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The features of the biennial shoot systems of *Ulmus glabra* Huds. characteristic of the crown in the virginal age state

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Abstract. The morphological features of crowns were studied on the material of individuals of *U. glabra* of seed regeneration in the gaps of decaying three-hundred-year-old oak forests. We collected data on all crown shoots of five trees of young virginal age (from 10 to 18 years). The principal component method was used twice: first on the model tree to characterize features of the shoots biennial systems under the study, then to reveal ontogenetic and structural features of the crown organization of five virginal trees. Using the method of shoots biennial systems extraction allowed us to form a set of qualitative and quantitative characters reflecting crown structure properties of virginal trees of *U. glabra*, namely: properties of axes branching order, ontogenetic age of shoots in the crown, crown density, individual properties of tree crown structure.

1 Introduction

A tree is a modular, long-lived, slow-moving organism with a complex structure and responds to multiple environmental influences by the variability of its form. The crown of a tree is variable and plastic, but it has features peculiar to the species. If you take into account the structural properties of the tree crown in ontogeny, you can actively influence the characteristics of trees. It is necessary for successful work in the field of forestry, arboriculture, landscaping, fruit-growing, and other areas of human economic activity connected with woody plants in one way or another.

The virginal age state is characterized by a complete crown already formed. In this age state, woolly elm (*U. glabra*) already leaves the undergrowth layer and is able to enter the undergrowth layer of the stand. The study of the spatial and temporal structure of the crown of virgin individuals of *U. glabra* will make it possible to reveal structural patterns of crown development in broad-leaved trees of the temperate zone.

The work aims to identify the characters of two-year shoot systems that describe the dimensional, structural, and ontogenetic features of the crown of the virginal tree *U. glabra*.

2 Material and methods

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The material was collected in the end of July 2018 in the central part of the range, in the natural habitat of the upland three-hundred-year-old oak tree of the Belogorye Reserve (Belgorod Region). The studied trees grew on the sycamore in the conditions of windows of 1-2 trees of the first tier [1]. The height of undergrowth groups, among which the selected individuals grew, was 1.5-2.5 m in these conditions.

The age state of individuals was determined taking into account the classification "Diagnoses and keys of age states" [2]. Plants, of seed origin, of early virginal age state, of normal viability were investigated. A total of 83 individuals were analyzed. Five separately selected individuals further designated as trees 1-5 and having astronomical age of 10, 13, 16, 18 and 18 years, respectively, were measured in laboratory conditions, a detailed scheme of shoot arrangement was made for each, a number of morphological and structural features of biennial shoot systems were investigated. The following variables were collected: 1-4) lengths of the first, second, third, and fourth (from above) internodes of the shoot (a, b, c, d); 5) number of all internodes of the shoot (internodes); 6) number of green leaves on the shoot (leaves); 7) age of the shoot in years from its appearance in crown up to the year of material collection (age); 8) shoot position on the mother shoot of the previous year (numbering from the shoot tip) (location); 9) branching order of the axis the shoot belongs to (order); 10) type of biennial shoot system which the shoot is maternal for (type of BSS); 11) length of the mother shoot (L); 12) length of maximal lateral shoot (L max s.sh); 13) ratio of length of maximal lateral shoot to length of maternal shoot (L max s.sh/L); 14) relative degree of development (in terms of length) of trunk growth, on which branch to which the shoot belongs, expressed in points - from 1 (long shoot) to 4 (short shoot) (total 4 gradations) (trunk growth); 15) number of branch from the trunk, which the shoot belongs to (numbering from the top of the tree crown) (branch).

Separation of axes of different branching orders was carried out in accordance with the principles given in the literature [3]. Types of two-year shoot systems were determined according to the technique developed at the Department of Geobotany and Plant Ecology of St. Petersburg State University [4, 5]. The following morphofunctional types of biennial shoot systems are distinguished in the crowns of tree plants of the temperate zone: "Growths", "Supergrowths", "Basic", "Narrow", "Filling", and "Choppers".

Statistical processing was performed in the R environment using the RStudio program. The principal component analysis was used.

3 Results

Based on the collected variables and sample of all 971 shoots of tree 1 (tree age 10 years), a principal component analysis was performed. Maximum number of both morphometric and structural ("age", "location", "trunk growth", "branch") shoot variables was included in the analysis.

Among the variables that made the main contribution to the first principle component, a group of closely correlated dimensional variables stands out (Fig. 1). This allowed us to subsequently reduce the number of variables. Those were the variables of shoot length; length of the first four internodes taken separately; total number of internodes of the shoot; number of green leaves on the shoot. The first principle component can be interpreted as a factor of metrical variables (52% of explained variance).

In the second component (14% of explained variance), the greatest contribution is made by the variables of branching order, expression of trunk growth length, shoot age (Fig. 1). Significant contribution to this component is made by the character of the ratio of the length of the maximum lateral shoot to the length of the parent shoot. On the one hand, it is a metric characteristic; on the other hand, it characterizes the shape of two-year shoot system. The second main component can be interpreted as a factor of structural variables of the shoot system as a whole, according to the set of variables which make maximum contribution to it.

In the third component, which explains 8% of variability, the greatest contribution is made by the variable of shoot position in the biannual shoot system of the previous year (location) and the character of trunk growth expression. The greater is the length of trunk growth, the more shoots are preserved closer to its base. Large trunk growth occurs mainly in the upper part of the crown, which explains the negative value of the character contribution. In the fourth component (6% of variability), these two variables act in one direction.

The points of the shoots were marked according to the type of the two-year shoot system of the shoot, as the mother shoot of the biennial shoot system. The idea of this approach is that the features corresponding to the shoot can be interpreted as properties of the shoot system (Fig. 1). In constructing the diagram in Figure 1, only those shoots, which could be maternal to the two-year shoot system, are taken into account.

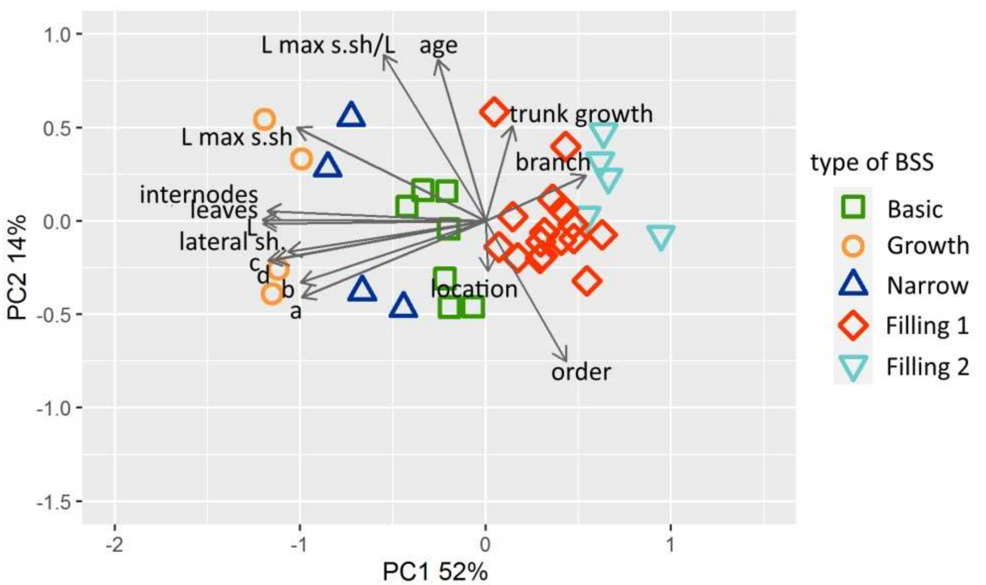

Fig. 1. The result of principal component analysis for a sample of shoots of a single tree using the maximum number of features.

Distribution of shoots in the plane of the first two components revealed clusters of shoots, which are maternal shoots of different groups of biennial shoot systems (Fig. 1). Separation of different types occurs to the greatest extent according to the first main component. The second main component characterizes internal features of each type of biennial shoot system, distinguishing them in different parts of the crown. This division is primarily inherent in "Basic", "Narrow" and "Growth" biennial shoot systems.

Then, principal component analysis was carried out for each tree separately, taking into account all shoots of an individual, which number in our case varied quite significantly. Thus, for tree 3, the total number of shoots was 1665, and for tree 4 - only 799 shoots. Structural variables selected on the basis of test analysis on small sample described above were used. These are variables "location", "order", "age", "branch". From the dimensional characters the variable "lateral sh." was used.

The first three variables characterize the internal structure of the tree crown. Thus, the feature "location" characterizes a shoot within one shoot system. The attribute "age" allows taking into account the position of a shoot in time, the reference point here for each shoot is the moment of its emergence in the crown. The "order" shows the position of a shoot in the perennial branch system, how far it is from the trunk in spatial terms. The variable "lateral sh." is indirectly connected with the length of a shoot, and also characterizes the intensity of its branching.

The result showed that the contribution of these variables to the principle components in all trees is similar. It turned out that each of the analyzed variables acts on the level of an individual tree in the same way. At the same time, we can note the regularities associated with the individual features of the trees.

The character "order" makes the greatest contribution to the first principle component in all plants. This is especially characteristic of younger individuals (10, 13, 16 years old). In two older trees (18 years old), the "order" character is enhanced by the "age" and "branch" variables (acting in the same direction). The character "lateral sh.", which acts in the opposite direction to the three above-mentioned variables, also contributes greatly to the first component. Thus, the first principle component can be interpreted as a factor of branching order.

The second principle component in all trees is greatly contributed by the character "branch", and then by "age" and "location". It is interesting that the older the tree is, the greater the role in this component is played by the "location" character. The attribute " location " acts in the same direction as the attribute "age". This process reflects denudation of branches and trunk in the crown due to successive elimination of small shoots. The character "branch" acts in the opposite direction to the variables "location" and "age". The lower a branch is located along the trunk, the more pronounced is the process of dying off of small shoots (having a large value of the attribute " location "). The second component can be called a factor of shoot age in the branch and crown system – a factor of ontogenetic age of a shoot.

It is interesting that for less old trees, the relative contribution of the signs "location", "age" and "branch" to the third component is similar to that for the second component of ontogenetic age described above. In the oldest tree, only the signs "branch" and " location" make the greatest contribution to the third component. Overall, the third component explains from 15% to 19% of the variability. This component can be interpreted as explaining individual internal structural features of crown of each tree.

The fourth principle component in all trees has the maximum contribution of the character "number of lateral shoots". This component can be interpreted as a component of crown density. It explains less than 10% of the variance.

4 Conclusion

Regardless of astronomical age of the studied trees (10-18 years), we identified a group of features, the combination of total contribution of which to the principle components is similar. Such characters are the order of shoot branching, position of a shoot on the maternal two-year shoot system, age of a shoot in the crown, number of a branch from the top of a tree crown. All these variables characterize tree crown structure and are interpreted according to ontogenetic peculiarities of virginal crowns.

Identification, of which constituent units the tree crown is organized from, description of these structures and analysis of their properties in ontogenesis, plays a key role in understanding the organization of complex hierarchical structure of tree organism [6, 7, 8]. Recent work by French researchers shows how by controlling the architecture of a tree in the early stages of its development, it is possible to optimize the productivity of light energy interception [9]. To build a model of tree development, the authors subdivide shoots into vegetative, fruiting and vegetative short shoots. The study shows the dependence of leaf surface area of shoots of different types on whether the tree was bi-axis or single-axis, i.e. on the way the tree crown structure began to develop at the early stage of its formation. Our studies allow us to approach this structure from the position of biennial shoot systems as minimal modular units in which spatial and temporal properties are most rigidly connected [4, 5].

When studying tree crown structure, it is important to understand that anyway plant properties change during its ontogenesis. Each charcteristic that describes the structural features of the crown of a tree is not static and changes naturally over time. This allows to characterize tree crown more accurately, to reveal laws of its formation and development.

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