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RESEARCH ARTICLE

The first comprehensive assessment at the Central Asian scale of the phylogenetic diversity of urban floras in the arid and temperate regions of Uzbekistan

Zukhuridin Juraev[1], Ilkhomjon Urinboev[2], Husniddin Esanov[3], Feruz Akbarov[1], Gulkhayo Gofurova[4], Bobur Karimov[1], Inom Juramurodov[1], Nazokat Daminova[1], Kimyo Aslonova[3], Dilmurod Makhmudjanov[1], Komiljon Sh. Tojibaev[1]

1 *Institute of Botany, the Academy of Sciences of the Republic of Uzbekistan, 32 Durmon Yuli St., Tashkent, 100125, Uzbekistan*
2 *Fergana State University, 19 Murabbiylar St., Fergana, 150100, Uzbekistan*
3 *Bukhara State University, 11 Muhammad Iqbol St., Bukhara, 705018, Uzbekistan*
4 *Samarkand State University named after Sharof Rashidov, Samarkand, Uzbekistan*

Corresponding author: Komiljon Sh. Tojibaev (ktojibaev@mail.ru)

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Abstract

Although urbanization is recognized as a major driver of biodiversity change globally, its impact on the evolutionary history of flora in arid regions remains understudied. This study provides a comparative analysis of the phylogenetic structure of the floras of three major cities in Uzbekistan Tashkent, Fergana, and Bukhara, located in different climatic zones. Species richness, phylogenetic diversity (Faith's PD), and phylogenetic structure indices (MPD and SES.MPD) were employed in the study. The results indicated that while urbanization leads to an increase in species diversity across all cities due to alien species, the phylogenetic structure differs sharply depending on the regional climate. In the temperate cities of Tashkent and Fergana, the urban environment was observed to act as a harsh "ecological filter", resulting in strong phylogenetic clustering among alien species. In contrast, a distinct mechanism the "Phylogenetic Release" phenomenon was identified in the arid city of Bukhara.

Here, anthropogenic maintenance mitigates natural stress factors, allowing the urban environment to act as a "facilitator" and enabling the persistence of evolutionarily diverse species. This study demonstrates that urbanization in arid regions can alter the evolutionary dynamics of flora and highlights the necessity of considering local climatic characteristics when creating sustainable urban ecosystems.

Keywords
Alien species, biotic homogenization, community assembly, ecological filtering, evolutionary history, phylogenetic release, species richness

Introduction

According to United Nations estimates, the share of the global urban population, which stood at 55% in 2018, is projected to reach 68% by 2050 (United Nations 2019). In the current "Anthropocene" era, characterized by global urbanization and the acceleration of human activity, the breakdown of natural biogeographical barriers limiting plant migration is taking place (Kueffer 2017; Potgieter and Cadotte 2020). This process leads to the degradation of native flora in urban ecosystems and the dominance of alien species with wide ecological tolerance (Aronson et al. 2014; Cadotte et al. 2017). Recent studies conducted in cities across North America, Europe, and Asia have confirmed that urbanization results in the homogenization of interregional floristic composition a process known as "biotic homogenization" (McKinney 2006; Pearse et al. 2018; Tretyakova et al. 2024; Doğan et al. 2025).

However, analyzing urban flora solely through taxonomic lists cannot fully reveal ecological mechanisms (Gerhold et al. 2015; Cadotte et al. 2019; Swenson 2019). To understand ecosystem functions, not only species richness but also their evolutionary histories and functional traits are crucial (Cadotte et al. 2019; Swenson 2019). Therefore, Phylogenetic Diversity (PD) analysis, based on evolutionary relationships between species, is becoming a leading approach in assessing the impact of urbanization processes on flora (Webb 2000; Knapp et al. 2008; Ricotta et al. 2009). In many studies, PD is considered a reliable proxy for Functional Diversity (Losos 2008; Flynn et al. 2011; Tucker et al. 2018; Cadotte et al. 2019). This approach clearly demonstrates which evolutionary branches of the flora are lost and which are preserved under the influence of urbanization (Gerhold et al. 2015).

The formation of urban flora is based on the theoretical model of “Hierarchical filters” (Aronson et al. 2016). According to this model, for species to transition from the regional native flora to the urban flora, they must pass through a sequence of filters comprising climatic, environmental, and anthropogenic barriers. If the urban environment acts as a strong stressor (e.g., pollution, soil compaction, temperature anomalies), closely related species tend to aggregate within the community, resulting in phylogenetic clustering (Webb 2000; Knapp et al. 2008; Ricotta et al. 2009; Tretyakova et al. 2021). Conversely, under conditions of abundant resources, increased competition, or the introduction of diverse alien species, phylogenetic overdispersion is observed (Ricotta et al. 2009; Mayfield and Levine 2010; Pearse et al. 2018).

Nevertheless, a distinct geographical imbalance is observed globally in assessing the impact of urbanization on phylogenetic structure. Most studies are limited to the humid regions of Europe (Ricotta et al. 2009), North America (Pearse et al. 2018), and East Asia (Cheng et al. 2018; Zhu et al. 2019; Gao et al. 2024). Significant work on cities in Russia and the Ural region, which are geographically closer to Central Asia, has been conducted by Veselkin et al. (2017) and Tretyakova et al. (2018; 2021). They demonstrated that under temperate and cold climatic conditions, urbanization acts as a strong ecological filter, leading to the homogenization of floristic composition (phylogenetic clustering).

In recent years, significant progress has been achieved in the study of urban flora in Uzbekistan. For example, Juramurodov et al. (2025) analyzed the flora of the Surkhan–Sherobod botanical–geographical region. Esanov et al. (2016, 2018, 2020) elucidated the structural, ecological–floristic, and regional characteristics of the urban flora of Bukhara. Tojibaev and Esanov (2021) compiled an updated inventory of invasive species, while Umedov and Esanov (2024) investigated the flora of Bukhara using a grid-based analytical approach. Furthermore, Urinboev (2025) and Gafarova et al. (2024) conducted detailed taxonomic and biomorphological analyses of the flora of the cities of Fergana and Bukhara. In parallel, Central Asian researchers have conducted a series of phylogenetic and biogeographical studies at regional and global scales, focusing on various plant families and genera (Juramurodov et al. 2023; Makhmudjanov et al. 2023a; Makhmudjanov et al. 2022; Makhmudjanov et al. 2023b; Makhmudjanov et al. 2025). These investigations have provided an important theoretical and empirical framework for understanding the evolutionary history and spatial assembly of the regional flora.

Notably, the cities of Uzbekistan, situated within the arid zone of Central Asia, differ fundamentally from the temperate systems upon which most ecological models of urban vegetation have been developed. Their sharply continental climate and the near-total dependence of urban green spaces on artificial irrigation create highly distinctive environmental conditions. Such characteristics complicate the direct application of generalized ecological theories and highlight the need for region-specific analyses of urban flora assembly processes. However, all of the above-mentioned studies have primarily focused on taxonomic and floristic aspects, as well as on genus-level phylogenetic analyses, whereas the factors shaping the phylogenetic structure (PS) and phylogenetic diversity (PD) of native and alien species in arid and temperate urban environments remain insufficiently elucidated.

Considering that studies on the phylogenetic diversity of urban flora have hardly been conducted in Central Asia, and that Uzbekistan is one of the floristically rich and biogeographically interesting areas of the region, the main objective of this study is to comparatively assess the mechanisms of phylogenetic diversity and phylogenetic structure formation in the floras of three major urbanization centers Tashkent, Fergana, and Bukhara located in different climatic zones (relatively temperate and arid) of Uzbekistan.

Materials and methods

Study area

The study was conducted in three major urbanization centers covering different biogeographical and climatic zones of Uzbekistan (Tojibaev et al. 2016): Tashkent (northeast), Fergana (east), and Bukhara (southwest) (Fig. 1, Table 1). These cities were selected along a precipitation and temperature gradient, allowing for a comparative assessment of the impact of urbanization and climatic variables on the phylogenetic structure of the flora.

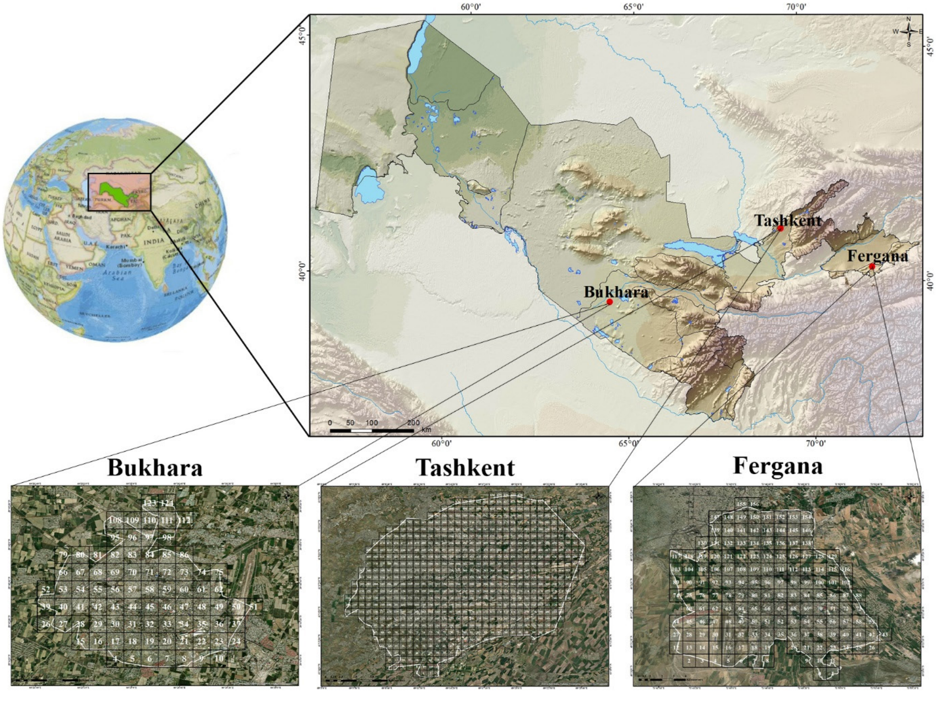

Figure 1. Geographical location of the three studied cities in Uzbekistan.

Tashkent (41°18′ N, 69°16′ E) is located in the foothills (piedmont plain) of the Western Tien Shan mountain ranges, in the valley of the Chirchik River. The region has a relatively mild, continental, semi-arid climate, with the highest annual precipitation among the selected cities. The soil cover consists mainly of typical sierozems. Tashkent is the largest city in the country and is characterized by the highest level of anthropogenic pressure.

Fergana (40°23′ N, 71°47′ E) is situated in the southern part of the Fergana Valley, on the proluvial plain at the foothills of the Alay Range. The region is characterised by fertile, irrigated agricultural landscapes (oases) and a climate with continental subtropical features. The soils are predominantly light sierozems and meadow-oasis soils.

Bukhara (39°46′ N, 64°26′ E) is located in the center of the ancient Bukhara Oasis (lower reaches of the Zarafshan River), bordering the Kyzylkum Desert. The city is characterized by a sharply continental, extreme arid climate (arid desert climate), with high summer temperatures and low atmospheric precipitation. The soil cover is highly saline, consisting mainly of irrigated meadow-oasis and solonchak soils.

The selected cities differ not only in natural conditions but also in demographic and economic scale: the population size ranges from 222,000 (Bukhara) to over 3 million (Toshkent), representing different levels of urbanization intensity (Table 1).

Table 1. Main geographic, climatic, and floristic characteristics of the studied cities

Characteristics	Tashkent	Fergana	Bukhara
Cities attributes			
East longitude	69°16′	71°47′	64°26′
North latitude	41°18′	40°23′	39°46′
City area, km²	334.8	90	70
Population, thousand people	3,040.8	328.4	274.8
Altitude, m above sea level	455	580	225
Mean annual temperature, °C	+14.5	+13	+15
Mean annual rainfall, mm	415	192	138
Subzone	Foothill–plain	Valley–plain	Desert
Taxonomic structure (number/percent of total flora)			
Div. Polypodiophyta	2/0.3	2/0.4	1/0.4
Div. Pinophyta	0	1/0.2	0
Div. Magnoliophyta	734 / 99.7	532 / 99.4	255 / 99.6
Clas. Liliopsida	167 / 22.7	103 / 19.2	40 / 15.6
Clas. Magnoliopsida	567 / 77	429 / 80.2	215 / 84
Species groups (number/percent of total flora)			
Total	736	535	256
Native	586 / 79.6	391 / 73.1	160 / 62.5
Alien	150 / 20.4	144 / 26.9	96 / 37.5

Data collection and taxonomic standardization

Field studies were conducted during the growing seasons (March–October) from 2020 to 2025. To ensure the reliability and comparative accuracy of floristic data, a single standardized methodology of systematic grid mapping with a cell size of 1×1 km was applied in all three cities (Fig. 1). Within each grid cell, all available biotopes were covered, and a complete inventory of plant species was carried out.

Species identification was performed through field observations and a critical analysis of historical collections in national and international herbaria (LE, MW, TASH) and digital international and regional databases, including GBIF (2025), GMOCA (2025), and Plantarium (2025). Species were identified using fundamental works such as "Flora of Uzbekistan" (Sennikov 2017a, 2017b, 2019, 2022, 2023a, 2023b) and "Conspectus Florae Asiae Mediae" (1968–1993).

The scientific names and systematic positions of all species were verified based on the World Flora Online (WFO 2025) and Plants of the World Online (POWO 2025) databases and aligned with the APG IV (2016) phylogenetic classification system.

Species were categorized into the following groups according to their biogeographical origin:

1. Native: Species historically present in the flora of Uzbekistan without human intervention, whose natural range covers the study area.
2. Alien: Species separated from their natural range as a result of human activity, introduced, and adapted to the urban environment to varying degrees.

Unlike European traditions that use strict chronological boundaries (e.g., 1492/1500 AD) to classify alien species into archaeophytes and neophytes, establishing such precise temporal limits for the flora of Uzbekistan is highly challenging. As noted by Baranova et al. (2018), temporal criteria should be region-specific, depending on the historical and anthropogenic influences on the specific area. Due to Central Asia's long history of ancient agriculture and transcontinental trade (e.g., the Great Silk Road), combined with a lack of precise archaeobotanical records, establishing an exact historical timeframe to distinguish between archaeophytes and neophytes is currently infeasible. Therefore, our categorisation of native and alien species was based primarily on biogeographical analyses, native-range assessments, and fundamental regional floristic literature.

The degree of naturalization of alien species was assessed using the conceptual framework proposed by Richardson et al. (2000) and Pyšek et al. (2004). According to these criteria, alien species were categorized into three main groups: 1) casual aliens, which do not form self-replacing populations; 2) naturalized aliens, which sustain populations without direct human intervention; and 3) invasive aliens, a subset of naturalized plants that produce reproductive offspring at considerable distances and have the potential to spread over a wide area. Furthermore, to align our assessment with regional conservation strategies, the recommendations for compiling regional 'Black Books' of flora (Vinogradova et al. 2010) and recent fundamental assessments of the invasive flora of Uzbekistan (Tojibaev and Esanov 2021) were followed, and invasive species were further evaluated based on their ecological impact. Specifically, we identified 'transformers' (highly aggressive agriophytes) — species that actively penetrate natural and semi-natural communities, significantly alter ecosystem structure, and suppress native flora. To ensure the objectivity of the analysis, strictly cultivated non-naturalised plants that require constant agrotechnical care were excluded from the checklist. The complete species checklists for each city, including taxonomic details and origin status (native/alien), are provided in Suppl. materials 1–3.

Phylogenetic tree construction

A phylogenetic tree comprising all species recorded during the study (total 1,022 species) was constructed using the U.PhyloMaker package (Jin and Qian 2023) within the R 4.2.0 software environment (R Core Team 2020). This package is a general-purpose tool for generating large phylogenetic trees for plants and animals. The largest vascular plant mega-phylogeny, GBOTB.extended.TPL (Jin and Qian 2022), was selected as the backbone megatree. Species were bound to the tree using the package's build.nodes.1 function under Scenario 3. In this scenario, species absent from the megatree are added as new branches at the basal node of their respective genus or family, thereby preventing taxonomic data loss. As a result of the tree generation, 559 species were placed directly into the megatree (species level), while the remaining 418 and 45 species were attached to the root of their genus (genus level) and family (family level), respectively. Analyses conducted by Qian and Jin (2021) demonstrated that phylogenetic metrics calculated from genus-level trees exhibit a strong correlation ($R^2 > 0.95$) with results from fully resolved species-level trees. Therefore, this approach is considered reliable for assessing the evolutionary structure of urban flora.

Phylogenetic diversity and structure analysis

Two quantitative approaches were employed to assess the evolutionary history of urban floras. First, to assess the community's evolutionary potential, Faith's PD was calculated using Faith's (1992) methodology. This index represents the total length of phylogenetic branches connecting all species in the community and typically exhibits a strong correlation with species richness (Tucker et al. 2017).

Simultaneously, the Mean Phylogenetic Distance (MPD) index was applied to identify ecological mechanisms (environmental filtering and interspecific competition) driving community assembly (Webb et al. 2002). This metric, representing the mean pairwise phylogenetic distance between every pair of species in a community, is notable for being richness-independent, thereby enhancing the ecological precision of the analysis (Cadotte, Davies 2016).

To assess the non-randomness of the phylogenetic structure, a Null-model approach was employed. For each city, 1,000 randomized communities were generated. In this process, the taxa.labels null model was used, where the species list remained constant while the positions of species on the phylogenetic tree were randomly shuffled. The Standardized Effect Size of MPD (SES.MPD) was calculated based on the observed MPD value and the mean value of the null model using the following formula:

$$SES.MPD = \frac{MPD_{obs} - meanMPD_{null}}{sdMPD_{null}}$$

The ecological interpretation of the results was based on the criteria proposed by Swenson (2014). According to these criteria, negative SES.MPD values (SES.MPD < 0) indicate phylogenetic clustering, reflecting the co-occurrence of closely related species under environmental filtering. Conversely, positive values (SES.MPD > 0) indicate phylogenetic overdispersion, suggesting an environment free from limiting factors or driven by interspecific competition. The statistical significance of the analysis was assessed using a 95% confidence interval; clustering was considered statistically significant at $p < 0.025$, and overdispersion at $p > 0.975$.

Statistical analysis

All statistical analyses and visualizations were performed in the R 4.2.0 software environment (R Core Team 2022).

The degree of similarity in the taxonomic composition of urban floras was determined using the Jaccard similarity index (*J*):

$$J = \frac{a}{a + b + c}$$

Where: a is the number of species shared by both cities; b and c are the number of species recorded in only one of the two cities, respectively (Legendre and Legendre 2012).

Phylogenetic diversity indices (PD, MPD, SES.MPD) and p-values were calculated using the ‘picante’ R package (Kembel et al. 2010).

The statistical significance of differences between groups (specifically between native and alien species) was tested using the Mann-Whitney U (Wilcoxon rank-sum) test.

Results

Taxonomic composition and species richness

Among the studied urbanization centers, the highest species richness was recorded in Tashkent (736 species; Suppl. material 1: Table 1), followed by Fergana (535 species; Suppl. material 2: Table 2) and Bukhara (256 species; Suppl. material 3: Table 3). In the taxonomic spectrum of the flora, the division Magnoliophyta absolutely dominated, accounting for 99.4–99.7% of the total species composition. In particular, the class Magnoliopsida had the highest average share, at 79.8% (Table 1).

Analysis of the flora by origin revealed that native species predominate in all cities (average 71.7%). Alien species accounted for an average of 28.3% of the total flora (Table 1).

Floristic similarity analysis

Analysis of floristic similarity revealed that Jaccard similarity coefficients for native species among cities were relatively low (0.130–0.230), with an average of 0.184. This indicates that the native flora of each city has retained its distinct regional characteristics.

In contrast, the degree of similarity in alien species composition was found to be significantly higher than that of native species (0.155–0.395; average 0.242). Notably, the alien flora of Fergana and Bukhara cities recorded the highest similarity coefficient (J = 0.395) (Table 2). This result suggests that the urbanization process is reducing interregional floristic differences through the spread of alien species.

Table 2. Jaccard similarity coefficient values between urban floras

Urban flora of:	1	2	3
1. Bukhara	–	0.193	0.130
2. Fergana	0.395	–	0.230
3. Tashkent	0.155	0.176	–

Note: Cells upper the diagonal show values for native species and cells below the diagonal present the alien species values.

Phylogenetic diversity and mean phylogenetic distance

As expected, the analysis of Faith's PD demonstrated a strong positive correlation with species richness. Across the regions, the highest evolutionary diversity was recorded in Tashkent (PD = 17,601.5 million years), while the lowest value was observed in Bukhara (PD = 8,698.8 million years) (Table 3). Simultaneously, the Mean Phylogenetic Distance (MPD) of all urban floras was found to be relatively stable, ranging from 237.6 to 243.3 million years.

The statistical analysis found no statistically significant difference in mean MPD values between native and alien species across cities ($t = 0.687$, $p = 0.56$). The mean MPD value for native species was 240.37 million years, and for alien species, 235.07 million years. This indicates that in the urban flora of Uzbekistan, native and alien species occupy various branches of the phylogenetic tree in nearly equal proportions, and the general evolutionary structure of the flora has formed based on a similar logic for both groups.

Table 3. PD and MPD of native and alien species in urban flora

City	Total flora	Urban flora plant class	
		Native	Alien
		PD:	
Bukhara	8,698.77	6,445.29	4,543.83
Fergana	14,402.06	11,764.93	5,498.65
Tashkent	17,601.5	14,633.98	5,852.93
		MPD:	
Bukhara	237.6	233.3	243.4
Fergana	243.3	246.4	232.6
Tashkent	240.4	241.4	229.2

Note: Values in millions of years.

Phylogenetic structure analysis (SES.MPD)

The results of the Standardized Effect Size of MPD (SES.MPD) analysis revealed significant differences between the phylogenetic structure of native and alien species in urban floras (Fig. 2).

Figure 2. Results of null-model analysis of the phylogenetic structure of native and alien species (classes) in three cities of Uzbekistan. Positive SES.MPD values indicate phylogenetic overdispersion, whereas negative values indicate phylogenetic clustering. Red dashed lines represent statistical significance thresholds ($p < 0.025$ and $p > 0.975$).

Specifically, in Bukhara, the SES.MPD value for native species was found to be negative and statistically significant (SES.MPD = -1.592, p = 0.015). This indicates distinct phylogenetic clustering in this region, implying that only closely related species have survived environmental filtering. In contrast, in Fergana (SES.MPD = 1.384, p = 0.92) and Tashkent (SES.MPD = -0.359, p = 0.366), the phylogenetic structure of native species did not differ from null-model expectations and was confirmed to be random.

The situation was markedly different for alien species: in Tashkent (SES.MPD = -2.237, p = 0.001) and Fergana (SES.MPD = -1.607, p = 0.007), alien species exhibited strong, statistically significant phylogenetic clustering. Conversely, in Bukhara, the phylogenetic structure of alien species was found to be random (p = 0.649) and free from clustering.

Discussion

Urbanization and species richness

This study aimed to comparatively assess the phylogenetic diversity and structural assembly mechanisms of the floras of three major urbanization centers located in different climatic zones of Uzbekistan. Our results showed that the species richness of urban flora has a strong positive correlation with the scale of urbanization (area and population size). Tashkent, having the largest area (334.8 km^2) and population (over 3 million), exhibited the highest species richness (736 species), while Fergana showed an intermediate value (535 species). This result is fully consistent with global urbanization patterns, which suggest that large cities support a rich flora due to habitat heterogeneity and a high number of introduction sources (Pyšek 1998; Aronson et al. 2014).

In contrast, the remarkably low number of species in Bukhara (256 species) is attributable not only to urbanisation but also to regional climatic constraints. Specifically, the arid climate of the desert zone where Bukhara is located (annual precipitation 138 mm) limits the natural distribution of many mesophilic species (e.g., native taxa such as *Viola* spp. and *Adiantum capillus-veneris* L., as well as moisture-demanding aliens like *Aesculus hippocastanum* L., which are successfully established in the more temperate cities of Tashkent and Fergana). This confirms that the relationship between urban area and species richness is modified by climatic factors, as observed in the arid cities of Uzbekistan (Veselkin et al. 2017).

However, the high proportion of alien species in Bukhara cannot be explained solely by modern urbanization but also by profound historical factors. Owing to their long-standing position as strategic crossroads of the Great Silk Road, the cities of Bukhara, Samarqand, and Xorazm have historically provided a conducive context for the introduction of plant diasporas from diverse geographic regions and for their subsequent persistence through sustained human activity (Spengler 2019). This led to the formation of a distinct alien (especially archaeophyte) layer in the urban flora despite arid climatic constraints (Tojibaev and Esanov 2021).

Furthermore, although the arid climate of Bukhara exerts significant stress on alien species, they have been able to spread freely due to reduced competition from a relatively depauperate native flora (Pyšek 1998; Aronson et al. 2014). This phenomenon can be explained by the concept of "biotic resistance"; when native floras are species-poor, more ecological niches remain vacant, which are then readily occupied by incoming alien species. In Tashkent and Fergana, where the richness of native species is relatively higher, the expansion potential for alien species appears to be more constrained.

Alien species and biotic homogenization

Analysis of Jaccard similarity indices indicated that alien species are the primary driver of the homogenization of regional floras. Specifically, while the similarity of native species between Fergana and Bukhara was relatively low (J = 0.193), the similarity in alien species composition was nearly twice as high (J = 0.395). This result suggests that biotic homogenization is accelerating across Uzbekistan's cities.

The urbanization process facilitates the widespread distribution of a few cosmopolitan species known as "global winners", which are highly adapted to human activity (McKinney 2006; Aronson et al. 2014). Consequently, although Tashkent, Fergana, and Bukhara are situated in different natural-climatic zones, identical weed and ornamental plant species (e.g., widespread aliens like *Amaranthus retroflexus* L., *Portulaca oleracea* L., and *Chenopodium album* L.) spread by anthropogenic factors are homogenizing the floristic appearance of these cities, leading to a loss of regional distinctiveness.

Phylogenetic diversity and evolutionary history

During the study, phylogenetic diversity (Faith's PD) of native species was significantly higher than that of alien species across all cities (e.g., in Tashkent: Native PD = 14,634 million years; Alien PD = 5,853 million years). This expected result reaffirms the general pattern that phylogenetic diversity is strongly positively correlated with species richness (Forest et al. 2007; Tucker et al. 2017). This indicates that the native flora has evolved over a long period, adapting to regional conditions and encompassing numerous families and genera across diverse branches of the phylogenetic tree.

However, along the gradient of decreasing urban area and increasing aridity (Tashkent → Fergana → Bukhara), a proportional decrease in total PD values was also observed (17,601 > 14,402 > 8,699). This trend suggests that severe water scarcity in arid regions not only limits taxonomic richness but also significantly shortens the community's "evolutionary branch length." Such a reduction in evolutionary history may weaken the functional stability of arid urban ecosystems and reduce their resilience to external stress factors (Flynn et al. 2011; Cadotte et al. 2019).

The "Bukhara anomaly": relaxation of filtering

The most remarkable and distinctive result of this study was recorded in Bukhara. Here, strong phylogenetic clustering was observed in native species (SES.MPD = -1.592), while alien species exhibited a random or overdispersed structure. We interpret this "Bukhara anomaly" based on the theory of Mayfield and Levine (2010) through a dual mechanism:

1. Intensification of Abiotic Filtering (For Native Species): In the desert ecosystems surrounding Bukhara, water scarcity and high salinity act as potent abiotic filters. Since stress-tolerance traits are often phylogenetically conservative, the environment selects only closely related groups that possess these adaptations (e.g., various genera of Amaranthaceae), resulting in significant phylogenetic clustering.
2. Relaxation of Filtering (For Alien Species): The presence of intensive anthropogenic management within the urban environment (constant irrigation, fertilization) artificially overcomes natural climatic barriers (relaxation of environmental filtering). This allows diverse alien species (e.g., *Hibiscus trionum* L., *Datura stramonium* L., and *Portulaca oleracea* L.) that are evolutionarily distant and could not survive under local natural conditions to coexist in the same urban space. This process manifests as a "Phylogenetic Release" mechanism, forming the random phylogenetic structure of the alien flora.

From this perspective, and in analogy to the case of Bukhara, systematic research efforts are currently underway in Samarqand, as well as in other urban areas of Uzbekistan not yet encompassed by the present study. These initiatives aim to assemble comprehensive distributional datasets, develop complete floristic inventories, and quantify the relative contributions of native and alien components within urban plant assemblages. Such coordinated investigations will provide a robust empirical framework for disentangling the interactive effects of climatic, historical, and anthropogenic drivers on urban flora assembly. Moreover, they will enable more rigorous comparative assessments of species richness patterns and the strength of biotic resistance across spatially distinct regions. Consequently, these expanding datasets will facilitate a clearer understanding of floristic differentiation among Uzbek cities, particularly by elucidating structural and compositional contrasts between arid and relatively mesic urban ecosystems.

Conclusion

The results of this study demonstrate that, although the urban floras of Uzbekistan have been enriched by alien species, their phylogenetic structure varies sharply across regional climates. Specifically, in Tashkent and Fergana, the urban environment acts as a strong "ecological filter", similar to patterns observed in other temperate cities, resulting in significant phylogenetic clustering among alien species.

The primary scientific novelty of this research is the identification of the "Phylogenetic Release" mechanism in the arid city of Bukhara. In this extreme environment, the urban setting functions not as a restrictive filter, but as a "facilitator". It has been shown that anthropogenic support enables the coexistence of evolutionarily diverse and distantly related alien species by mitigating natural environmental stressors.

In conclusion, the urban flora of Uzbekistan exhibits a unique evolutionary dynamic resulting from the complex interaction between global urbanization patterns and regional arid climatic factors. These scientific findings provide a crucial foundation for developing strategies to preserve urban biodiversity and implement sustainable landscaping amid global climate change.

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Supplementary material 1

Table 1. Checklist of the urban flora of Tashkent city

Authors: Zukhuridin Juraev, Ilkhomjon Urinboev, Husniddin Esanov, Feruz Akbarov, Gulkhayo Gofurova, Bobur Karimov, Inom Juramurodov, Nazokat Daminova, Kimyo Aslonova, Dilmurod Makhmudjanov,Komiljon Sh. Tojibaev

Data type: table

Link: https://journal.asu.ru/biol/article/view/19360/16535

Supplementary material 2

Table 2. Checklist of the urban flora of Fergana city

Authors: Zukhuridin Juraev, Ilkhomjon Urinboev, Husniddin Esanov, Feruz Akbarov, Gulkhayo Gofurova, Bobur Karimov, Inom Juramurodov, Nazokat Daminova, Kimyo Aslonova, Dilmurod Makhmudjanov,Komiljon Sh. Tojibaev
Data type: table

Link: https://journal.asu.ru/biol/article/view/19360/16536

Supplementary material 3

Table 3. Checklist of the urban flora of Bukhara city

Authors: Zukhuridin Juraev, Ilkhomjon Urinboev, Husniddin Esanov, Feruz Akbarov, Gulkhayo Gofurova, Bobur Karimov, Inom Juramurodov, Nazokat Daminova, Kimyo Aslonova, Dilmurod Makhmudjanov,Komiljon Sh. Tojibaev
Data type: table

Link: https://journal.asu.ru/biol/article/view/19360/16537