Syntaxonomy of the xero-mesophytic oak forests in the Republic of Tatarstan (Eastern Europe)

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Abstract

Aims: To develop a syntaxonomic classification of the xero-mesophytic broad-leaved oak forests of the Republic of Tatarstan with a preliminary analysis of their unique ecological features. Study area: The Republic of Tatarstan (European part of the Russian Federation). Methods: A total of 91 relevés were processed. Most of them (73.6%) were sampled in Tatarstan during 2016 and 2017, the remaining ones (26.4%) were historical published data. They were classified by means of a modified TWINSPAN algorithm using total inertia as a heterogeneity measure. Diagnostic, constant, and dominant species were identified using analytical tools in the JUICE 7.0 program. Results: The xero-mesophytic forests of the study area were assigned to four clusters. We describe two of them as new associations: Astragalo ciceri-Quercetum roboris ass. nova and Sanguisorbo officinalis-Quercetum roboris ass. nova. We classify them within the class Quercetea pubescentis. Conclusions: Our study is the first attempt to classify thermophilous and xero-mesophytic oak forests of the Republic of Tatarstan using the Braun-Blanquet system.

Taxonomic reference: Czerepanov (1995).

Syntaxonomic reference: Mucina et al. (2016) unless stated otherwise in the text.

Abbreviations: GIVD = Global Index of Vegetation-Plot Databases; NMDS = Non-metric multidimensional scaling.

Keywords

Aceri tatarici-Quercion, Lathyro pisiformis-Quercion, oak forest, Quercetalia pubescenti-petraeae, Quercetea pubescentis, Republic of Tatarstan, xero-mesophytic forest

Introduction

The xero-mesophytic broad-leaved forests of the Republic of Tatarstan (hereafter referred to as Tatarstan) are of interest for several reasons. These forests are characterized by high biodiversity and host many rare and protected plant species. Quercus robur, a canopy-forming tree species of these ecological communities, is found here near the northeastern boundary of its native range (Gorchakovskij 1968). The communities of this type form an ecotone between forest and steppe, which has long attracted researchers, starting with the works of Korzhinsky (1888) and Markov (1935).

Xero-mesophytic broad-leaved forests occupy a large area within the forest-steppe zone of Central and Eastern Europe. Communities of this type occur eastward as a gradually tapering belt that extends to the following territories of Eastern Europe: Ukraine (Goncharenko 2003; Onyshchenko et al. 2007; Solomakha 2008; Semenishchenkov and Panchenko 2012; Panchenko 2013); Crimea (Korzhenevskij et al. 2003); the regions of Bryansk (Bulokhov and Solomeshch 2003), Kursk, Tula, Belgorod (Semenishchenkov and Poluyanov 2014), Voronezh, Tambov, Penza, Saratov, Samara, and Ulyanovsk (Blagoveshchenskij 2005); the Republics of Mordovia, Chuvashia, Tatar-
stan (Markov 1935), and Bashkortostan (Yamalov et al. 2004); and the Orenburg region.

Until recently, the classification of plant communities of Tatarstan has been performed using the dominance approach (Rogova and Shajhutdinova 2000; Pozdnyak 2005). The syntaxonomic position of the xero-mesophytic oak forests of Tatarstan in the Braun-Blanquet system is still unclear.

The westerly distributed analogues have been attributed to the alliance Aceri tatarici-Quercion (Semenishchenkov and Poluyanov 2014) and the eastern analogues to the alliance Lathyro pisiformis-Quercion roboris (Yamalov et al. 2004; Willner et al. 2016). However, Semenishchenkov and Panchenko (2012) suggested that some associations previously assigned to the Aceri tatarici-Quercion should be classified in the Quercion petraeae. They also pointed out that the xero-mesophytic oak forests of Tatarstan are distinct from both of the aforementioned alliances. In a recent revision of the thermophilous oak forests of the steppe and forest-steppe zones of Ukraine and Russia, Goncharenko et al. (2020) described the eastern part of the Aceri tatarici-Quercion as a new alliance Scutellario altissimae-Quercion roboris and the eastern part of the Quercion petraeae as Betonio officinalis-Quercion roboris.

The aim of this article is to address the following research questions: 1. Are there communities in Tatarstan that may be assigned to the order Quercetalia pubescenti-petraeae? 2. To which lower-level syntaxa can they be assigned? 3. What are the compositional, ecological, and chorological characteristics of these syntaxa?

**Study area**

The Republic of Tatarstan is located in the eastern part of the East European Plain at the confluence of the largest European river Volga with the rivers Kama and Belaya (Figure 1). The northwesternmost point is approximately 56.67°N, 047.26°E, the southeasternmost one 53.97°N, 054.27°E. The total area is 67,600 km². The territory is divided by the rivers into clearly separated natural and geographical parts: Cis-Volga region (west and south of the Volga valley), Cis-Kama region (north of the Kama and Volga valleys), Trans-Kama region (south of the Kama valley) (Butakov 1994).

Large uplands alternate with lowland areas across the study area. The lowest elevation in the territory is along the line of the Kuibyshev Reservoir with an average of 53 m, while the maximum elevation of 380 m is reached in the south-east of the study area (Butakov 1994). Being located within the Sarmatian mixed forests and the East European forest-steppe (Dinerstein et al. 2017), the study area has high biodiversity, particularly regarding its vegetation cover (Bakin et al. 2000). The heterogeneity of site conditions due to climatic and soil characteristics, as well as the long-term human impact on vegetation (Bakin et al. 2000), has determined the complexity and diversity of the vegetation cover. The territory is comprised of 18% forests, 21.5% grasslands and 6% water bodies (Shadrikov 2019). The remaining 54.5% of the territory is agricultural and urban land. Young forest stands prevail in the forest vegetation (secondary birch, aspen, and lime coppice), whereas the ancient forests...
are small and fragmented. Steppe communities occupy very small territories. They are represented by meadow steppes along the edges of deciduous forests and gentle slopes. The steep slopes of southern exposure in the southeastern part of the Tatarstan are occupied by xerophytic steppes (Bakin et al. 2000).

Methods

Vegetation data

All relevés of the oak forests of Tatarstan were previously classified and analyzed to exclude hygrophytic and mesophytic communities (Kozhevnikova et al. 2018). For the present study, a total of 91 relevés of xero-mesophytic oak forests were compiled from the study area. The majority of relevés (n = 67), was sampled in the field during the field seasons of 2016 and 2017, with the aim of investigating the communities of thermophilous oak forests following the construction of a model of their potential distribution (Kozhevnikova et al. 2019). Further 24 relevés were historical data retrieved from the literature (Markov 1935).

The newly collected relevés were sampled using the standard phytosociological methodology (Dengler et al. 2008). In most cases, the plot size was 400 m². For each vegetation plot, all vascular plant species were recorded with indications of their layer and abundance based on the Drude scale (Drude 1896). In addition, the geographical coordinates, altitude, exposition, and slope were recorded for each relevé.

The published relevés of Markov (1935) include information on all species of vascular plants, their abundance on the Drude scale and the geographical position, which we georeferenced with an accuracy of 200 m.

To compare the newly sampled relevés with the previously described associations, we used published relevés assigned to the Aceri tatarici-Quercion from the Belgorod and Kursk regions (Semenishchenkov et al. 2013; Semenishchenkov and Poluyanov 2014): Chamaecytiso ruthenici-Quercetum roboris Semenishchenkov et al. 2014, Pyro pyrastris-Quercetum roboris Semenishchenkov et al. 2014, Vicio pisiformis-Quercetum roboris Semenishchenkov et al. 2014, Lathyro nigri-Quercetum roboris Bulokhov et Solomeshch 2003. We also analyzed the published relevés of the Lathyro pisiformis-Quercion roboris from Southern Urals (Gorchakovskij 1972; Schubert et al. 1979; Solomeshch et al. 1989; Martynenko et al. 2005, 2008): Filipendulo vulgaris-Quercetum roboris Martynenko et al. 2008, Omphalodo scorpoidis-Quercetum roboris Martynenko et al. 2008, Brachypodio pinnati-Quercetum roboris Grigorjew in Solomeshch et al. 1989, Aconogono alpini-Quercetum roboris Gorchakovskij ex Solomeshch et al. 1989, Calamagrostio epigei-Quercetum roboris Gorchakovskij ex Solomeshch et al. 1989, Carici macrourae-Quercetum roboris Gorchakovskij ex Solomeshch et al. 1989, Pruno-Quercetum roboris Solomeshch et al. 1989, Bistorto majoris-Quercetum roboris Martynenko et Zhigunov, 2005. All processed relevés are included in the information system “Flora” (Rogova et al. 2010), which contains data from Tatarstan (Prokhorov et al. 2017) and adjacent territories.

Analysis

The relevés of xero-mesophytic communities were exported from the information system “Flora” with simultaneous translation of the Drude abundance grades into cover percentage (soc – 95%, cop – 75%, cop – 50%, cop – 25%, sp – 3%, sol – 2%, un – 0.5%). This file was then imported into the JUICE 7.0 program (Tichý 2002) with the transformation of cover percentage into the Braun-Blanquet scale. The relevés were classified by applying the modified TWINSPAN algorithm (Roleček et al. 2009). For optimizing the number of clusters, the procedure OptimClass proposed by Tichy et al. (2010) was used. The resulting clusters were analyzed by calculating the species frequency and by identifying diagnostic, constant and dominant species. The following threshold values were used: for diagnostic species, a phi value > 0.6, for constant species, a frequency > 60%, and for dominant species, average cover > 80%.

The resulting clusters were compared with the aforementioned associations of the alliances Aceri tatarici-Quercion and Lathyro pisiformis-Quercion by combining them into a single constancy table. For all vegetation units, the frequency sum of diagnostic species of the following syntaxa was calculated: Lathyro pisiformis-Quercion roboris, Betonio officinalis-Quercion roboris, and Scutellario altissimae-Quercion roboris. Diagnostic species follow Goncharenko et al. (2020).

The names of classes, orders and alliances follow Mucina et al. (2016), except for those newly described in Goncharenko et al. (2020). The newly described associations follow the ICPN, 4th edition (Theurillat et al. 2021). Biogeographic characteristics of the species are given according to Bakin et al. (2000).

The TWINSPAN clusters were compared with the other associations by calculating a distance matrix. As a distance metric we used 1 – Jaccard coefficient following the recommendations of Legendre and De Cáceres (2013). As vectors for paired comparison, we used the species list of each group and the frequency of the species. The results are visualized using a “heat map” combined with a dendrogram, which is computed by complete-linkage clustering method. We also used non-metric multidimensional scaling (NMDS) as a “dimensional reduction” method (Kraemer et al. 2018).

Results

TWINSPAN classification

The OptimClass procedure resulted in four clusters (Table 1, Suppl. material 1).
Cluster 1 contained five relevés located at the single site on the high and steep slope of the Volga terrace. Species identified as diagnostic for this cluster included ruderal and meadow plants (Asparagus officinalis, Crepis tectorum, Melandrium album, Phleum phleoides, Polygonatum odoratum, Rumex acetosella, Tanacetum vulgare), which indicates the derivative nature of these communities.

Cluster 2 also contained a small number of relevés (seven) and a mixture of ruderal, meadow and shade-tolerant nemoral species as diagnostic (Fragaria vesca, Glechoma hederacea, Tilia cordata, Trifolium hybridum, Veronica chamaedrys).

Cluster 3 contained 37 geographically widespread plots, which indicates a regular occurrence of this community type. Only one species was identified as diagnostic – Laser trilobum. When the phi value threshold was decreased from 0.6 to 0.3, Astragalus cicer, Adonis vernalis, Campanula rapunculoides, and Xanthoselimum alsaticum also became diagnostic.

Cluster 4 contained 42 relevés. Diagnostic species included forest, forest-meadow and steppe plants (Adenophora lilifolia, Aegopodium podagraria, Crepis sibirica, Dactylis glomerata, Euphorbia sempervillosa, Geranium sylvaticum, Heracleum sibiricum, Lathyrus vernus, Pteridium aquilinum, Pulmonaria mollis, Rubus saxatilis, Sanguisorba officinalis, Viola mirabilis).

In the following, we describe clusters 3 and 4 as new associations. We refrain from describing clusters 1 and 2 formally as new syntaxa because of the small number of relevés and their presumable derivative nature.

**Description of new syntaxa**

*Astragalo ciceri-Quercetum roboris* ass. nova

Diagnostic species: Adonis vernalis, Astragalus cicer, Campanula rapunculoides, Laser trilobum, Xanthoselimum alsaticum.

Geographical range: Communities assigned to this association are found in the southeast of Tatarstan, Cis-Volga region, and the western part of Tatarstan. The most typical of these communities were described from the Central Cis-Volga region, Kamskoe Uste and Apastovo districts (a distribution map and a photo of the community are provided in Suppl. material 3).

Floristic composition: These communities represent a sparse open forest. The first tree layer is dominated exclusively by Quercus robur, which also occurs in the shrub layer. In the second tree layer, Betula pendula, Tilia cordata and Sorbus aucuparia are found along with oak. The shrub layer is not dense and mainly consists of Euonymus verrucosa, Corylus avellana, Rhamnus cathartica, Sorbus aucuparia, and Lonicera xylosteum. The proportion of shrubs in these communities increases if there are signs of fire impacts. In case of intensive grazing, the undergrowth density is reduced, and the proportion of herbs increases. The floristic composition is homogeneous; only 94 plant species were recorded at the 37 plots of this association (with most commonly 20–30 species per plot). The composition of dominant species is determined by quite high light availability. Among the dominant species, Brachypodium pinnatum, Carex muricata, Fragaria viridis and Laser trilobum prevail.

Habitat characteristics: These communities grow on the middle parts of gentle (5–15°) slopes of southwestern exposure at altitudes less than 150 m a.s.l. The flat surfaces adjacent to the tops of these slopes are usually plowed up or, more rarely, occupied by meadow steppes with a large number of grasses (including Stipa species) and legumes. The lower parts of the slopes are most often occupied by a strip of shrubby vegetation with Cerasus fruticosus, Genista tincoria and Spiraea species. The soils are generally rich in nutrients. The parent rocks are characterized by high content of calcium.

**Typus relevé:**

Database ID 13,119
20 Jul 2016; Kuralovo; 55.65813°N, 048.77161°E; 97 m; plot size 400 m²; species richness: 45.

Tree layer: Quercus robur 3; shrub layer: Euonymus verrucosa r, Corylus avellana r, Prunus spinosa r, Rhamnus cathartica r, Sorbus aucuparia r, Lonicera xylosteum r; herb layer: Laser trilobum 4, Brachypodium pinnatum 3, Vincetoxicum hirundinaria r, Galium mollugo r, Rumex acetosella r, Crepis praemorsa r, Medicago falcata r, Pimpinella saxifraga r, Pyrethrum corymbosum r, Carex rhizina r, Viola collina r, Campanula rapunculoides r, Geranium sanguineum r, Carex tomentosa r, Poa angustifolia r, Brachypodium pinnatum r, Silene nutans r, Campanula persicifolia r, Asarum europaeum r, Convallaria majalis r, Viola mirabilis r, Vicia pisiformis r, Rubus saxatilis r, Cichorium intybus r, Picris hieracioides r, Trifolium medium r, Viola tenuifolia r, Inula salicina r, Serratula coronata r, Centaurea scabiosa r.

*Sanguisorbo officinalis-Quercetum roboris* ass. nova

Diagnostic species: Adenophora lilifolia, Heracleum sibiricum, Pulmonaria mollis, Sanguisorba officinalis.

Geographical range: The communities assigned to this association occur in the southeast of Tatarstan, within the western slope of the Bugulma-Belebey Upland at the territories of the Bugulma, Leninogorsk, Bavlly, Aznakayev and Almetevsk districts of Tatarstan (a distribution map and photos of the community are provided in Suppl. material 3).

Floristic composition: The communities are characterized by an extremely high species diversity. The total number of species is 293, while the average number of species per relevé is 50. In the tree layer, Betula pendula, Prunus sylvestris, Populus tremula, Tilia cordata and Ulmus glabra are found in addition to the dominant Quercus robur. Trees are distributed unevenly within the plots: some of them grow close to each other, while others are separated and form open areas (meadows) with sparse tree stands. In the meadow areas, heliophytes are abundant. The shrub layer is not dense, being characterized by high species diversity (total number of species 21) without any clear dominance among them. The most abundant species
is Euonymus verrucosa. The herb layer is multilayered, polydominated, with tall forest-steppe herbs (Campanula trachelium, Euphorbia semivillosa, Heracleum sibiricum, Lilium pilosiusculum and Pleurospermum uralese). Habitat characteristics: In Tatarstan, the communities of this type occur at altitudes of 250–300 m a.s.l. They occupy areas near the water divide and middle parts of the gentle (up to 5°) slopes of mostly southeastern exposure. The soils are leached and typical chernozems. The parent material can be Permian bed rocks, Permian eluvial clays and loams, deluvial deposits on the gentle slopes, and post-Pliocene loess-like loams.

Types relevé:
Database ID 13,057
21 May 2016; Leninogorsk district, near Tuktaro-Urdula village; 54.39278°N, 052.15631°E; 262 m a.s.l.; plot size 400 m²; species richness: 43.

Tree layer: Quercus robur 3, Betula pendula 1, Acer platanoides 1; shrub layer: Acer platanoides 1, Padus avium +, Populus tremula +, Sorbus aucuparia +, Ulmus laevis +; herb layer: Calamagrostis arundinacea 2, Carex montana 1, Adenophora lilifolia +, Aegopodium podagraria +, Angelica sylvestris +, Campanula persicifolia +, Carex rhizina +, Centaurea pseudophygia +, Convallaria majalis +, Crepis sibirica +, Dracocephalum ruyschiana +, Euphorbia semivillosa +, Filipendula vulgaris +, Galium boreale +, Galium tinctorum +, Geranium sylvaticum +, Heracleum sibiricum +, Lathyrus pustformis +, Lathyrus vernus +, Lilium pilosiusculum +, Phlomoides tuberosa +, Poa pratensis +, Pteridium aquilinum +, Pulmonaria mollis +, Pyrethrum corymbosum +, Quercus robur +, Rubus saxatilis +, Sanguisorba officinalis +, Serratula coronata +, Silene nutans +, Stellaria holostea +, Thesium ebracteatum +, Trommsdorffia maculata +, Veronica chamaedrys +, Vicia tenuifolia +, Viola mirabilis +.

Comparison with associations in other regions

The comparison of the identified syntaxa and previously described associations of the Lathyrus pustformis-Quercion and Aceri tatarici-Quercion (sensu lato) are given in Table 1. The analysis of the table reveals significant differences in both floristic composition and combinations of characteristic species between identified syntaxa and previously described associations.

| Cluster/association | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| Number of relevés   | 5 | 7 | 37 | 42 | 23 | 6 | 54 | 5 | 10 | 9 | 14 | 7 | 17 | 24 | 18 | 10 |
| Tree layer 1:       |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Quercus robur (BQ, SQ, LQ) | 100 | 100 | 100 | 93 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Tilia cordata       | 20 | 86 | 7 | 17 | 80 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Betula pendula      |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Acer platanoides    |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Ulmus glabra        |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Populus tremula     |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Pinus sylvestris    |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Rubus idaeus        |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sorbus aucuparia    |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Abies sibirica      |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Tree layer 2:       |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Quercus robur (BQ, SQ, LQ) |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Betula pendula      |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sorbus aucuparia    |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Padus avium        |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Malus sylvestris    |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Shrub layer:        |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Rosa majalis (LQ)   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Caragana frutex (LQ) |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Chamaecytisus ruthenicus (BQ) |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Ceratocystis fruticosa (SQ) | 60 | 29 | 46 | 17 | 65 |   |   |    |    |    |    |    |    |    |    |    |
| Acer tataricum (SQ) |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Prunus spinosa (SQ) |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Quercus robur (BQ, SQ, LQ) | 20 | 71 | 43 | 38 | 78 | 83 | 22 |   |    |    |    |    |    |    |    |    |
| Sorbus aucuparia    |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Euonymus verrucosa  | 60 | 100 | 76 | 24 | 83 |   |   |    |    |    |    |    |    |    |    |    |
| Acer platanoides    | 40 | 43 | 32 | 40 | 22 | 22 |   |   |    |    |    |    |    |    |    |    |
| Rubus idaeus        |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Rhamnus cathartica  |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Tilia cordata      | 13 | 33 | 22 | 60 | 100 | 44 |   |   |    |    |    |    |    |    |    |    |
| Padus avium        | 43 | 8 | 7 | 43 |   |   |    |    |    |    |    |    |    |    |    |    |
| Viburnum opulus     | 12 | 11 |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Cluster/association | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15  | 16 |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|
| Malus sylvestris     | 14 |    |    |    |    |    |    |    |    |    |    |    |    |    | 20  |    |
| Lonicera xylosteum   | 14 | 5  |    |    |    |    |    |    |    |    |    |    |    |    | 20  |    |
| Acer campestre       |    |    |    |    |    |    |    |    |    |    |    |    |    | 4  | 90  |    |
| Euonymus europaeus   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 90  |    |
| Pyrus pyraster       |    |    |    |    |    |    |    |    |    |    |    |    |    | 29 | 50  |    |
| Ulna macrocarpa      | 5  | 22 |    |    |    |    |    |    |    |    |    |    |    |    | 50  |    |
| Cornus sericea       | 59 | 7  |    |    |    |    |    |    |    |    |    |    |    |    | 50  |    |
| Frangula alnius      | 3  | 2  |    |    |    |    |    |    |    |    |    |    |    |    | 50  |    |
| Fraxinus excelsior    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 50  |    |
| Ulmus laevis         | 43 | 5  |    |    |    |    |    |    |    |    |    |    |    |    | 50  |    |

**Herb layer:**

- *Brachypodium pinnatum* LQ 86 51 48 87 93 60 100 56 79 43 33
- *Heracleum minus* (LQ) 16 62 65 60 70 100 71 17
- *Lathyrus pratensis* (LQ) 46 55 70 80 90 22 43
- *Phleum pratense* (SQ) 20 29 57 55 74 10 58
- *Pyrethrum cynosboscum* 29 81 88 91 13
- *Pleuropermum useulense* (LQ) 3 31 13 80 90 33
- *Senecio lycopersicum* (LQ) 20 14 19 78 10 44 14
- *Geranium sylvaticum* (LQ) 14 74 22 60 40 22 14
- *Lathyrus clymeni* (LQ) 14 5 30 67
- *Carex maxima* (LQ) 100
- *Lathyrus litvinovii* (LQ) 61
- *Cerastium fontanum* (SQ) 20 8 5
- *Origanum vulgare* (BQ) 100 57 24 43 96 100 59 10 65 86 53 17
- *Veronica chamaedrys* (BQ) 100 11 52 30 26 33 14 76 58 78 90
- *Campanula persicifolia* (BQ) 20 5 36 52 37 14 14 35 83 72
- *Digitalis grandiflora* (BQ, LQ) 2 52 60 90 78 71
- *Viola hirta* (BQ) 20 3 17 65 20 30 78 8
- *Vincetoxicum hircundorum* (BQ) 80 27 12 44 18 21 60
- *Melampyrum nemorosum* (BQ) 100
- *Campanula bononiensis* 40 17 43
- *Chamaecytisus rathenius* (BQ) 40 2 15 43
- *Trifolium alpestre* (BQ) 21
- *Securigera varia* (BQ) 2
- *Allium oleraceum* (BQ) 46
- *Tussilago farfara* (BQ) 3 2 22 11
- *Serratula tinctoria* (BQ) 8
- *Potentilla alba* (BQ) 21
- *Vicia pannonica* (SQ) 41 2
- *Euphorbia nemorosa* (SQ) 38 64 11
- *Crataegus rhodophylla* (SQ) 100
- *Acer tataricum* (SQ) 79 10
- *Anemone nemorosa* (BQ) 40 8
- *Vicia sepium* (BQ, LQ) 29 3 40 26 39 60 50 56 14 29 41 27
- *Betonica officinalis* (BQ) 20 14 19 60 52 10 50 57 63 40
- *Quercus robur* (BQ, SQ, LQ) 14 13 43
- *Lathyrus vernus* 14 8 79 78 83 87 80 100 100 100 100 34 65 4 50 20
- *Poas nemoralis* 40 43 11 12 70 63 40 100 56 57 100 58 83 100
- *Calamagrostis arundinacea* 20 14 33 100 100 100 50 100 6 67 22
- *Rubus saxatilis* 14 16 83 83 50 74 100 100 100 86 71 6
- *Visia nivosa* 38 69 52 83 74 100 100 100 100 100 17 50
- *Aegopodium podagraria* 24 86 43 67 69 80 100 100 71 17 56
- *Stellaria holostea* 14 5 43 91 60 40 89 100 100 4 22 100
- *Polygonatum odoratum* 100 29 5 36 57 67 48 10 22 79 14 18 88 17 20
- *Melica nutans* 29 14 26 26 67 100 78 57 57 71 63 20
- *Fragaria vesca* 60 100 38 31 30 67 30 30 71 33 28 30
- *Calamagrostis epigeios* 40 14 3 33 87 13 26 80 100 100 71 24 63 33
- *Salicaginaria virens* 14 29 57 67 41 80 50 36 71 12 63
- *Galium boreale* 29 41 71 87 70 71 53 4 30
- *Dactylis glomerata* 3 45 74 50 80 100 43 38 20
- *Artemisia vulgaris* 11 2 50 39 100 60 67 50 29 12 22
- *Glehnia hederacea* 86 5 14 13 40 10 33 100 14 12 29 11 30
- *Galium verum* 100 32 31 52 17 15 11 6 25
- *Petrorhagia aquilinum* 3 57 19 80 100 33 21 41 33
- *Urtica dioica* 5 21 17 67 13 20 10 56 57 47 25 44
- *Geum urbanum* 11 38 48 67 28 11 47 50 70
- *Convallaria majalis* 40 29 35 52 94 50 22 40
- *Hypericum perforatum* 80 14 24 17 10 44 7 41 42 80
- *Galium odoratum* 17 26 33 50 100 100 22
| Cluster/association | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
|                     | LQ | LQ | LQ | LQ | LQ | LQ | LQ | LQ | LQ | LQ  | LQ  | LQ  | LQ  | LQ  | LQ  | LQ  |
| Number of relevés   | 5 | 7 | 37 | 42 | 23 | 6 | 54 | 5 | 10 | 9 | 14 | 7 | 24 | 18 | 10 |

- Scrophularia nodosa
- Pulmonaria obscura
- Hieracium umbellatum
- Bupleurum longifolium
- Fragaria viridis
- Paeonia angustifolia
- Crepis biflora
- Achillea millefolium
- Hylotelephium triquetrum
- Geranium sanguineum
- Silene nutans
- Milium effusum
- Filipendula vulgaris
- Angelica sylvestris
- Vicia tenaxfolia
- Thalictrum minus
- Asparagus officinalis
- Agrimonia eupatoria
- Polygonatum multiflorum
- Chelidonium majus
- Carex muricata
- Clinopodium vulgare
- Veronica teucrium
- Aconitum napellus
- Chamaeneron angustifolium
- Trifolium medium
- Inula salicina
- Galium mollugo
- Viola collina
- Aconitum lycoctonum
- Elytrigia repens
- Fagopyrum esculentum
- Anthriscus sylvestris
- Vicia cracca
- Carex praecox
- Pulmonaria mollis
- Campanula latifolia
- Veronica spicata
- Lythrum salicaria
- Asperula tinctoria (BQ)
- Lilium martagon
- Carex rhzina
- Taraxacum officinale
- Sanguisorba officinalis
- Primula macrocalyx
- Vicia vulgaris
- Lysimachia nummularia
- Galeopsis hispida
- Bistorta major
- Euphorbus verrucosa
- Geranium pseudoalbum
- Pimpinella saxifraga
- Toluca japonica
- Viola canina
- Adenophora liliifolia
- Brachypodium sylvaticum
- Linaria vulgaris
- Cicuta arvensis
- Campanula rapunculoides
- Dryopteris felix-mas
- Anemoneoides ranunculoides
- Carex pilosa
- Pheum phleoides
- Anemone lutea
- Veronica longifolia
- Verbacum nigrum
- Dicranum scoparium
- Frangula abrus
- Astragalus glycyphyllos
- Puris quadrifolia
| Cluster/association | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| Alliance            | 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q| 1Q|
| Number of relevés   | 5 | 7 | 37 | 42 | 23 | 6 | 54 | 5 | 10 | 9 | 14 | 7 | 17 | 24 | 18 | 10 |

- Carex contigua
- Campanula glomerata
- Hylotelephium maximum
- Adonis vernalis
- Geranium robertianum
- Knautia arvensis
- Trifolium montanum
- Conioselinum tataricum
- Peucedanum oreoselgum
- Melandrium album
- Tanacetum vulgare
- Laser trilobum
- Aegopodium tenax
- Viola epipolia
- Poa pratensis
- Cirsium heterophyllum
- Dracocephalum ryszchiana
- Melampyrum cristatum
- Valeriana wolgensis
- Serratula gmelinii
- Knautia tatarica
- Festuca valesiaca
- Campanula trachelium
- Artemisia vulgaris
- Valeriana officinalis
- Anemoneoides altaica
- Trommesdorfera maculata
- Stellaria graminea
- Serratula coronata
- Vincetoxicum albowianum
- Moehringia trinervia
- Nepeta pannonica
- Lamium album
- Stachys sylvatica
- Verbascum lychnitidis
- Veronica spica
- Euphorbia virgata
- Artemisia armeniaca
- Ranunculus polyanthemos
- Genista tinctoria
- Phrumica carthaginensis
- Crepis tectorum
- Veronica officinalis
- Hypericum lanatum
- Sorbus aucuparia
- Euphorbia coasa
- Lathyrus pratensis
- Carex caryophyllea
- Maianthemum bifolium
- Medicago falcata
- Festuca rubra
- Papules avium
- Carex montana
- Pulanta pinetens
- Helictotrichon pubescens
- Lactuca serriola
- Hypericum maculatum
- Populus tremula
- Euphorbia gmelinii
- Rumex acetosa
- Dracocephalum thymiflorum
- Artemisia campestris
- Ficaria verna
- Artichochis alpestris
- Scorzonera purpurea
- Galatellia bifida
- Myosotis sylvatica
- Senecio schweinfurthii
- Campanula sibirica
- Brachythecaciastrum velutinum
- Lathyrus nigricans
Compared to the *Chamaecytis ruthenici-Quercetum roboris*, *Pyro pyrastris-Quercetum roboris*, *Vicio pisiformis-Quercetum roboris* and *Lathyro nigri-Quercetum roboris* associations, the *Astragalo ciceri-Quercetum roboris* has a higher proportion of Euro-West Asian species (41.5% against 30% in the above-listed associations, on average) and a lower number of European species (9.6% against 16%).

Based on the floristic composition, the *Sanguisorbo officinalis-Quercetum roboris* is most similar to the *Filipendulo vulgaris-Quercetum roboris*, but it differs from the latter by the absence of such characteristic species as *Galatella biflora* and *Artemisia armeniaca*, as well as because of the lower proportion of *Carex praecox*, *Veronica spuria* and *Campanula bononiensis*. Compared to the *Sanguisorbo officinalis-Quercetum roboris*, the *Filipendulo vulgaris-Quercetum roboris* has a much lower proportion of European species (3.4% against 8.5%) and more Eurasian species (23.3% against 19%).

An analysis of “heat maps” shows that all associations have a low similarity. The largest number of pairs being compared has a distance between 0.4 and 0.8 (Figure 2).

The newly identified associations are clustered in the dendrogram into one group with the associations of the *Sanguisorbo officinalis-Quercetum roboris* and *Lathyro nigri-Quercetum roboris*. This clustering is generally consistent with the analysis of the composition of diagnostic species. Cluster 2 was grouped with the new associations from the territory of the Republic of Tatarstan, and cluster 1 was grouped with the association *Vicio pisiformis-Quercetum roboris*.

However, the NMDS ordination (Figure 3) shows that the *Sanguisorbo officinalis-Quercetum* is intermediate between the *Lathyro pisiformis-Quercion* and *Aceri tatarici-Quercion* and is closer to the *Filipendulo vulgaris-Quercetum* than to the newly described *Astragalo ciceri-Quercetum roboris*. The left group of points unites the “western” (in relation to the territory of the Republic of Tatarstan) associations of the *Aceri tatarici-Quercion*. Clusters 1 and 2 adjoin them, together with the *Astragalo ciceri-Quercetum roboris*. The right part unites the “eastern” associations of the *Lathyro pisiformis-Quercion*. It is also noticeable that the “eastern” associations are less homogeneous and may require a revision of their syntaxonomic position.

Cluster 1 also has a higher frequency sum of diagnostic species of the *Betonicoides officinalis-Quercion roboris* alliance (or *Aceri tatarici-Quercion* in the previous concept).

![Figure 2. “Heat map” of distance matrix combined with a dendrogram.](image)

![Figure 3. Non-metric multidimensional scaling (NMDS) of the communities similarity matrix.](image)
In clusters 2, 3 and 4, the frequency sum of the diagnostic species of the 
Lathyro pisiformis-Quercion roboris is higher than the frequency sum of the 
diagnostic species of the Betonica officinalis-Quercion roboris and Scutellaria altissimae-Quercion roboris alliances (Table 2).

Table 2. Frequency sum (in %) of diagnostic species of the alliances Betonica officinalis-Quercion roboris, Scutellaria altissimae-Quercion roboris and Lathyro pisiformis-Quercion roboris in clusters 1–4 (this paper) and previously described associations. 1 – cluster 1, 2 – cluster 2, 3 – cluster 3 (Astragalo ciceri-Quercetum roboris), 4 – cluster 4 (Sanguisorbo officinalis-Quercetum roboris), 5 – Filipendulo vulgaris-Quercetum roboris, 6 – Omphalodo scorpoides-Quercetum roboris, 7 – Brachypodio pinnati-Quercetum roboris, 8 – Aconogono alpinii-Quercetum roboris, 9 – Calamagrostis epigei-Quercetum roboris, 10 – Carici macrourae-Quercetum roboris, 11 – Pruno-Quercetum roboris, 12 – Bistorta majoris-Quercetum roboris, 13 – Lathyro nigris-Quercetum roboris, 14 – Chamaezytis ruthenici-Quercetum roboris, 15 – Pyro pyrastris-Quercetum roboris, 16 – Vicia pisiformis-Quercetum roboris.

| Number of cluster (association name) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|--------------------------------------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Betonica officinalis-Quercion roboris| 440| 371| 284| 470| 651| 183| 220| 240| 290| 456| 142| 400| 258| 867| 183| 440|
| Scutellaria altissimae-Quercion roboris| 240| 229| 369| 324| 395| 83| 44| 100| 120| 144| 171| 100| 35| 333| 33| 600|
| Lathyro pisiformis-Quercion roboris | 140| 228| 288| 481| 747| 83| 83| 480| 570| 688| 256| 314| 76| 284| 33| 180|

Discussion

The NMDS ordination diagram shows distinct floristic and ecological composition of the identified syn-taxa (Figure 3).

The Astragalo ciceri-Quercetum roboris is close to some associations within the Betonica officinalis-Quercion alliance, but they are found under more continental conditions. It comprises the following diagnostic species of this alliance (Goncharenko et al. 2020): Asperula tinctoria, Betonica officinalis, Campanula persicifolia, Origanum vulgare, Veronica chamaedrys, and Vincetoxicum hirundinaria. However, important species characteristic of Betonica officinalis-Quercion, such as Anthericum ramosum, Clematis recta, Digitalis grandiflora, Melampyrum nemorosum, Potentilla alba and Trifolium alpestre, are absent.

Our results suggest that the communities of the Sanguisorbo officinalis-Quercetum roboris are close to the group of associations of the Lathyro pisiformis-Quercion roboris alliance. However, they differ from the latter by their preference for warmer sites with more light availability. Sanguisorbo officinalis-Quercetum roboris includes the diagnostic species of this alliance (Willner et al. 2016) such as Geranium sylvaticum, Heracleum sibiricum, Lathyrus pisiformis, L. sylvestris, Pleuroserpium uralense, Rosa majalis, Seseli libanotis. Some of diagnostic species of Lathyro pisiformis-Quercion are absent: Caragana frutex, Carex macroura, Lathyrus gmelinii, and L. litvinovii.

We conclude that the xero-mesophytic oak forests in the Republic of Tatarstan can be assigned to the alliance Betonica officinalis-Quercion roboris (ass. Astragalo ciceri-Quercetum roboris), and to the alliance Lathyro pisiformis-Quercion roboris (ass. Sanguisorbo officinalis-Quercetum roboris). However, a syntaxonomic revision of the entire phytocoenotic material of xero-mesophytic oak forests in Europe, including the European part of Russia, is necessary to clarify the exact delimitation of these alliances.

Data availability

The original plot records are included in Suppl. material 1.

Author contributions

Both authors have equally planned the study, conducted field sampling, performed taxonomic considerations, and contributed to writing the article.

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Supplementary material

Supplementary material 1
Ordered table of individual relevés (*.xlsx)
Link: https://doi.org/10.3897/VCS/2021/39583.suppl1

Supplementary material 2
Diagnostic, constant and dominant species of the four clusters. (*.pdf)
Link: https://doi.org/10.3897/VCS/2021/39583.suppl2

Supplementary material 3
Distribution maps and photos of the newly described associations. (*.pdf)
Link: https://doi.org/10.3897/VCS/2021/39583.suppl3