State assessment of dominant tree layers of oak forests based on quantitative analysis of population strategies

A Kirik¹, T Parakhnevich² and V Popova³

¹Department of Botany and Mycology, Voronezh State University, 1, University sq., 394087 Voronezh, Russian Federation
²Department of Agrochemistry, Soil science and Agroecology, Voronezh State Agrarian University named after Emperor Peter the Great, 1, Michurina Street, 394087 Voronezh, Russian Federation
³Department of Botany and Plant Physiology, Voronezh State University of Forestry and Technologies named after G. F. Morozov, 8, Timiryazeva st., 394087 Voronezh, Russian Federation

E-mail: kirik@bio.vsu.ru

Abstract. The article considers the results of assessing the state of the tree layer of oak forests based on calculating the severity of population strategies of species in the community. The obtained values made it possible to establish how actively the strategy is being implemented in various types of oak forests. The data analysis showed a high degree of correlation with succession processes characteristic of the considered communities, which expands the possibilities of quantitative assessment of forest sustainability. It has been established that the optimal condition of oak forests depends not so much on the presence of such a typical competitor as oak, but on the possibility of growing tree species with other strategies, which allows for a normal generational turn of in the plant community. Very important is the joint growth of trees belonging to all three types of population strategies: competitive - *Quercus robur*, ruderal - *Betula pendula*, *Alnus incana*, elm species; tolerant - *Tilia cordata*, *Acer platanoides* etc. The presence of external influences ensuring the creation of gaps in the tree layer for the development of oak undergrowth and heliophilous species also contributes to the long-term existence of the forest community. It was found that the existence of a relatively stable forest community can be expressed with the following values of degree of severity population strategies of the stand: competitiveness - 50-58, reactivity - 35-44, tolerance - 21-29.

1. Introduction

The basic principles of the doctrine of plant life strategies were stated by L.G. Ramensky at the beginning of the last century [1]. However, the concept considering the direction of development of plant adaptations under conditions of competition in the plant community became widely known thanks to the work of J. Grime [2-4]. Both researchers, independently of each other, described the following types of strategies: competitors (Ramensky violent tapes), stress tolerants (patents), and ruderals (explants). Additionally, J. Grime identified the so-called secondary strategies that occupy intermediate positions between the main types. In the future, the property of plant strategies was considered as the implementation of a genotypic program of species behavior in the community, the results of which, among other things, are manifested in the phytocenotic position of the population. In
2004, a quantitative assessment of the severity of a population tree strategy was proposed [5]. Based on a set of qualitative and quantitative indicators, an integrated assessment was carried out to calculate the total points of competitiveness, the phytocenotic tolerance and reactivity of the representatives of the wood layer of the East European forests.

Broad-leaved forests occupy a significant area on the territory of the East European Plain. Oak forests of the forest-steppe, as one of the types of broad-leaved forests, are formed mainly by the oak *Quercus robur* L., with the accompanying linden heart-shaped *Tilia cordata* Mill., maple *Acer platanoides* L., and ash-tree *Fraxinus excelsior* L. [6].

*Quercus robur* L. populations significantly transform the environment, actively using biotope resources and suppressing competitors. As a result, oak forests have the appearance of relatively homogeneous plant communities, which, in addition to oak, include species with a predominance of stress-tolerant or reactive life strategies. The correlation of trees with different strategies can serve as an important characteristic for assessing the state of an existing community.

The work aim was to establish quantitative indicators of the population strategies of the species that form the oak tree tier and identify the values characteristic of stable, long-standing oak forests.

2. Methods and material

The studies were conducted in 2016-2019 years on the territory of the Voronezh upland oak grove (city line of the city of Voronezh), as well as the Podseka oak grove of the “Galichya Gora” Nature Reserve (Lipetsk Region). Both communities belong to the landscape complex of upland oak forests characteristic of the forest-steppe, but in 2010 the forest almost completely burned out in the reserve, therefore, when conducting a comparative analysis, the data of 2009 collected before the fire were used.

The Voronezh upland oak forest belongs to the oak groves with dominance in herbaceous layer *Carex pilosa-Aegopodium podagraria*, with a predominance of oak specimens belonging to a young, less often middle-generative age stage, characterized by an average standrative density. Dubrava Podseki of the “Galichya Gora” Nature Reserve is a sprout-origin oak forest belongs to the oak groves with dominance of *Aegopodium podagraria* in herbaceous layer, with a high stand density, individuals of a young generative age stage prevail.

The total area of the Voronezh upland oak forest is 7046 hectares. Sample plots were laid on the territory of the Old-Age oak forest of the right-bank district Prigorodnoye forestry with an area of 71.5 hectares. Descriptions were carried out on 11 sites measuring 20x20 m, an area of 0.44 hectares was surveyed. The area of the Podseka oak forest is 37.4 hectares, within which 11 sample plots of 20x20 square meters were laid. Thus, an area of 0.44 ha was researched. Based on the data obtained, stand formulas were compiled, the number of trees of each species was multiplied by the corresponding total score of competitiveness, tolerance and reactivity. The obtained values were summarized and scores for the degree of expression of population strategies in different types of communities were calculated.

The scoring system for population strategies of forest trees in Eastern Europe is presented in table 1. The first results of this work were published in 2004 [7], the assessment system continues to improve as well [8, 9].

In the work process, the need was identified to confirm the conclusions made using additional parameters. Stem diameter at 1.3 m height (dbh) is a mark, the increase of which (along with age) is a good indicator of the degree of the severity the competitiveness strategy. The number of shrub species and the abundance of herbaceous plants of the nemoral group are characteristics that confirm the implementation of the environment-transforming activity of the oak population. For convenience, these indicators were reduced to normalized values (from 0 - the minimum to 1 - the maximum) and summed up. The normalized values were calculated by the formula [7]:

$$N = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$
Table 1. Total points of competitiveness, tolerance and reactivity of some tree species [7].

| Species                        | Competitiveness (C) | Stress-tolerance (S) | Reactivity (R) |
|-------------------------------|---------------------|----------------------|----------------|
| Quercus robur L.              | 10.05               | 0.94                 | 4.08           |
| Fraxinus excelsior L.         | 5.61                | 4.03                 | 4.42           |
| Pinus sylvestris L.           | 5.25                | 1.11                 | 6.28           |
| Acer platanoides L.           | 3.48                | 3.82                 | 3.42           |
| Tilia cordata Mill.           | 3.24                | 3.83                 | 4.08           |
| Betula pendula Roth           | 2.89                | 0.45                 | 8.23           |
| Populus tremula L.            | 2.69                | 0.65                 | 9.57           |
| Acer campestre L.             | 2.19                | 3.89                 | 2.83           |

3. Calculations, results and discussion

The results of studies at test sites are presented in Table 2.

Table 2. Forest stand formulas* and population strategy scores at test sites of the studied oak forests.

| Voronezh upland oak forest | Oak forest in Natural Reserve “Galichya Gora” |
|----------------------------|-----------------------------------------------|
| Sample plot                | Forest stand formulas | C | R | S | Sample plot | Forest stand formulas | C | R | S |
| C1                         | 4Q4T1Ap1Ac            | 58 | 38 | 26 | Pd1         | 5Q5B                   | 64 | 61 | 6 |
| C2                         | 2T8Ap                | 13 | 35 | 38 | Pd 2        | 5Q4B1Ap               | 65 | 56 | 10 |
| C3                         | 6Q3T1Ap              | 73 | 40 | 20 | Pd 3        | 7Q2B1Pt               | 78 | 54 | 8 |
| C4                         | 3Q6T1Ap              | 53 | 40 | 29 | Pd 4        | 9Q1B                   | 93 | 44 | 8 |
| P5                         | 1Q2T3Ap4F            | 49 | 40 | 36 | Pd 5        | 7Q3Ap                  | 80 | 38 | 18 |
| P6                         | 3T4Ap3F              | 40 | 39 | 38 | Pd 6        | 4Q6B                   | 57 | 65 | 6 |
| P7                         | 3Q4T3Ap              | 53 | 38 | 29 | Pd 7        | 6Q3Ap1At              | 71 | 37 | 20 |
| O8                         | 9Q1B                 | 93 | 44 | 8  | Pd 8        | 3Q2B4Ap1At            | 50 | 44 | 21 |
| O9                         | 3Q7B                 | 50 | 69 | 5  | Pd 9        | 6Q4Ap                 | 74 | 38 | 20 |
| O10                        | 9Q1B                 | 93 | 44 | 8  | Pd 10       | 4Q5Ap1At              | 58 | 35 | 25 |
| O11                        | 2Q2T1Ap5Pt           | 46 | 77 | 17 | Pd 11       | 4Q6B                  | 57 | 65 | 6 |

*Legend: Ac – Acer campestre L.
Ap – Acer platanoides L.
At – Acer tataricum L.
B – Betula pendula Roth
F – Fraxinus excelsior L.
Pt – Populus tremula L.
T – Tilia cordata Mill.
Q – Quercus robur L.

For the values obtained within the Voronezh upland oak grove, it was found that the highest competitive points were set for sites No. O8 and O10 (93.34 has a value on both). The smallest values for this parameter are characteristic for site No. C2 (13.24) due to the absence of individuals of the oak on it. The maximum values for the reactivity parameter are sites No. O9 and O11 (69.85 and 77.16 points). It is worth noting that both sites are located on the territory of the Olympic sports and fitness complex, which is probably due to the relatively high degree of disturbance of the territory. Minimum
reactivity values lying below the mid-range region have not been established (which may indicate the presence of a constant external load), however, the smallest reactivity values relate to sites C1, C2, P7. The site C2 is characterized by a minimal degree of severity of the strategy of both reactivity and competitiveness. This situation has arisen due to the replacement of competitive oak with more stress-tolerant lindens and maples and the simultaneous suppression of the activity of potential species with high reactivity. This can be interpreted as a situation of smooth rather than abrupt replacement of the edifier of the tree layer, i.e. replacements without forming a renewal gap. This is also confirmed by the maximum stress tolerance scores at the same site (38.22). High reactivity indicators combined with low stress tolerance at the O9 site indicate the presence of a renewal window here, which arose as a result of a strong violation of the integrity of the tree layer. In the event of the disappearance of the factor that formed this window, recovery processes may begin here.

On the territory of the overgrown oak grove of the “Galichya Gora” Nature Reserve, competitiveness values do not fall below 50 conventional points, reaching 93 at the Pd4 site. This is a consequence of the high density of the stand and the almost complete absence of renewal windows. Moreover, due to the strong suppression of oak by its competitors, stress tolerance is also small. Complete deforestation that took place before this territory was included in the reserve manifests itself in fairly high reactivity values.

Thus, the obtained values confirm the results of visual observations with a rather high degree of accuracy. With the correct interpretation of quantitative indicators of the degree of severity of strategies of tree species, it is possible to accurately assess the current state of oak groves, predict the intensity of further succession processes and the possibility of restoration of forest communities.

However, as it turned out during the research, the main problem is precisely the correct explanation of the results. Initially, the assumption was made that the main “guarantee” for the stable existence of oak groves is the maximum competitiveness score, which is provided by a large number of oak individuals. The values of stress tolerance and reactivity were supposed to be more important for disturbed communities.

According to the literature, in a historical retrospective, violations had a significant impact on the formation of modern broad-leaved forests. So, in the article D.L. Shumway, M.D. Abrams, Ch.M. Ruffner [10] hypothesized that oak forests developed and were maintained as a result of periodic low-intensity fires of the degree of disturbance [11, 12]. The sources of ignition of the eastern forests of the United States included lightning, indigenous activities, land use of migrants from Europe, intensive felling for construction and coal mining for metallurgy [13]. Periodic fires in conjunction with logging made it possible to gain a foothold in relation to fire-resistant oak species [14]. The indirect evidence is the observation that late succession fire-resistant species easily invade and show increasing dominance in many upland oak forests, where fires were suppressed during the twentieth century [15]. The data of paleoecological analysis were also given, according to which the beech-maple forests were replaced by pine-oak forests in a certain area during the residence of the Iroquois tribes there, who conducted agriculture using fire and fires [16]. In addition, repeated disturbances (including fires) at various sites in Massachusetts are associated with the suppression of northern hardwoods and the introduction of oak, pine and chestnut during the last millennium [17].

According to the studied literature data, in old-age communities, the oak replacement with more tolerant species takes place, which led to the need to lead additional research. To do this, the community was assessed by additional parameters: the diameter of the trunks of the petiolate oak, the number of shrub species, and the abundance of non-moral groups in the grass layer. These parameters were selected as potential markers of stable oak grove with clear numerical indicators. For convenience, these indicators were reduced to normalized values and summarized (table 3).
Table 3. Additional parameters for assessing the stability of the Voronezh upland oak grove.

| Sample plots | Stem diameter at 1.3 m height (dbh) | Normalized diameter score | The number of species in the shrub layer | Normalized scrub tier score | The abundance of the nemoral group | Normalized abundance score | Total score |
|--------------|------------------------------------|---------------------------|----------------------------------------|-----------------------------|---------------------------------|---------------------------|-------------|
| C1           | 42.83                              | 0.70                      | 3                                      | 0.5                         | 3.5                             | 1                         | 2.20        |
| C2           | -                                  | 0.00                      | 3                                      | 0.5                         | 2.6                             | 0.55                      | 1.05        |
| C3           | 31.95                              | 0.16                      | 3                                      | 0.5                         | 3                               | 0.75                      | 1.41        |
| C4           | 48.73                              | 1.00                      | 5                                      | 1                           | 2.3                             | 0.4                       | 2.40        |
| P5           | 39.49                              | 0.54                      | 1                                      | 0                           | 3                               | 0.75                      | 1.29        |
| P6           | -                                  | 0.00                      | 4                                      | 0.75                        | 1.5                             | 0                         | 0.75        |
| P7           | 28.82                              | 0.00                      | 4                                      | 0.75                        | 3                               | 0.75                      | 1.50        |
| O8           | 40.89                              | 0.61                      | 3                                      | 0.5                         | 1.86                            | 0.18                      | 1.29        |
| O10          | 36.68                              | 0.39                      | 3                                      | 0.5                         | 1.625                           | 0.0625                    | 0.96        |
| O11          | 42.2                               | 0.67                      | 4                                      | 0.75                        | 3                               | 0.75                      | 2.17        |

Based on the calculation results, trial plots were selected, the total score of which exceeded the sum of the average and standard deviation (Trial areas C1 and C4: 2.20 and 2.40 points, respectively). The ratio of population strategies at these sites was taken as optimal: competitiveness score of about 50-60, reactivity ~ 40 points, stress tolerance ~ 20-30 points.

To verify this assumption, additional studies were carried out, and, for comparison, the oak grove of the “Galichya Gora” reserve was taken. At the same time, a model of community recovery after severe damage was considered.

The indicators of population strategies reflect well the state of the community in the form of a growth of oak groves with an inferior ontogenetic and age composition. The forest stand was formed mainly by the oak, i.e. Most sites have a high average competitive score. The disturbance of the community is indicated by the frequent presence of warty birch, which creates the basic values of the reactivity strategy score. Among the trial plots, those were selected whose scores for population strategies fit as much as possible into the derived optimal ratio. The site numbers and scores obtained are shown in table 4.

Table 4. Sample plots with optimal strategy indicators in the Voronezh upland oak forest and Podseka oak forest of the “Galichya Gora” reserve.

| Sample plot | C strategy | R strategy | S strategy |
|-------------|------------|------------|------------|
| C1          | 58         | 38         | 26         |
| C4          | 53         | 40         | 29         |
| Pd 8        | 50         | 44         | 21         |
| Pd10        | 58         | 35         | 25         |

It is worth noting that within the borders of the oak grove of Morozova mountain these points are provided by the following stand formulas: 3Q2B4Ap1At and 4Q5Ap1At. In comparison with the formulas of other sample areas, these descriptions show a wider variety of species that fold the tree layer.
4. Conclusion
As a result of the studies, it was found that for the existence of a relatively stable forest community with the participation of pedunculate oak, several conditions must be met:

1. A constant turn of tree generations related to all three types of population strategies: (C - pedunculate oak, common ash, ordinary pine, spruce; R - trembling poplar, warty birch, gray alder, elm species; S - heart-shaped linden, Norway maple etc.), and the corresponding age and ontogenetic completeness of populations. The sustainable existence of the community is possible if there are species with significant competitiveness: pedunculate oak, common ash, and temporary tolerant substitutes for oak (heart-shaped linden, maple, etc.);

2. The presence of external influences, ensuring the creation in the tree layer of windows for the development of oak undergrowth and photophilous species.

All two conditions can be satisfied with the following severity of population strategies of the stand: competitiveness - 50-58, reactivity - 35-44, tolerance - 21-29.

References
[1] Ramensky L G 1930 Zur Methodik der vergleichenden Bearbeitung und Ordnung von Pflanzenlisten und anderen Objekten, die durch mehrere, verschiedenartig wirkende Faktoren bestimmt werden Beiträge zur Biologie der Pflanzen J 18 269–304
[2] Grime J P 1974 Vegetation classification by reference to strategies Nature 250 26–31 doi: 10.1038/250026a0
[3] Grime J P 1977 Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory The American Naturalist 111 (982) 1169–1194 doi: 10.1086/283244
[4] Grime J P 1979 Plant strategies and vegetation processes (New York) p 222
[5] Smirnova O V 2004 Vostochnoevropejskie lesa: istorija v golocene i sovremennost (ed.) (Moscow: Nauka) part 1 p 479
[6] Smirnova O V, Bodrovsy M V and Khanina L G 2017 European Russian forests: Their Current State and Features of Their History (Springer) vol 15 p 566 doi: 10.1007/978-94-024-1172-0
[7] Evstigneev O I 2004 Populyacionnye strategii vidov derev’ev Vostochnoevropejskie lesa: istorija v golocene i sovremennost (Moscow: Nauka) chapter 3.3 vol 1 pp 176-205
[8] Evstigneev O I 2018 Ontogenetic scales of relation of trees to light (on the example of eastern european forests) Russian Journal of Ecosystem Ecology 3(3) 1–18 doi: 10.21685/2500-0578-2018-3-3
[9] Evstigneev O I and Korotkova N V 2019 Features of undergrowth development in eastern European forests Russian Journal of Ecosystem Ecology 4(2) 1–23 doi: 10.21685/2500-0578-2019-2-3
[10] Shumway D L, Abrams M D and Ruffner C M 2001 A 400-year history of fire and oak recruitment in an old-growth oak forest in western Maryland Canadian Journal of Forest Research 31 1437–1443
[11] Lourimer C G 1985 The role of fire in the perpetuation of oak forests Challenges in oak management and utilization (Madison) 8–25
[12] Abrams M D 1992 Fire and development of oak forests Bio-Science 42 342–353
[13] Abrams M D and Nowacki C G 1992 Historical variation in fire oak recruitment, and post-logging accelerated succession in central Pennsylvania Bull. Torrey Bot. Club 199 19–28
[14] Abrams M D 1996 Distribution, historical development, and ecophysiological attributes of oak species in the eastern United States Ann. Sci. For. 53 487–512
[15] Lourimer C G 1984 Development and red maple understory in northeastern oak forests Forest Sci. 3 3–22
[16] Clark J S and Royall P D 1995 Transformation of a northern hardwood forest by aboriginal (Iroquois) fire: charcoal evidence from Crawford lake, Ontario, Canada The Holocene 5 1–9
doi: 10.1177/095968369500500101

[17] Foster D R and Zebryk T M 1993 Long-term vegetation dynamics and disturbance history of a Tsuga-dominated forest in New England *Ecology* 74 982–998