SEEFOR SOUTH-EAST EUROPEAN FORESTRY
ISSN 1847-6481
eISSN 1849-0891

Preliminary communication

Natural Regeneration of Beech Forests in the Strict Protected Area of the Plitvice Lakes National Park

Tomislav Dubravac [1] ✉, Stjepan Dekanić [2], Vladimir Novotny [3], Josip Milašinčić [1]

[1] Croatian Forest Research Institute, Cvjetno naselje 41, 10 450 Jastrebarsko, Croatia
[2] Institute for Research and Development of Sustainable Ecosystems, Jagodno 100a, 10415 Novo Čiče, Velika Gorica, Croatia
[3] Croatian Forest Research Institute, Trnjanska cesta 35, 10 000 Zagreb, Croatia

✉ Corresponding author: e-mail: tomod@sumins.hr

Citation:
DUBRAVAC T, DEKANIĆ S, NOVOTNY V, MILAŠINČIĆ J 2013 Natural Regeneration of Beech Forests in the Strict Protected Area of the Plitvice Lakes National Park. *South-East Eur For* 4 (2): 95-103

Abstract

Background and Purpose: The study presents the results of an investigation of regeneration processes, growth, development and survival of young growth by field measurement and three-dimensional visualization of horizontal and vertical structure. The results are based on the ten-year investigation (1998-2009) on a permanent experimental plot in a mountain beech forest with dead nettle tree (*Lamio orvale - Fagetum sylvaticae* Ht. 1938) in conditions of passive protection.

Materials and Methods: Basic structural indicators were measured (diameter at breast height and height), structural crown elements (size and shape, ground cover crowns) and the occurrence and survival of young growth as the basic conditions of natural regeneration. Particular emphasis in the investigation was paid to the development of crown structures and the process of natural regeneration during the 10 year period.

Results and Conclusions: Investigation indicates the occurrence of young growth regeneration cores arising as a result of the die-back of one dominant beech tree with horizontal crown projections of 145 m^2 which initiated the possibility of natural regeneration. The greatest change occurred in the beech seedling count, whose numbers increased fourfold from 3556 plants per hectare in 1998 to 12694 plants per hectare in 2009. The share of beech seedlings increased from 8.7% to 22.6% of all species of young growth and shrubs. Thus beech became dominant among the tree species regeneration. However, the majority of the young plants of beech are of poor quality and thus their further development in conditions of passive protection is questionable. The investigations also showed the possibility of a new approach to the study of the dynamics of crown structures and the process of natural regeneration by methods of three-dimensional visualization of horizontal and vertical structures. The methods presented offer a more graphic illustration of the development of stands and high quality presentation of the obtained results. For a long-term scientifically based plan, with the aim of reaching the most favourable decisions on the future of forest stands in protected areas, particularly in today's conditions of climatic changes, continuous improvement and expansion of monitoring methods by means of a network of permanent experimental plots in all protected forest areas is necessary.

Keywords: forest reserve, passive protection, close-to-nature-forestry, crown structure, natural regeneration, beech (*Fagus sylvatica* L.).

INTRODUCTION

Almost half of the continental territory of the Republic of Croatia (48%) is covered by forests. Of the total forest areas approximately 56% consists of beech dominated forests, beech forests with sporadic sessile flowered oak, and mixed beech-fir forests [1]. In contrast to many countries, where the natural composition of the forest has been significantly changed by the activity of man, in Croatia a large part of the forests have retained its natural characteristics mainly due to the endeavours of the foresters and the nature of forest management based on the principles of sustainable development. This determined the stability and conservation of forest ecosystems and offered the possibility of establishing national parks during the middle and second half of the past century, in which the main, or one of the main, basic natural phenomena are the forests. The Plitvice Lakes National Park, one of eight national parks in Croatia, was established in 1949 for the protection of the hydrologic system of the lakes, forests and other ecosystems, and natural phenomena. In recognition of the great importance of the forest for the future of the Plitvice Lakes National Park, employees of the Croatian Forest Institute (formerly Forest Institute, Jastrebarsko) established four forest reserves with a total surface area of 1 347 ha: Medveđak (1976), Čorkova uvala-Čudinka (1977), Kik-Visibaba (1979) and Rječica-Javornik (1981). The basic objective of establishing forest reserves was to determine the basic (zero) condition of vegetation, determine structural relations and to monitor the further growth and development of forest ecosystems, particularly the condition and possibility of their natural regeneration as the basic factor for permanent forest ecosystem sustainability and survival.

This problem has been studied by many forest experts in Croatia. Seventy years ago prof. I. Horvat began the first systematic phytocoenological investigation in the Risnjak National Park. The start of forestry scientific research in virgin forests of Croatia can be attributed to the investigations of Čorkova uvala in the Plitvice Lakes National Park, which were commenced by academician Milan Anić in 1957. With the object of monitoring the development of forests in natural conditions in the area of the Plitvice Lakes National Park the investigation of Cestar et al. [2] should be mentioned, who, after carrying out typological investigations, showed that the method of performed management did not encourage the occurrence of young growth, particularly of beech. Hren [3] investigated the structure of the beech virgin forest "Ramino korito", and Prpić [4] investigated the characteristics of the beech-fir virgin forest "Čorkova uvala" in the Plitvice Lakes National Park. Klepac [5, 6] advocated active protection of the forests in the Plitvice Lakes National Park, and in 1994 proposed ecological management of the forests with emphasis on the need to enable permanent natural regeneration of forests. In his investigation Novotny et al. [7] pointed to the growth and development of basic structural elements and elements of regeneration in the Plitvice Lakes National Park.

These investigations, with periodic measurements on permanent experimental plots, carried out by employees of the Croatian Forest Research Institute (basic structural elements, indicators of growth structures and development of tree crowns, including the number and quality of young growth), indicate that the possibility of satisfactory natural regeneration in national parks is questionable [8-14]. The aforementioned investigations showed that, although nature is continuously active, we cannot be satisfied only with its activity. Long-term study has shown that passive protection clearly does not give the expected results.

This study aimed to investigate regeneration processes, growth, development and survival of young growth in a mountain beech forest with dead nettle tree (*Lamio orvale - Fagetum sylvaticae* Ht. 1938) in conditions of passive protection. For that purpose field measurements on a permanent experimental plot in 1998 and 2009 were conducted as well three-dimensional visualization of horizontal and vertical structure.

MATERIALS AND METHODS

Study Area

The investigation was performed in the "Medveđak" Forest Reserve on a permanent experimental plot in a natural stand of mountain beech forest with dead nettle (*Lamio orvale-Fagetum sylvaticae* Ht.1938) 570 m above sea level (Figure 1). The reserve is situated within a larger forest complex of beech forests, in the north-eastern part of the "Plitvice Lakes" National Park. The reserve comprises three compartments with a total area of 156.3 ha. The highest point of the reserve is 875 m, and the lowest 580 m above sea level. The reserve is located on a geological base of limestone with three soil types. On the high positions and on the ridges is humus (black soil) on limestone (10%), on the steep slopes shallow brown soil on limestone (20%), on the less steep slopes moderately deep brown soil on limestone (40%), and in karst sinkholes is loessial soil or illimerised soil (30%) [9]. Inclination ranges from 10^0 to 25^0. In the south-eastern lowest part of the reserve are karst sinkholes, from which the terrain rises up towards the north-east up to the highest point, and again over the ridge descends towards the north and north-east.

Data Collection

In 1998 a permanent experimental plot was established, 1 ha in size (plot coordinates: N=44^0 53′ 09″; E=15^0 38′ 01″) according to the method of Dubravac and Novotny [15] as a part of a network of permanent experimental plots established in the national parks of Croatia (Risnjak, Plitvice Lakes, Paklenica, Mljet, Brijuni). The plots were established with the aim of monitoring the dynamics of forest ecosystems in conditions of strict protection of nature. The age of the stand at the time of the establishment of the plot was 147 years. All trees with diameter at breast height (DBH) greater than 7.5 cm were marked and their basic characteristics measured (DBH, tree height and stem length). In the most homogenous part of the plot a sub-plot was set up, 60m x 60m in size, on which the spatial arrangement of the trees was recorded, their horizontal crown projections were mapped. Furthermore, elevation data of each tree were recorded, according to which a digital terrain model (DTM) was created (Figure 2). In three

FIGURE 1. Beech stand in the Medveđak Forest Reserve

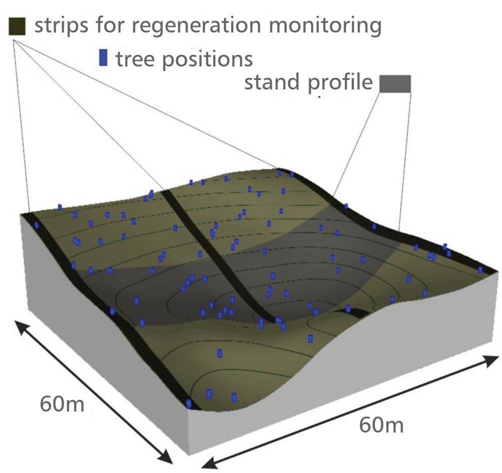

FIGURE 2. Digital terrain model (DTM) of the experimental plot with basic measuring elements

strips, 2 m x 60 m (total surface area 360 m^2), the height structure of young growth and shrub layer was recorded and they were grouped into the height classes (<30 cm; 31-60 cm; 61-130 cm; 131-150 cm; 151-200 cm; 201-250 cm). Ten years later (2009) DBH and height of all trees were measured again, and on the strips the structure of young growth and shrub layer was recorded according to height classes and species. The horizontal projections of crowns were measured on the trees on the part of the plot (20 m x 60 m), for comparison with the changes in the vertical profile of the stand between the two measurements. More information on data collection procedure could be found in earlier authors' works [9, 10, 12, 16]. On the two occasions (1998 and 2009) dimensions of young growth which developed after the die-back of one of the dominant beech were also recorded and it was grouped into already mentioned height classes. ArcMap programme was used for digitalization of horizontal crown projections and production of the DTM. For preparation and analysis of data MS Excel was used and for visualization of stands and vertical profile Stand Visualization System and EnVision (USDA Forest Service, USA) programmes were used.

RESULTS

Basic structural characteristics of the experimental plot are shown in Table 1. Comparing the obtained data with growth and yield tables [17] which have volume on I. cite class of 646 $m^3 \cdot ha^{-1}$, it may be seen that the obtained volume of the researched stand is considerably higher, mainly due to passive protection of the stand and absence of the management activities. More details on the stand structure elements and comparison between two measurements (1998 and 2009) may be found in the paper of Novotny et al. [7].

Crown structure

From the layout of horizontal projections of crowns in the first measurement in 1998, it was determined that the crown cover of ground amounted to 96%. Mean area of a horizontal crown projection amounted to 53.67 m^2 ranging from 5.94 to 158.36 m^2. Crown projection area of trees exhibits a non-linear relationship with the DBH, in the form of the power function (Figure 4).

In the left lower quadrant of the experimental plot an advanced regeneration was found in the opening of the stand canopy, which had resulted from the die-back of one dominant beech tree from the upper canopy layer prior to the establishment of the plot. From the DBH of the dead tree, the area of the horizontal crown projection was estimated to be 145 m^2. The opening created in the canopy layer stimulated the occurrence of the advanced regeneration. In order to estimate the growth dynamics of the crown structure development between the two measurements, two stand profiles were set up on a part of the plot, 20 m x 60 m in size (Figure 5). In the first measurement the total area of the horizontal crown projections of 27 trees in the profile amounted to 1,492.24 m^2, with the average size of projection area for one tree at 55.27 m^2. Prior to the second measurement die-back occurred in 3 trees of the total area of the horizontal crown projection of 69.27 m^2. However, an increase occurred in the mean

TABLE 1. Basic stand structure elements (stem number – N, basal area – BA, volume – V) and average values (diameter at breast height – DBH, height – h, basal area – ba, volume – v) of the beech trees of the experimental plots in 2009

Measurement year	N trees·ha^{-1}	BA $m^2 \cdot ha^{-1}$	V $m^3 \cdot ha^{-1}$	DBH cm	h m	ba m^2	v m^3
2009	291	45.68	803.07	41.1	27.1	0.15	2.46

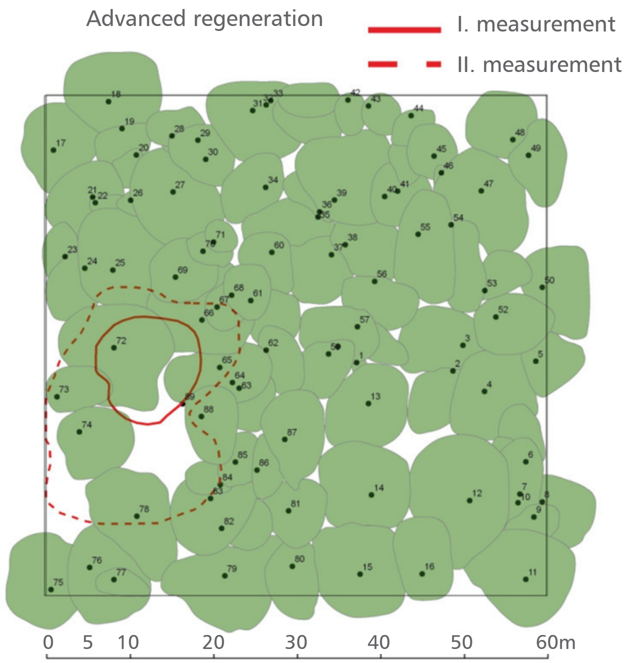

FIGURE 3. Horizontal projections of crowns (first measurement 1998) with advanced regeneration (1998 full line, 2009 broken line)

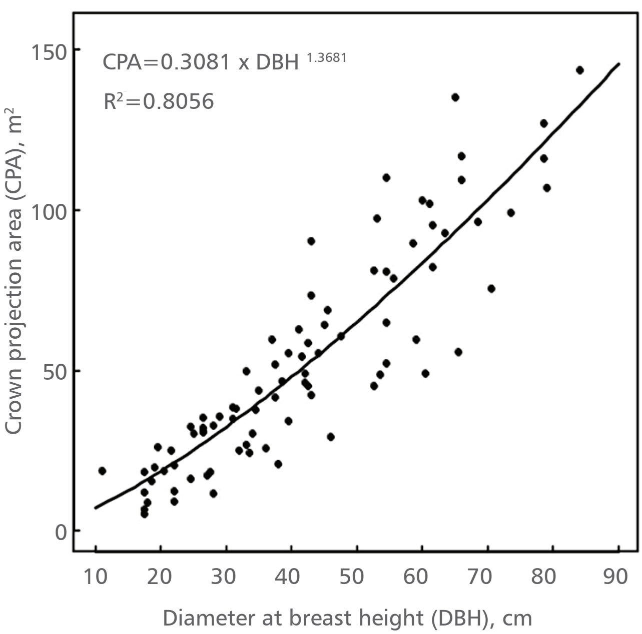

FIGURE 4. Relationship of the crown projection area (CPA) and the DBH

area of crown projection per tree of 63.04 m^2 (+ 7.77 m^2), and increase also occurred in the total area of the of horizontal crown projections of 1,512.89 m^2 (+ 20.65 m^2). In the period between the two measurements no more significant changes occurred in the vertical canopy, regardless of the 3 missing trees.

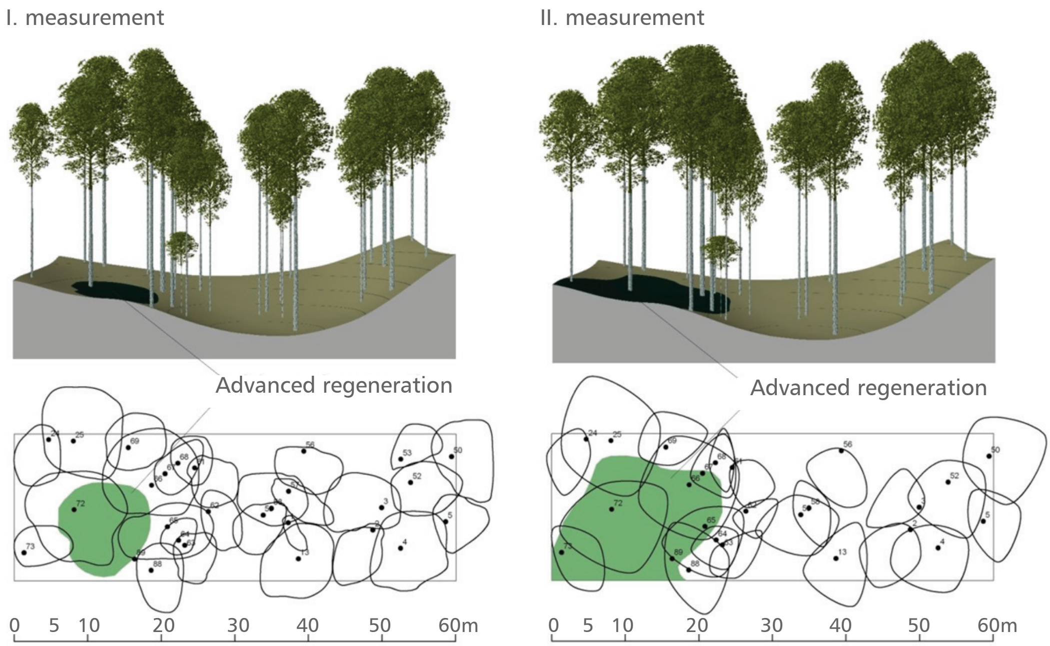

FIGURE 5. Scheme of the development of initiated advanced regeneration between two measurements

Process of natural regeneration

As has already been stated that the process of natural regeneration was mainly influenced by the opening of the canopy due to the die-back of one dominant beech tree and by development of advanced regeneration (Figure 5). The area of the advanced regeneration in 1998 amounted to 124.7 m^2 which increased fourfold in the second measurement, to 512.2 m^2. By measuring the numbers of the regeneration and shrubs on three strips (Figure 2) on total area of 360 m^2 in 1998 and 2009, an increase in the overall number of plants from 40.8 to 56.2 plants per hectare, was determined (Table 2). The greatest changes occurred in the share of beech seedlings, the number of which increased fourfold from 3,556 plants per hectare in 1998 to 12,694 plants per hectare in the second measuring. In the percentage share common beech increased from 8.7% to 22.6% of all plants of young growth and shrubs, and took a dominant role among the young crop of trees. With regard to the height structure of the young beech trees, their increased number is most visible in height class up to 30 cm (Figure 6). The majority of the young beech plants is of poor quality and it is questionable how they will continue their further development in the conditions of passive protection.

Today, information on stand structure (spatial arrangement of trees, tree measurements, and particularly crown measurements) may be visually presented by means of one of numerous computer programmes. On the basis of a digital model of tree-crown projections, measured values in the field (tree heights, stem length, length and width of crowns) and standard bases, a three-dimensional photo-realistic digital model of a stand was produced. In the production of the model the spatial arrangement of trees and phenotype of crown forms were taken into account [18]. In this investigation stand structure is visualized in the programme packet EnVision (USDA Forest Service, USA) which is shown in Figure 7.

TABLE 2. Number of seedlings, saplings and shrubs per hectare in two measurements
* *Acer pseudoplatanus* L., , *Picea abies* (L,) H.Karst, *Fraxinus excelsior* L.
** *Sambucus nigra* L, *Daphne mezereum* L., *Corylus avellana* L. and others

Height class (cm)	Beech		Other tree species*		Shrubs**		Total	
	1998	2009	1998	2009	1998	2009	1998	2009
to 30	1528	10194	1556	1028	28167	36194	31250	47417
31-60	1417	1111	1056	1306	5500	3917	7972	6333
61-130	556	1139	361	611	361	222	1278	1972
131-150	28	139	56	28			83	167
151-200	28	83	167	111		56	194	250
201-250		28	28	83			28	111
Total	3556	12694	3222	3167	34028	40389	40806	56250

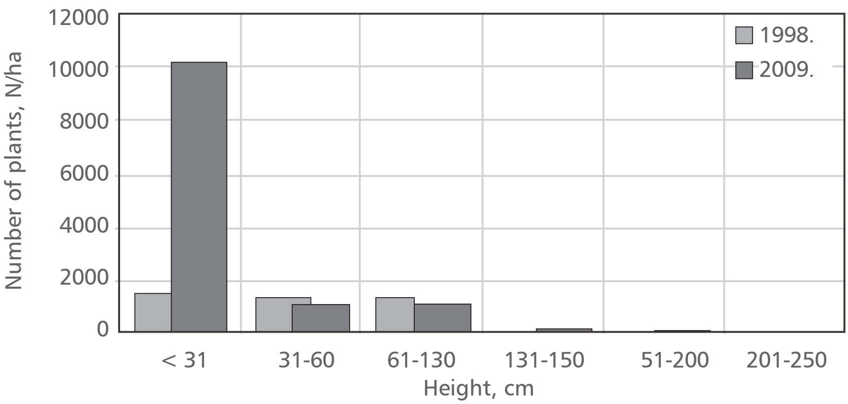

FIGURE 6. Height structure of young beech growth

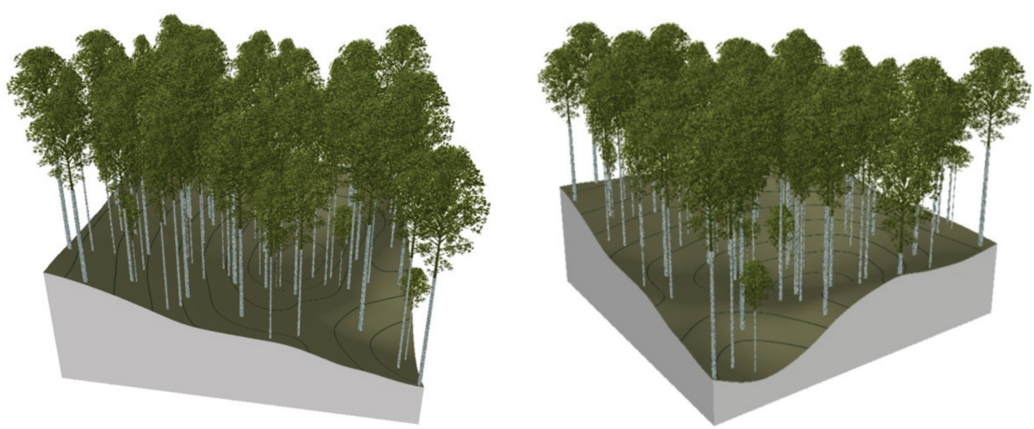

FIGURE 7. Visualization of beech stand on the experimental plot (En Vision), two views

DISCUSSION

Although the observation was carried out in a relatively short period of time (10 years), the methods and results of this investigation present new contributions to understanding crown structure dynamics and the process of natural regeneration of pure beech stands in conditions of passive protection. Investigations so far [e.g. 19-24], also confirmed in this study, indicate that natural regeneration should be carried out on initiated regenerative cores, by opening the canopy in small areas and groups. Similar to this research, results of the research conducted by Rugani et al. [25] showed that gaps smaller than 500 m^2 are the dominant driving force of stand development. Therefore, we think that opening canopy in small areas present the best form of regeneration for nature, especially in protected forest ecosystem. In order to attain scientifically based plans for deciding on the future of forest stands of protected areas, particularly in conditions of climatic changes today, it is necessary to constantly improve and broaden methods of monitoring by means of a network of permanent experimental plots in all protected forest areas. The possibilities offered by modern computerised models for high quality presentation of obtained knowledge should not be ignored. Furthermore, modern remote sensing methods and data (e.g. airborne images, satellite images, LiDAR) may be used for characterising forest dynamics on large-scale areas. For instances, Hobi [26] founded that high resolution satellite images (WorlView-2) have a large potential for forest canopy modelling (for characterising forests' gap dynamics).

By acknowledging existing laws and provisions in areas which are not under a regime of strict protection, it is necessary to assist natural processes which are already in progress in the forest ecosystems. The aforementioned activities are the fundamental method for optimization of priority functions of the forests with specific assignment. Such work should include two important principles: 1) high-production forest is biologically the most stable forest, which offers the greatest generally useful functions and 2) professional silvicultural activities are at the same time the condition and only way in which we can, on the one hand utilize productive functions of the forest, and on the other hand ensure the protection and natural regeneration in these forests.

Knowledge of these problems clearly indicate that increased engagement of the forestry profession is necessary, particularly in those protected areas whose basic phenomena, and most recognized characteristics, are forest ecosystems. In such cases forest interventions should be adapted to the preservation and natural characteristics of the forest ecosystems on particular sites. This is also confirmed by other researches conducted in the 'Medveđak' forest reserve [20, 24, 27]. Therefore, so called 'close-to-nature-forestry' silvicultural approach [19, 23, 28], with existed but reduced human activities, which is accepted in most of the Central European countries may be adapted in forest managing of Croatian Natural Parks, as well.

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