Vegetation composition analysis for sequestration potential evaluation in the Republic of Tatarstan

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Abstract. To assess the carbon sequestration potential of terrestrial ecosystems of the Republic of Tatarstan, vegetation classification was carried out at the class level using the Braun-Blanquet system. 17,000 relevés from the "Flora" database were used as source materials. The classification was carried out using the EuroVeg Checklist expert system in the Juice 7.0 software. A total of 34 classes of vegetation were identified. The 14 largest classes have been selected for vegetation cover modelling.

1 Introduction

Terrestrial ecosystems, as well as marine ones, are the main participants in sequestration when producing and retaining (storing) the organic mass of air carbon within the plant and soil biomass. A large number of measurement methods and practical cases were reviewed in the work of A.I. Kurbatova [1]. One of the cornerstones in carbon balance modeling is the classification of systematic units for further extrapolation of field observations.

Vegetation is one of the key elements of terrestrial ecosystems. It is one of the integral indicators of the ecosystem as a whole because the vegetation component is formed depending on both abiotic factors and anthropogenic impact. We propose to use a spatial model of vegetation cover as a basis for assessing the sequestration potential of ecosystems in a particular territory. The vegetation cannot be analysed without initially classifying it using one or another system.

Since the main goal is to evaluate the ability of ecosystems to sequester carbon, it is logical to base the classification on markers of those processes that directly affect carbon accumulation. In the work [2] developed a system for classifying Brazilian tropical forests into carbon storage classes, which was applied to large areas, focusing on different tree species composition and climatic variables. The results of the study published in the article [3] showed that carbon accumulation in the soil depends on both the species composition of trees and ground cover. This article postulates that the use of forest classification by V.N. Sukachev [4] makes it possible to consider both of these vegetation components.

A large review of works devoted to the relations between functional characteristics of plants or vegetation communities is given in [5]. The authors note that because plant

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species vary in their ability to sequester, store, and emit carbon, the collective functional characteristics of vegetation communities (functional diversity) should be a major driver of carbon storage in terrestrial ecosystems. The results of this study indicate that all three main components of plant functional diversity–dominant feature values, diversity of feature values, and the presence of specific species in a community–contribute to explaining carbon storage at the ecosystem level. Considering the functional characteristics of plants is a very promising course. Its application is possible through classification and mapping of the floristic composition of communities.

The classification approach that most fully reflects the floristic composition of communities is the Braun-Blanquet method [6-8]. The main advantages of this method, which allowed it to become so widespread, are: high information content of syntaxa, flexibility of classification criteria; openness of the system, successive nature of the development of the classification; consistent reductionism; use of the researcher's intellectual potential; developed nomenclature system [9]. That is why this concept became the basis for the classification of vegetation in Russia, which was presented by leading scientists from biological institutes at the Presidium of the Russian Academy of Sciences in December 2019 [10].

The main aim of the study is to carry out a preliminary classification of the vegetation of the Republic of Tatarstan in the Braun-Blanquet system to the level of vegetation class and for the further creation of a spatial model of these structural units of vegetation.

2 Materials and methods

The study area is located in the eastern part of the European part of Russia (Figure 1) and is divided by the valleys of the Volga, Kama, and Vyatka rivers into natural areas, including landscapes related to the Eastern European taiga and eastern semi-humid broad-leaved forests [11-12].

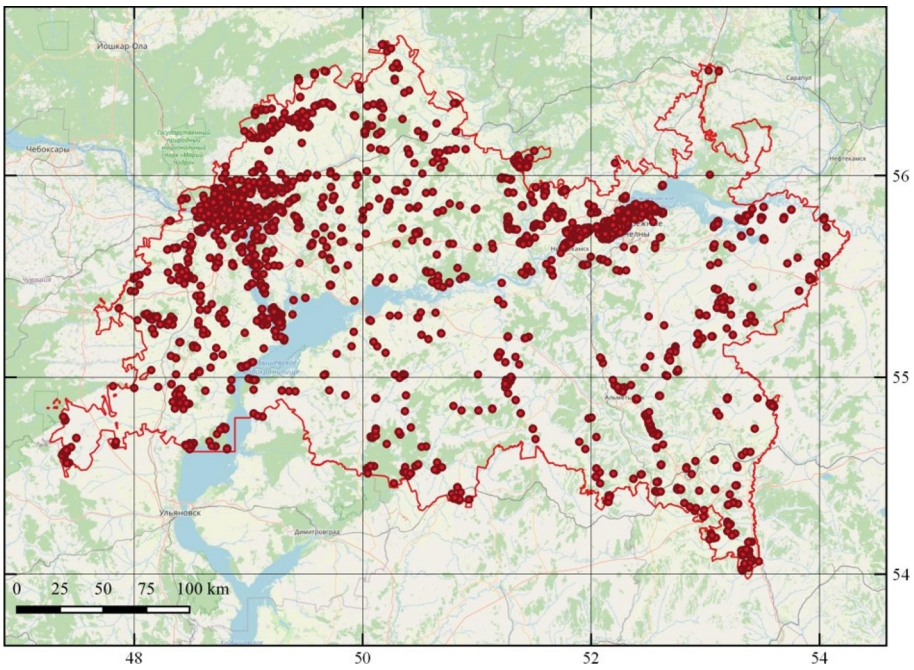

Fig. 1. Location of vegetation plots in the study area.

The data from the "Flora" database [13], containing more than 17,000 vegetation plots relevés, was used as the source material for the work. Relevés made after 2000 and containing geographical references were downloaded from the database. The nomenclature of plant species was brought into line with the database "The Plant List" (http://www.theplantlist.org) [14]. Bryophyte species were excluded from the sample. The location of the selected plots shown in the figure 1.

The classification of relevés was carried out at the vegetation classes level in the Braun-Blanquet system using the EuroVeg Checklist expert system [15] in the Juice 7.0 software package [16].

3 Results and Discussion

As a result of the classification, 34 classes of vegetation were identified. 14 classes containing more than 10 relevés were selected for the creation of a spatial model of vegetation cover.

The summary of selected higher syntaxa for the Republic of Tatarstan is as follows:

1. Zonal and intrazonal vegetation.
    1.1. Boreal vegetation.
        PIC: *Vaccinio-Piceetea* Br.-Bl. In Br.-Bl. Et al. 1939.
        BRA: *Brachypodio pinnati-Betuletea pendulae* Ermakov et al. 1991.
    1.2. Vegetation of the nemoral forest zone.
        1.2.1 Zonal broad-leaved forests.
        FAG: *Carpino-Fagetea sylvaticae* Jakucs ex Passarge 1968.
        QUE: *Quercetea robori-petraeae* Br.-Bl. et Tx. ex Oberd. 1957.
        PUB: *Quercetea pubescentis* Doing-Kraft ex Scamoni et Passarge 1959
        1.2.2 Intrazonal grasslands and heathlands of the boreal and temperate zones.
        MOL: *Molinio-Arrhenatheretea* Tx. 1937.
    1.3. Vegetation of the steppe zone.
        FES: *Festuco-Brometea* Br.-Bl. et Tx. ex Soó 1947.
2. Azonal vegetation.
    2.1. Forests and bushes of alluvial sediments.
        POP: *Alno glutinosae-Populetea albae* P. Fukarek et Fabijanić 1968.
    2.2. Forests and shrub vegetation growing in swamp.
        ALN: *Alnetea glutinosae* Br.-Bl. et Tx. ex Westhoff et al. 1946.
    2.3. Near-water and swamp.
        PHR: *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941.
    2.4. Anthropogenic vegetation.
        SIS: *Sisymbrietea Gutte* et Hilbig 1975.
        ART: *Artemisietea vulgaris* Lohmeyer et al. in Tx. ex von Rochow 1951.
        EPI: *Epilobietea angustifolii* Tx. et Preising ex von Rochow 1951
        PAR: *Papaveretea rhoeadis* S. Brullo et al. 2001

Class PIC: *Vaccinio-Piceetea* includes communities of boreal coniferous forests of Eurasia and the temperate zone dominated by *Picea abies*, *Pinus sylvestris* or related species. Soil conditions are characterized by nutrient-poor, mostly acidic soils. On the territory of Tatarstan this type of communities is distributed mainly along the terrace-valley complexes of large (Volga, Kama, Vyatka) and medium-sized (Myosha, Sviyaga) rivers. In the dominant classification these are usually pine or bilberry-blackberry-spruce forests with advanced moss cover. The number of records classified in this class was 169. *Pinus sylvestris* and *Betula pendula* most often dominate the stand, *Picea* × *fennica* is a constant species, but almost never dominant. The ground cover is dominated by *Vaccinium myrtillus* and *Vaccinium vitis-idaea*. *Orthilia secunda* and *Calamagrostis arundinacea* are constant species.

Class BRA: *Brachypodio pinnati-Betuletea pendulae* is the fourth in terms of number of relives (404). It is described as a combination of light coniferous and small-leaved herbaceous forests of the southern part of Siberia. The main area of communities of this class is located in the southern plains and mountainous regions of Central and Western Siberia, extending from the Urals in the west to the Baikal region in the east. On the plains it occupies the forest-steppe and sub-Taiga zones in latitude [17]. In Tatarstan, the communities belonging to this class are distributed over the whole territory. *Pinus sylvestris* and *Betula pendula* dominate in the first layer, *Picea* × *fennica* in the second layer and undergrowth, *Pteridium aquilinum*, *Brachypodium pinnatum*, *Rubus saxatilis* in the herbage. Other constant species of this class are *Sorbus aucuparia*, *Polygonatum odoratum*, *Euonymus verrucosa*, *Calamagrostis arundinacea*, *Orthilia secunda*, *Galium mollugo*.

Class FAG: *Carpino-Fagetea sylvaticae* represents communities of zonal deciduous forests of the European temperate zone, dominated by tree species with medium to high requirements for soil moisture and nutrients. The area of this class extends from the westernmost part of Europe to the southern Urals. Similar forests are also found in western and southern Siberia [18]. The largest number of plots (1590) was assigned to this class. In Tatarstan these communities are distributed all over the territory. *Tilia cordata*, *Betula pendula* and *Pinus sylvestris* dominate in their first layer, *Tilia cordata* dominates in the second layer and undergrowth, *Carex pilosa*, *Aegopodium podagraria*, *Equisetum pratense* dominate in the herbage. Other constant species of this class are Corylus avellana, *Euonymus verrucosa*, *Lonicera xylosteum*, *Sorbus aucuparia*, *Dryopteris filix-mas*, *Lathyrus vernus*.

Class QUE: *Quercetea robori-petraeae* in Europe represents oak woods dominated by *Quercus petraea* agg. or *Q. robur* L., growing as ground cover on acid soils. The understory is generally sparse. These forests are found either on poorly weathered soils, on highly weathered acidic rocks, or on thicker leached soils on sedimentary rocks [19]. The communities of the Republic of Tatarstan classified in this class (22 records) are dry pine-oak forests occurring on sandy terraces of the Volga and Kama rivers. The stand is dominated by *Pinus sylvestris*, *Betula pendula* is co-dominant, *Pteridium aquilinum* dominates in the ground cover.

Class PUB: *Quercetea pubescentis* represents thermophilous, xeromesophytic lowland deciduous forests, which occupy a significant area of the territories of the Czech Republic, Slovakia, Bosnia and Herzegovina and Croatia. This type of communities occurs in the east in the form of a gradually narrowing tableau that extends to the territory of Ukraine, the Republic of Crimea, northern Moldavia, the Russian regions of Kursk, Tula, Voronezh, Tambov, Penza, Saratov, Samara and Ulyanovsk, the Republics of Mordovia, Chuvashia, Tatarstan and Bashkortostan, and the Orenburg region of the Russian Federation. 195 phytocenoses of this class have been identified; in the territory of Tatarstan they are located mainly in the Bugulminsko-Belebeyevskaya upland, as well as in the eastern part of Tatarstan at an altitude of 250-300 m above sea level. They occupy the watershed and middle parts of flat (up to 5º) slopes, mostly south-east facing; they grow on leached and typical chernozems developing on clay-mergel and clay-limestone beds of the underlying rocks of the Tatar stage of the Belebey Formation of the Ufimian stage of the Permian-Triassic system. The total number of species is 301, and the average number of species in the corresponding communities is 50. In addition to *Quercus robur*, *Betula pendula*, *Pinus sylvestris* and *Tilia cordata* occur in the first layer. The second tree layer is implicit. It includes *Ulmus scabra* and *Populus tremula* in addition to the species of the first layer. The undergrowth is sparse, but with a large number of species (21 in total), without any obvious dominance of any of them. *Euonymus verrucosa* is the most abundant. The herb layer is complex and polydominant, including species of tall forest-steppe grasses: Pleurospermum

uralense, *Campanula trachelium*, *Heracleum sibiricum*, *Euphorbia semivillosa* and *Lilium pilosiusculum*.

Class MOL: *Molinio-Arrhenatheretea* represents tall grass pastures and meadows on fertile soils distributed throughout Europe, except for high mountains [15]. In Tatarstan, communities of this class are found all over the territory, but more often north of the Volga and Kama rivers. 529 relevés have been assigned to this class. The most dominant species are *Bromopsis inermis* and *Poa angustifolia*. Other constant species are *Rumex confer*tus, *Lathyrus pratensis* and *Vicia cracca*.

Phytocenoses belonging to the class FES: *Festuco-Brometea* are characterized as communities of dry grassland and steppe vegetation on fertile soils of the sub-Mediterranean, nemoral and hemiboreal zones of Europe [15]. In Tatarstan, communities of this class represent xeromesophytic grassland vegetation. They are distributed all over the territory and are limited to the slopes of ravine and gully systems and river valleys, mainly of southern and southwestern exposition. There are 481 species assigned to this class. The dominant species are *Poa angustifolia*, *Fragaria viridis*, *Bromopsis inermis* and *Calamagrostis epigeios*. Other constant species of this class are *Rumex confertus*, *Potentilla argentea*, *Galium verum*.

POP class: *Alno glutinosae-Populetea albae* are coastal floodplain forests on nutrient-rich alluvial soils in the non-moral zone of Europe. They grow in habitats characterized by constantly fluctuating water levels with periods of flooding and drought, and thus disturbed and undeveloped soils [20]. Communities of this class are distributed along the floodplains of rivers (mainly large rivers) throughout Tatarstan, 165 descriptions are assigned to this class. In the dominant classification they correspond to alder forests, floodplain oak forests, elm forests, wet spruce forests and birch forests. *Alnus glutinosa* dominates in the stand, while *Glechoma hederacea*, *Urtica dioica* and *Rubus caesius* dominate in the ground cover.

Class ALN: *Alnetea glutinosae* includes waterlogged alder woods and willow thickets that occur in habitats with a permanently high-water table. The herbaceous layer consists of wetland tall grasses and sedges, while typical forest species are absent [21]. Communities of this class are distributed along river floodplains all over the territory of Tatarstan, their number amounted to 39. The tree layer of these communities is dominated by *Betula pubescens*, the ground cover by *Carex vesicaria* and *Carex nigra*.

Class PHR: *Phragmito-Magnocaricetea* comprises communities of reed and sedge vegetation found in freshwater or brackish water bodies and streams throughout Eurasia [15]. In Tatarstan, communities of this class are distributed along the banks of reservoirs and river floodplains. This class contains 204 records.

Class SIS: *Sisymbrietea* unites plant communities representing annual, ephemeral, ruderal, usually nitrophilous and subnitrophilous vegetation found worldwide except for warm tropical regions [15]. These communities are distributed throughout the territory in anthropogenically disturbed habitats. Communities of this type are typically dominated by *Chenopodium album*, with *Conyza canadensis* and *Setaria viridis* as co-dominants. A total of 39 vegetation plots were classified in this class.

Class ART: *Artemisietea vulgaris* comprises thermophilic vegetation found in sunny and dry habitats, consisting mainly of biennial and perennial species, with some annuals also present. Communities of this class are mainly distributed in disturbed habitats of settlements and their surroundings [22]. Phytocenoses classified in class 353 are distributed throughout the territory of Tatarstan and are mainly found in areas where cattle graze or where there is a high recreational load. The dominant species is usually *Calamagrostis epigeios*, with co-dominants often being *Elytrigia repens*, *Poa angustifolia*, and *Bromopsis inermis*. Other constant species include *Artemisia absinthium*, *Cichorium intybus*, *Conyza canadensis*, *Artemisia vulgaris*, *Achillea millefolium*, and *Tripleurospermum perforatum*.

Class EPI: *Epilobietea angustifolii* is a class of herbaceous vegetation found in forest glades and areas deforested due to forest fires, logging, insect pest outbreaks, or air pollution. These communities are typically found along forest gullies, screes, rocky scrapes along roads and railroads, quarries, and construction debris. They grow on relatively poor soils with temporarily increased nitrogen availability. The species composition of this vegetation type depends on the type of preceding or adjacent forest vegetation. If there is no directed impact, this vegetation typically lasts for three to seven years before giving way to shrubs or trees [23]. In Tatarstan, 18 communities of this class have been identified and are found throughout the territory. The plant community in these areas is dominated by *Urtica dioica*, with *Calamagrostis epigeios*, *Cirsium setosum*, *Bromopsis inermis*, *Pteridium aquilinum*, *Elytrigia repens*, and *Cannabis ruderalis* also noted as dominant species.

Class PAR: the annual vegetation *Papaveretea rhoeadis* is found in arable land, gardens, and orchards in temperate and taiga zones of Eurasia [15]. In Tatarstan, plant communities of this class (26) are distributed throughout the territory, but predominantly to the north of the Volga and Kama rivers.

4 Conclusion

During the study, the vegetation of the Republic of Tatarstan was classified at the Braun-Blanquet system class level. A total of 34 vegetation classes were identified. The 14 largest representative classes of vegetation of the study area were selected for the subsequent construction of a vegetation cover model used as a basis for calculating the sequestration potential of terrestrial ecosystems of the Republic of Tatarstan.

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References

1. A.I. Kurbatova, RUDN Journal of Ecology and Life Safety, **28**, **4**, 428-438 (2020)
2. H.C. David, E.J.G.de Araújo, V.A. Morais, J.R.S. Scolforo, J.M. Marques, S.P. Netto, D.W. MacFarlane, Forest Ecol. and Manag., **404**, 241-250 (2017)
3. N. Lukina, A. Kuznetsova, E. Tikhonova, V. Smirnov, M. Danilova, A. Gornov, O. Bakhmet, A. Kryshen, D. Tebenkova, M. Shashkov, S. Knyazeva, Forests, **11**, 979 (2020)
4. V.N. Sukachev, N.V. Dylis, Fundamentals of forest biogeocenology (Science, Moscow, 1964)
5. G. Conti, S. Díaz, J. Ecol., **101**, 18-28 (2013)
6. J. Braun-Blanquet, Pflanzensoziologie (J. Springer, Berlin, 1928)
7. M.V. Kozhevnikova;, V.E. Prokhorov, T.V. Rogova, Uch. Zap. Kazan. Univ. Ser. Estestv. Nauki, **160**, 445-458 (2018)
8. M.V. Kozhevnikova, V.E. Prokhorov, A.A. Saveliev, Tomsk State University Journal of Biology, **47**, 59-73 (2019)
9. B.M. Mirkin, L.G. Naumova, Current state of basic concepts in plant science (Gilem, Ufa, 2012)
10. Yu.V. Plugatar, N.B. Ermakov, P.V. Krestov, N.V. Matveyeva, V.B. Martynenko, V.B. Golub, V.Yu. Neshataeva, V.Yu. Neshataev, O.A. Anenkhonov, I.A. Lavrinenko,

O.V. Lavrinenko, V.V. Chepinoga, N.V. Sinelnikova, O.V. Morozova, E.A. Belonovskaya, A.A. Tishkov, T.V. Chernenkova, L.V. Krivobokov, M.Yu. Telyatnikov, E.D. Lapshina, V.G. Onipchenko, N.E. Koroleva, M.M. Cherosov, Yu.A. Semenishchenkov, L.M. Abramova, T.M. Lysenko, M.A. Polyakova, Vegetation of Russia, **38**, 3-12 (2020)

11. O. Yermolaev, B. Usmanov, A. Gafurov, J. Poesen, E. Vedeneeva, F. Lisetskii, I.C. Nicu, Remote Sensing, **13**, 4214 (2021)
12. O. Yermolaev, B. Usmanov, *The basin approach to the anthropogenic impact assessment in oil-producing region*, in Proceedings of 14th International Multidisciplinary Scientific Geoconference, vol.II: Ecology and Environmental Protection, SGEM 2014, 17-26, June, Bulgaria (2014)
13. V. Prokhorov, T. Rogova, M. Kozhevnikova, Phyto, **47**, 309 (2017)
14. R.D.M. Page, The Plant List with literature. Institute of Biodiversity, Animal Health and Comparative Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow. Checklist dataset (accessed via GBIF.org on 2024-01-19)
15. L. Mucina, H. Bültmann, K. Dierßen, J.-P. Theurillat, T. Raus, A. Čarni, K. Šumberová, W. Willner, J. Dengler, R. Gavilán García, M. Chytry, M. Hájek, R.Di Pietro, D. Iakushenko, J. Pallas, F.J.A. Daniëls, E. Bergmeier, A. Santos Guerra, N. Ermakov, M. Valachovič, J. H. J. Schaminée, T. Lysenko, Y. P. Didukh, S. Pignatti, J.S. Rodwell, J. Capelo, H.E. Weber, A. Solomeshch, P. Dimopoulos, C. Aguiar, S.M. Hennekens, L. Tichý, Appl. Veget. Sci., **19**, 1, 3-264 (2016)
16. L. Tichý, Journal of Vegetation Science, **13**, 3, 451-453 (2002)
17. N.N. Lashchinskiy, N.V. Vetluzhskich, Tomsk State University Journal of Biology, **3**, 7, 5-18 (2009)
18. K. Boublík., J. Douda, R. Hédl, M. Chytrý, 194-295: In Chytrý M. (ed.), Vegetace České republiky. 4. Lesní a křovinná vegetace (Vegetation of the Czech Republic 4. Forest and shrub vegetation) (Academia, Praha, 2013)
19. J. Roleček, 347-351: In Chytrý M. (ed.), Vegetace České republiky. 4. Lesní a křovinná vegetace (Vegetation of the Czech Republic 4. Forest and shrub vegetation) (Academia, Praha, 2013)
20. H. Ellenberg, Vegetation ecology of Central Europe, 4th ed. (Cambridge University Press, Cambridge, 2009)
21. J. Douda, 166-167: In Chytrý M. (ed.), Vegetace České republiky. 4. Lesní a křovinná vegetace (Vegetation of the Czech Republic 4. Forest and shrub vegetation) (Academia, Praha, 2013)
22. D. Láníková, Z. Lososová, 43-46: In Chytrý M. (ed.), Vegetace České republiky. 2. Ruderální, plevelová, skalní a suťová vegetace (Vegetation of the Czech Republic 2. Ruderal, weed, rock and scree vegetation]) (Academia, Praha, 2009)
23. P. Petřík, J. Sádlo, 379-382: In Chytrý M. (ed.), Vegetace České republiky. 4. Lesní a křovinná vegetace (Vegetation of the Czech Republic 4. Forest and shrub vegetation) (Academia, Praha, 2013)