share of stands on three site classes as percentage of the area of each age class.*

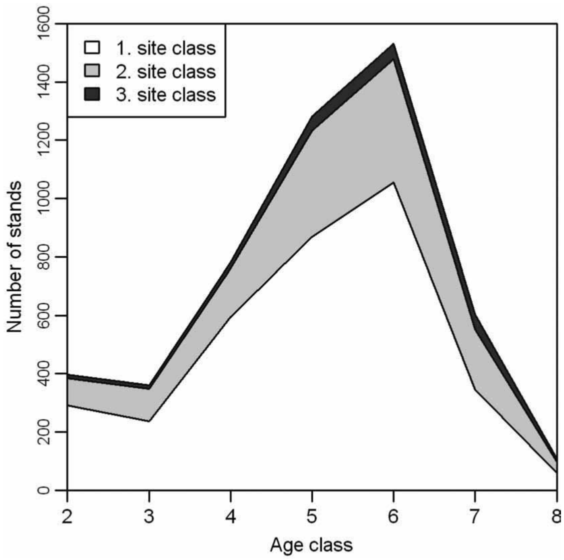


Figure 5. *Distribution of stands of three site classes over age classes.*

pedunculate oak and common hornbeam stands (Figures 4, 5). Similar results were also obtained in other recent research on oak forests in Croatia, either on smaller *(21)* or larger area *(22)*.

The main reasons for the irregular age-structure of oak stands could be traced back historically to their past management, especially to the rate at which they were cut and regenerated *(23)*. Intensive cutting and regeneration of the old-growth pedunculate oak forests in the period from 1820–1920 (~ 170,000 ha), cutting of the middle-aged oak forests between 1920 and 1945 (~ 60,000 ha) and intensification of forest exploitation after the second World War, all contributed to the skewness of the age distribution of today's oak forests.

Stand structural attributes were analyzed only on the subset of the stands on 1st site class because of their high share in the overall area of investigated stands.

From the Figures 6 through 11 it is evident that the particular structural attributes have significant band of variation around the mean value for a particular stand age. Krejci *(24)* has found in his research of the crown width of the pedunculate oak trees that the stand structure of oak forests is not constant trough their rotation length. As the stands age, trees transfer from lower to higher diameter classes, while simultaneously increasing the variation width of the stand structural parameters. This can be related to the importance of biodiversity, in this case the diversity of tree species and their dimensions, as a driver of the dynamic developmental process under constant influence of natural and anthropogenic factors *(25)*.

Both the quadratic mean diameter and tree height show constant increase with stand age, both in trees of pedunculate oak and common hornbeam. In the case of pedunculate oak, increase is steeper and larger during the whole stand age. Common hornbeam trees on the other hand have slower increase of the tree diameter and height, and this increase levels-off after the stand age of approximately 60 years. Variation of these two parameters for the stands of same age is lower compared to the variation of the stand parameters such as stand density, basal area or volume. However, there is still significant amount of variation in stands of same age, even more so in the case of the common hornbeam. Development of the diameter and height of the trees of these two species is mainly under the influence of tree competition within the stand and site conditions *(26)*. Management practices applied in mixed forests are other significant regulator of the development of tree diameters and heights due to the special emphasis that is given to the three-dimensional, i.e. vertical and horizontal spatial arrangement of trees within a stand *(27)*.

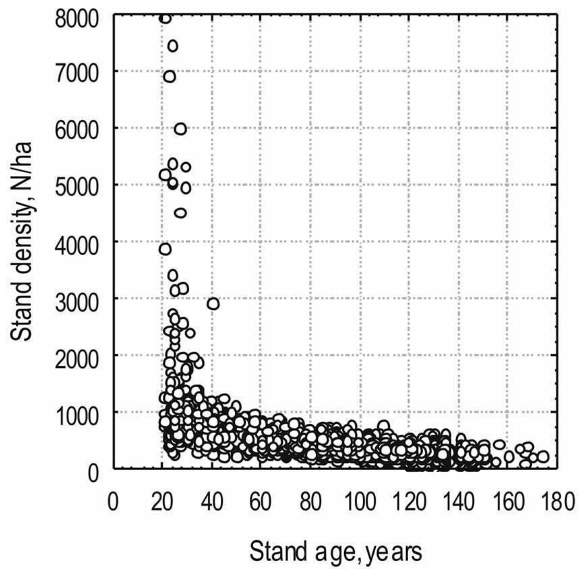


Figure 6. *Total stand density over stand age.*

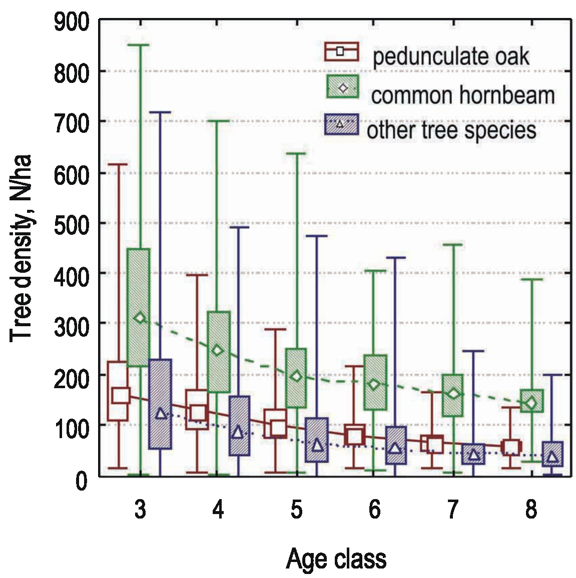


Figure 7. *Density of pedunculate oak, common hornbeam and other tree species per age classes.*

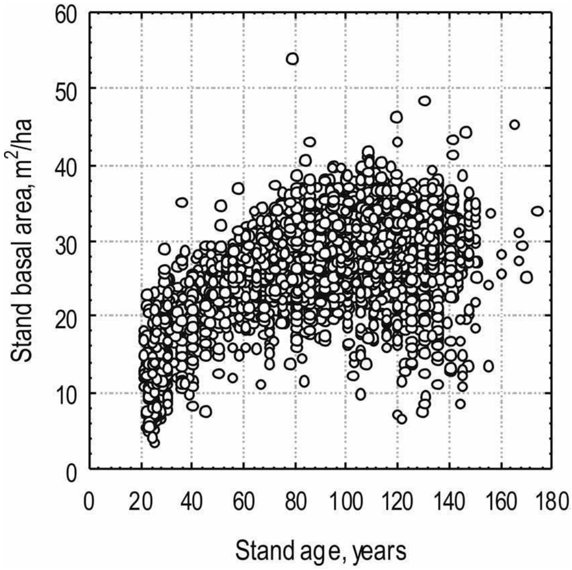


Figure 8. *Total stand basal area over stand age.*

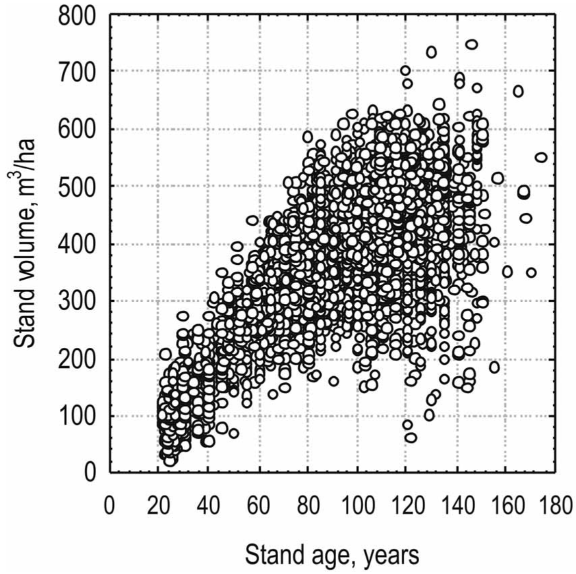


Figure 10. *Total stand volume over stand age.*

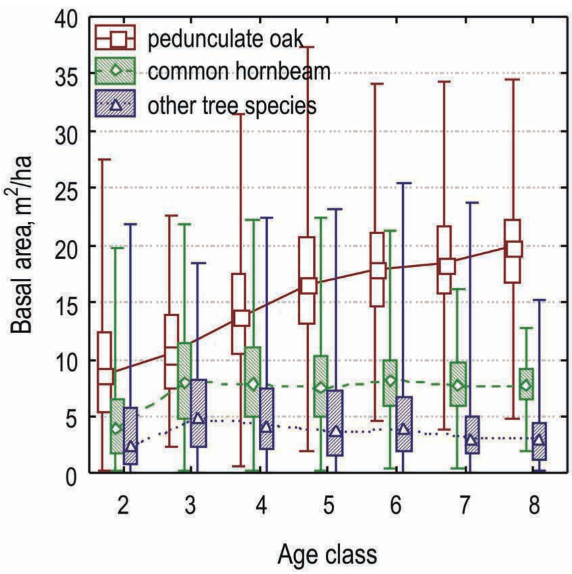


Figure 9. *Basal area of pedunculate oak, common hornbeam and other tree species per age classes.*

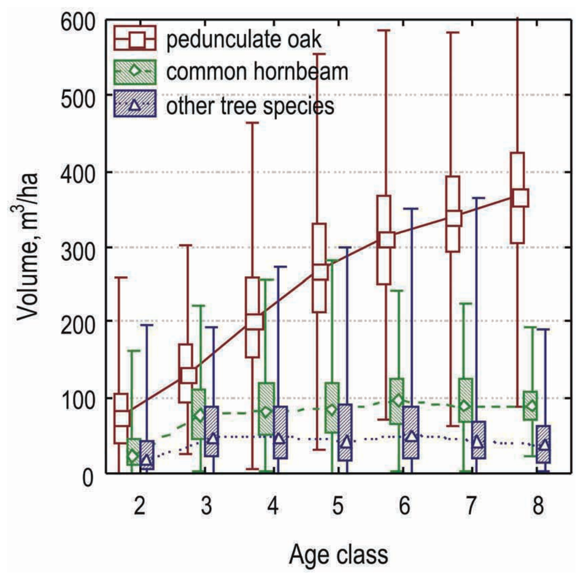


Figure 11. *Mean volume of pedunculate oak, common hornbeam and other tree species per age classes.*

Share of pedunculate oak, common hornbeam and other tree species in the total basal of investigated stands is given in Figure 16 as mean values and variation per age classes. Again, only stands on 1st site class were analyzed.

In all three cases (oak, hornbeam, and other tree species) share in total stand basal area exhibit extremely high degree of variation for the stands of similar age. Godina *(28)* concludes from his research that in mixed even-aged oak stands there is no final developmental stage as a permanent unchangeable state. Rather, nature always tries through the repetition to find a best possible developmental trajectory to adapt to given site conditions.

Share of different tree species in the total basal are of mixed forest stands is under direct influence of the growth and development of the diameters at breast height of different tree species, and the development of their respective diameter distributions. This trajectory can be regulated and influenced trough time by proper definition of management goals, and proper timing, frequency and intensity of silvicultural measures. Management plans with all these elements should always be based on the accurate information of the stand structure of each particular forest stand.

Share of pedunculate oak trees in the total stand basal area in each particular time segment of the stand development is mainly determined by the initial share of oak in stand basal area, spatial distribution of oak trees their vitality (especially near the end of the rotation length).

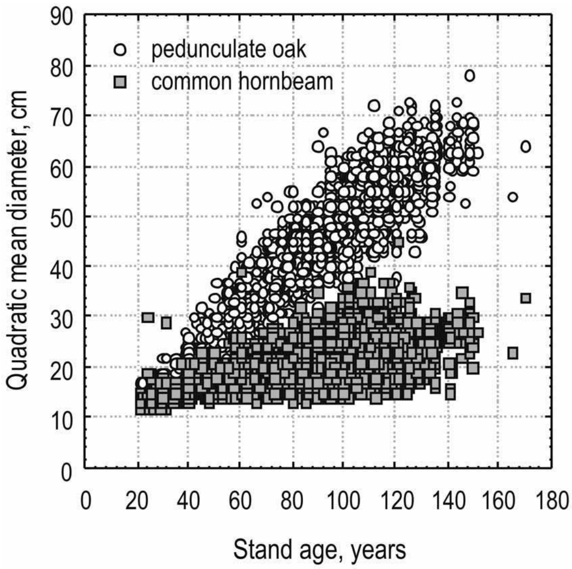


Figure 12. *Quadratic mean diameter of pedunculate oak and common hornbeam trees over stand age.*

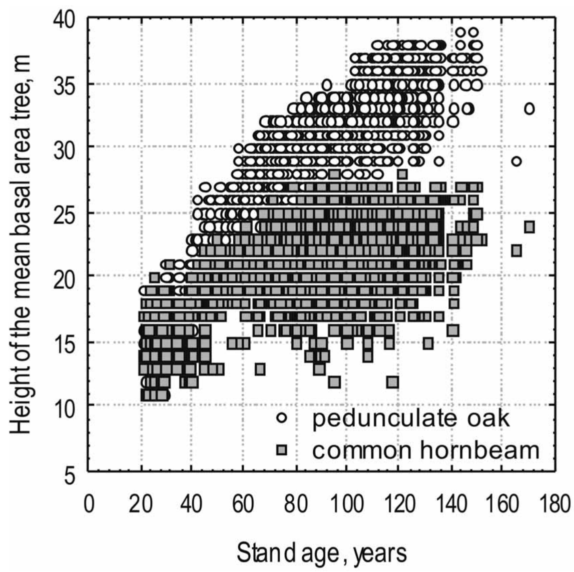
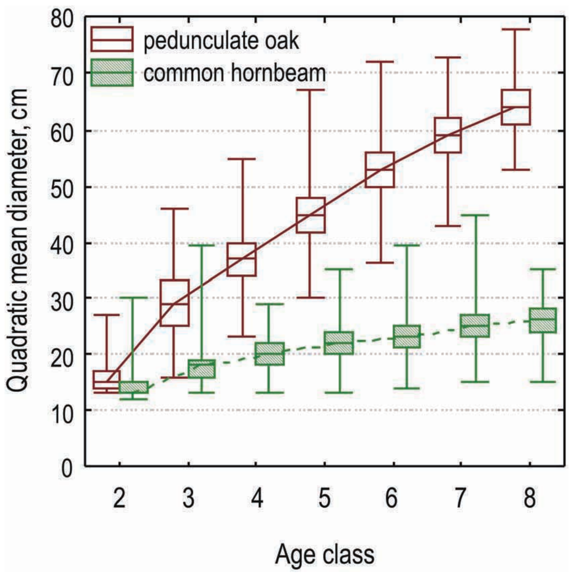


Figure 14. *Height of the mean basal area tree for pedunculate oak and common hornbeam trees over stand age.*



Slika 13. *Development of the average quadratic mean diameter of pedunculate oak and common hornbeam trees over stand age classes.*

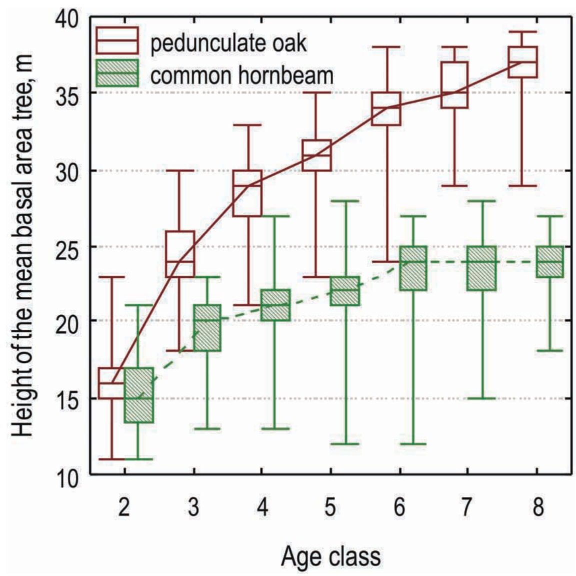


Figure 15. *Development of the height of the mean basal area tree for pedunculate oak and common hornbeam trees over stand age classes.*

Direction of future development of oak share in stand basal area can be determined, or directed through the appropriate planning and execution of management measures.

Investigated stands and growth and yield tables were compared by the total stand basal area (Figure 17), by the basal area of oak trees in the stand (Figure 18), and by the basal area of common hornbeam in (Figure 19).

Values of all three growth and yield tables for total stand basal area lie within the upper-middle and upper data cloud of the total basal area of actual stands (Figure 17). This result is in concordance with the fact that the used growth and yield tables were constructed in such a way to give the best possible, i.e. optimal values for stands of particular stand age. Tables of Meštrovic and Špiranec have the same developmental trend. However, the values from Meštrovic tables which were constructed for mixed oak and hornbeam stands give higher values than the tables of Špiranec which were intended for use in pure oak stands. Possible reason for this discrepancy could be ascribed to the higher productivity of mixed compared to pure forest stands. For example, Kelty *(29)* finds that species in mixed stands could reach higher increment due to the more pronounced differentiation of tree heights, shapes, photosynthetic activity, phenology and root structure.

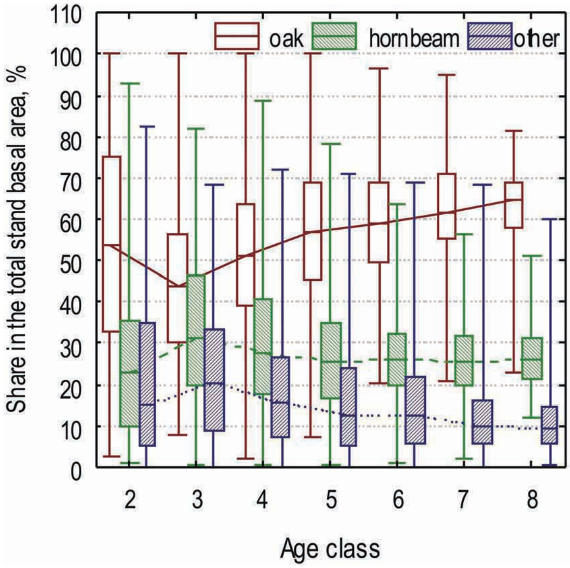


Figure 16. *Development of the share of pedunculate oak, common hornbeam, and other tree species in the total stand basal area per stand age classes.*

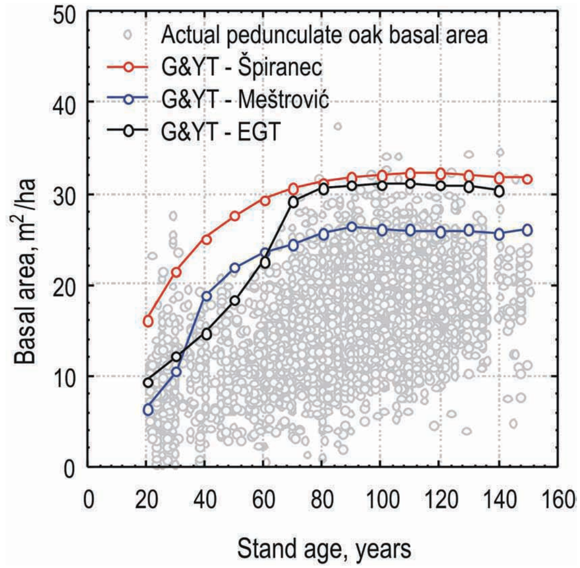


Figure 18. *Comparison of the observed pedunculate oak basal areas and the values from three G&Y tables.*

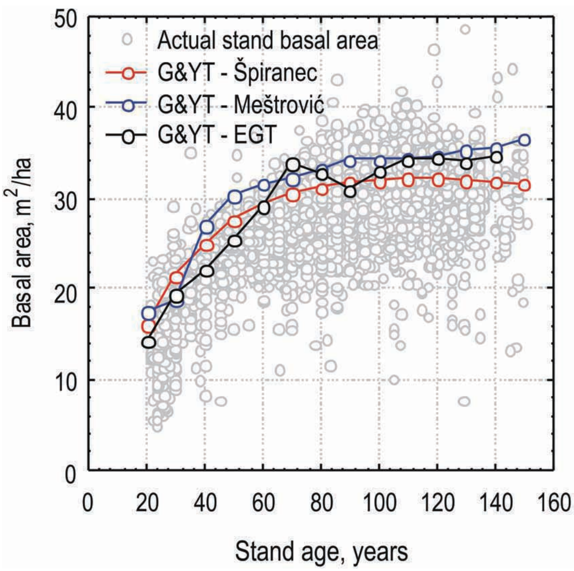


Figure 17. *Comparison of the observed total stand basal areas and the values from three G&Y tables.*

Godina *(28)* points to the higher productivity of mixed pedunculate oak stands as compared to the pure stands, due to the optimal distribution of oak trees trough all canopy layers of a stand.

Total stand basal area according to EGT tables is somewhat lower compared to other two tables up until the stand age of 60 years. But from stand age of 70 years on, they approach the values of Meštrović and Špiranec tables. The exception is the stand age of 90 years in which, according to the EGT tables, first rotation (generation) of common hornbeam trees in the stand ends, and the second rotation begins. This causes the total basal area of the stand to fall lower than the total stand basal area in tables of Špiranec for pure oak stands (Figures 17, 18, 19).

Basal are of oak trees in a stand from the growth tables of Špiranec is in all cases higher positioned than the values of two other tables (Figure 18). Reason for this lies in the fact that Špiranec constructed his tables for pure oak stands, i.e. the share of pedunculate oak in the total stand basal area is always 100%. Values of oak basal area from Meštrović growth tables are significantly lower than the values from Špiranec tables, although they share very similar growth trend. Growth trend of oak basal area in EGT tables differs from the other two tables, it follows an S-shaped growth curve up to the stand age of 90 years,

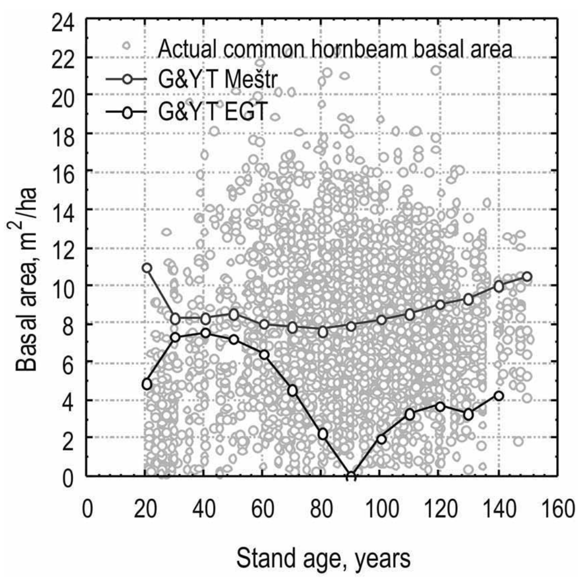


Figure 19. *Comparison of the observed common hornbeam basal areas and the values from three G&Y tables.*

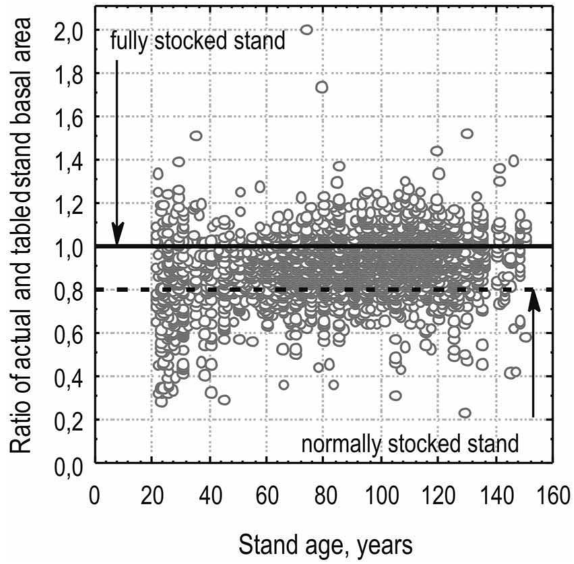


Figure 20. *Ratio of observed total stand basal area and the values given in the \piranec G&Y tables over stand age.*

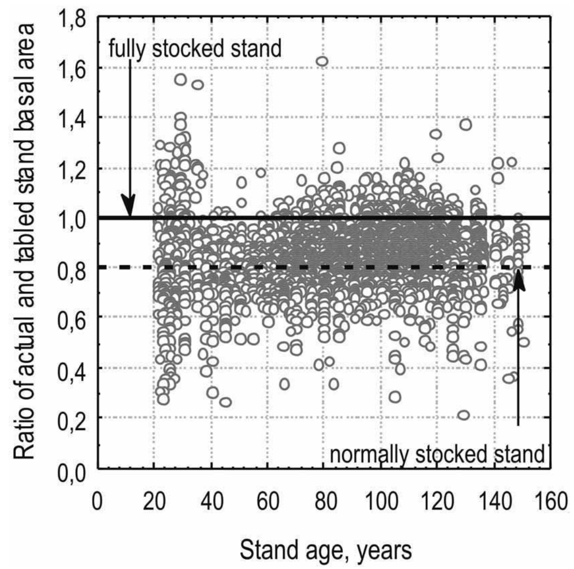


Figure 21. *Ratio of observed total stand basal area and the values given in the Me~trovic G&Y tables over stand age.*

and then levels-off with a minimal decrease towards the end of rotation. The point where the curve changes its shape is around the stand age of 70 years, and this is the age at which the first rotation of common hornbeam ends. It is assumed in the EGT tables that the removal of all hornbeam trees from the stands positively influences the growth of the remaining oak trees.

Values of the basal area of hornbeam from Meštrović tables pass through the middle of the data cloud (Figure 19) with approximately similar absolute value for the entire duration of the stand life. Given the observed high variability of the hornbeam basal area, it can be said that the values from Meštrović tables give the average basal area of hornbeam in these stands. Development of the hornbeam basal area over stand age according to EGT tables reflects the applied theory of two hornbeam rotations within one stand rotation. It is assumed that all hornbeam trees of the first rotation should be removed between the stand age of 60 and 90 years. In this case, the basal area of hornbeam trees in stand age of 90 years equals zero. From the comparison with the actual data of mixed oak and hornbeam forest stands in Croatia (Figure 19) it is evident that this theory could not be supported. Contrary to the assumptions around which these tables were constructed, the removal of mature and the ingrowth of the juvenile hornbeam trees actually occurs continuously trough the stand age.

Finally, stocking of the investigated mixed stands on 1st site class was calculated as a ratio of actual total stand basal area and the values of the total stand basal areas projected by three growth and yield tables for the corresponding stand age (Figures 20, 21, 22). Horizontal lines with values of 1.0 (fully stocked stands) and 0.8 (normally stocked stands) were added to the charts. These values are usually considered in the forest management planning as the guidelines for the definition of silvicultural prescriptions.

It is evident that in all three cases the majority of the stands could be classified as normally to fully stocked, with the ratios of actual to projected stand basal area between 0.8 and 1.0. However, there is still a large portion of the stands with stocking of less than 0.8, or above 1.0 (Figures 20, 21,22). Numerous factors could cause such a deviation from the projected total stand basal area values. Some of factors include the postponed application of thinnings and difficulties associated with the regeneration of these stands within the last 70 years *(14)*, inability to carry out planned management prescriptions, and the decline of pedunculate oak trees that leading to unforeseen sanitary felling of oak trees over larger areas.

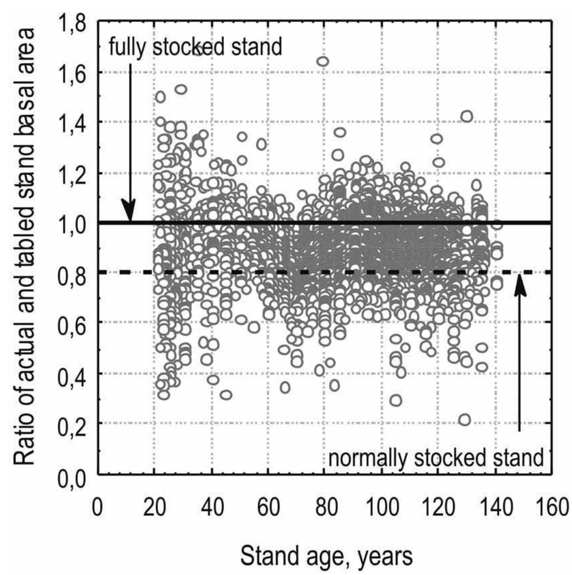


Figure 22. *Ratio of observed total stand basal area and the values given in the EGT G&Y tables over stand age.*

Comparison of the development of the actual stand basal area in Croatian mixed pedunculate oak and common hornbeam stands with the values from the growth and yield tables of domestic authors reveals the fact that the tables do not correspond with the real state of these stands. One of the reasons for this discrepancy is the way in which the tables were constructed, i.e. they try to give the best possible, or optimal values. Also, the basal area development as described in the tables gives the static view of only one possible trajectory of stand development for particular tree species and site quality taking into account only the stand age as one input factor. However, the structural development of mixed forest stands is a highly dynamic process, and multiple factors should be considered, especially the cyclical driving processes of organic and inorganic origin *(30)*

CONCLUSIONS

Mixed forest stands of pedunculate oak and common hornbeam in Croatia have highly irregular age-structure, both by the number of stands and their area. Mean stand age calculated in this research is 92 years, indicating the high prevalence of middle-aged and old stands. Reason for this is the variable rate at which the old-growth oak forests were cut and regenerated throughout their history, especially in the period from 1890 to 1920.

Development of basic structural elements in stands on 1^{st} site class, such as stand density, basal area and volume per hectare, as well as the quadratic mean diameter and height of the mean basal area tree, is characterized by the very high variability in stands of all age classes.

Share of pedunculate oak basal area in the total basal area of the stand has extremely high variation over all age-classes. Thus, it is very difficult to set or plan for a fixed basal area share in these types of stands, or expect to achieve some sort of permanent and stable share of peduncualte oak basal area share in the total stand basal area.

However, it is possible to influence the direction in which the share of oak basal area develops over the life-time of a stand. This could be achieved in directly through the frequency and intensity of silvicultural measures based on the information of the initial oak basal area, spatial distribution of oak trees over the stand area, vitality of oak trees especially near the end of the stand rotation length.

Structural development of mixed pedunculate oak and common hornbeam stands is influenced by diverse factors, e.g. tree species diversity, tree dimensions and their interactions, applied silvicultural measures, and many others. It is a dynamic process driven by various factors of natural and anthropogenic origin. On the other hand, growth and yield tables used to guideline their management are constructed with only limited number of driving factors, and are often used by only comparing only one of the stand structural factors (e.g. basal area). Therefore, the information derived from the growth and yield tables have only limited value for the management of forests in today's conditions of changing environment.

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