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SYSTEMATIC STUDY OF ARID TERRITORIES

Floristic Diversity of Insular Pine Forests of the Trans-Volga–Kazakh Steppe Province

E. A. Eremeeva[a], * and N. B. Leonova[a], **

[a] *Faculty of Geography, Moscow State University, Moscow, 119234 Russia*

**e-mail: erem_a995@mail.ru*

***e-mail: nbleonova2@gmail.com*

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Abstract—The insular pine forests of the Trans-Volga–Kazakh province of the Black Sea–Kazakh steppe region have high biodiversity and are relict in nature. The problems of their study and conservation are relevant in the context of increasing anthropogenic impact and climatic changes. A comprehensive analysis was performed for the floristic composition of communities of pine forests from the Burabai, Karkaraly, and Buzuluk national parks, the Naurzum Reserve, the Kanonersky forestry enterprise (south of the Priishimsky altitudinal zone pine forests), the pine forests of the Ilmensky Reserve and the Burlinsky altitudinal zone located in forest–steppe regions near the northern border of the province based on our own field materials and published data. For the first time, the data on the floristic diversity of all large pine forests in the province (the geographical aspect) are summarized in a unified manner. The similarity in the taxonomic, geographical, ecological, morphological, and coenotic structure of the floristic composition of all isolated insular pine forests indicate the presence of historical links and their relic character. The results of the correlation and cluster analysis of floristic lists showed a different degree of similarity between pine forests in different parts of the province in connection with the specific physical and geographical conditions. Three groups of pine forests have been identified: (a) pine forests of the sandy massifs of the Naurzum Reserve and the Kanonersky forestry enterprise, which have the most xerophilic appearance and are poor in composition, with a predominance of steppe species and turf grasses; (b) pine forests of granite massifs of the Kazakh Uplands (Burabay and Karkaraly national parks) with an average species richness; (c) the Buzuluk and Burlinsky pine forests, which occupy the most northern, borderline position in the province, with high floristic diversity and increased participation of forest species.

Keywords: insular pine forests, steppe province, taxonomic and typological diversity, ranges, ecological–coenotic groups of species

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INTRODUCTION

The nature, structure, and origin of insular forest ecosystems existing to the south of the border of the modern zonal distribution, in particular, within the Trans-Volga–Kazakh steppe province, have long attracted the attention of geographers and geobotanists (Sukachev, 1972; Karamysheva, 1973; Gorchakovskii, 1987; *Stepi Evrazii*..., 1991). At present, the problem of the preservation of these communities with unique phytodiversity is becoming more acute under the conditions of increasing anthropogenic pressure and climatic changes (Gorchakovskii, 2005; Kin, 2010; Sultangazina, 2015). However, the effective conservation of plant communities is possible only based on a comprehensive knowledge of their structure, ecology, and geography. Despite the quite large number of regional studies (Gael, 1962; Zaugol'nova and Vorontsova, 1975; Khrustaleva, 2009), modern studies of a generalizing nature are scarce. The purpose of this study is to identify the taxonomic and typological diversity of the floristic composition of relict pine forests of the Trans-Volga-Kazakh steppe province throughout its entire length in connection with ecological and geographical factors.

MATERIALS AND METHODS

The Trans-Volga–Kazakh steppe province (TVKP) refers to the Black Sea–Kazakh subregion of the Eurasian steppe region (Lavrenko, 1970). Seven insular pine massifs were considered, five of which are located in the subprovinces of the TVKP: the Burlinsky pine forest in the Trans-Volga-Ergeni subprovince, Naurzum Reserve in the Trans-Urals-Torgay subprovince, Burabay State National Natural Park in central Kazakhstan, and Karkaraly National Parks (NPs) and Kanonersky Forestry in the eastern Kazakh subprovince. In addition, the pine forests of the Ilmen Reserve in the southern Urals and the Burlinsky ribbon-like

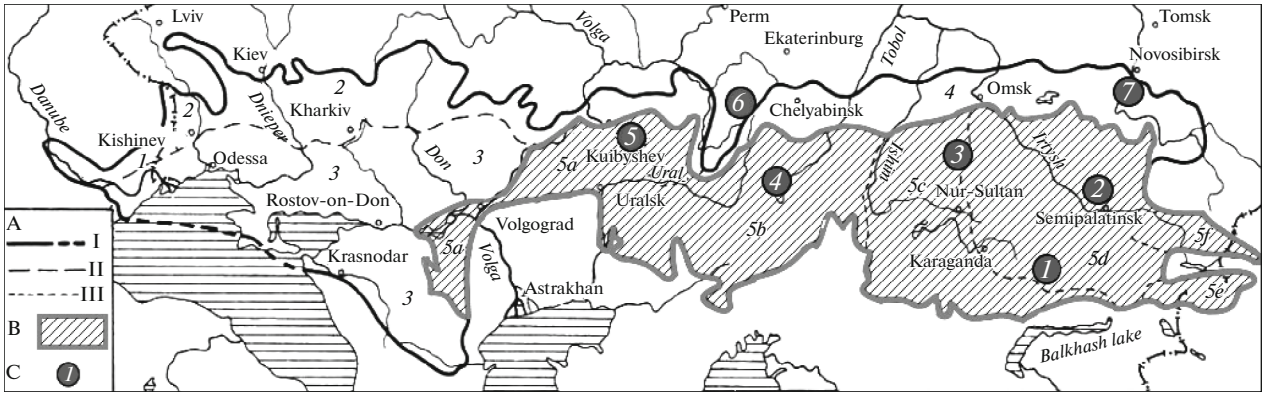

Fig. 1. Position of the considered pine massifs in the system of botanical–geographical zoning of the Black Sea–Kazakh subregion of the steppe region of Eurasia (*Stepi Evrazii*, 1991). *Legend.* (A) Borders: I, subareas; II, provinces; III, subprovinces. Provinces: (*1*) Balkan-Mesian forest–steppe; (*2*) eastern European forest–steppe; (*3*) Black Sea (Pontic) steppe; (*4*) western Siberian forest–steppe; (*5*) TVKP. (B) Territory of the TVKP: (*5a*) Ergeni–Trans-Volga steppe subprovince; (*5b*) Trans-Ural–Turgai steppe; (*5c*) central Kazakh steppe; (*5d*) eastern Kazakh steppe; (*5e*) Saur–Tarbagatai steppe; (*5f*) Kalba–Southern Altai mountain-steppe. (C) Covered pine massifs: (*1*) Karkaraly NP (RK*); (*2*) Kanonerski Forestry (RK); (*3*) Burabay NP (RK); (*4*) Naurzum Reserve (RK); (*5*) Buzuluk pine-forest NP (RF**); (*6*) Ilmen Reserve (RF); (*7*) Burlinsky ribbon-like pine forest (RF). *RK, Republic of Kazakhstan; **RF, Russian Federation.

pine forest were considered for comparison with similar communities of the forest–steppe zone (Fig. 1).

The botanical–geographical province of the Trans-Volga-Kazakh steppe occupies a vast area and is distinguished by a wide variety of geological structures, climatic conditions, landscapes, vegetation, and soil cover. The province includes flat areas with a developed sedimentary cover, shallow hills formed by granite intrusions with large areas of denudation plains between them, and the foothill parts of mountain ranges of the Caledonian and Hercynian orogeny. The climate throughout the province is continental with an increase in continentality from west to east; there is a lack of moisture, and the annual and daily temperatures have large amplitudes. The soil cover is mainly represented by chestnut soils, but chernozems are found in the northern part. Mountain chernozems and mountain chestnut soils form in the foothills and in areas adjacent to the shallow hills; large territories fall on areas of saline soils. The largest area of the vegetation cover is occupied by dry, sod–grass, fescue–feather grass steppes. Forests within the province have survived only in localized habitats represented by granite and metamorphic massifs or ancient sandy terraces. The best conditions for forest growth are created here due to the favorable edaphic conditions and the specificity of the mountainous Kazakh Upland. The considered pine massifs in physical and geographical terms can be divided into the following groups: (1) the *upland pine forests* include Karkaraly and Burabay NPs and the Ilmen Reserve, which have a relatively high moisture supply compared to the surrounding territories; (2) the *northern pine forests on the sands* include the Buzuluk pine forest and Burlinsky pine forest, which are located in the northern part of the steppe zone or in the forest–steppe and are characterized by a relatively large amount of precipitation and a developed hydrological network; (3) the *southern pine forests on sands* include the Naurzum Reserve and Kanonersky Forestry, which are located in the subzone of dry steppes and have a pronounced dry season.

The analysis of the floristic diversity of pine forests was based on the field materials collected by the authors and students of the Kazakh branch of Moscow State University in the Burabay and Karkaraly NPs of the Republic of Kazakhstan in 2008–2016 (99 relevés) and data from numerous scientific publications on the natural conditions, vegetation, and flora of pine forests in the TVKP (more than 50 sources and cartographic materials). Lists of the floristic communities of insular pine forests were identified based on them.

The taxonomic diversity and identification of similarities and differences in insular pine forests were analyzed on the basis of Kendall's correlation analysis in the SPSS Statistics software and cluster analysis in the Biodiversity Pro software. The nomenclature of species and their family classification are given in accordance with *Plantarium: Open online atlas-guide for identification of the plants and lichen of Russia and adjacent countries* (2007). The analysis of the typological diversity of the floristic lists of pine forests included the identification of ecological and ecological–coenotic groups of vascular plant species, the composition of life forms, the types of geographical areas, and a comparison of their spectra for pine forests in different parts of the province. We used data on the characteristics of vascular plant species according to published data (*Illyustrirovannyi...*, 1969, 1972; Keene, 2009; *Flora USSR* (1934–1964)) and Internet sources (Plantarium..., 2007; Flora of vascular plants..., 2001; Online

Table 1. Taxonomic diversity of pine forests of the TVKP and adjacent forest–steppe regions

Geographic area	Pine forests of the TVKP					Forest–steppe pine forests	
Forest name	Buzuluk pine forest	Naurzum Reserve	Burabay NP	Karkaraly NP	Kanonersky Forestry	Ilmen Reserve	Burlinsky ribbon-like pine forest
Total number of species	314	133	165	201	99	132	255
Number of genera	190	86	120	133	68	105	162
Number of families	67	35	45	50	25	41	53
Generic coefficient	**1.65**	**1.55**	**1.38**	**1.51**	**1.46**	**1.26**	**1.57**

catalogue..., 2001; *Interactive Agricultural...*, 2008). Due to the wide variety of species range types in the published data, it was necessary to combine them into groups according to latitudinal and longitudinal principles.

RESULTS

Taxonomic analysis. The insular pine forests differ significantly from each other in terms of taxonomic diversity (Table 1). The greatest taxonomic diversity at all levels (species, genera, families) within the province is found in the Buzuluk pine forest, which is located in the west of the province and which abuts deciduous forests, enriching its flora with nemoral species. A somewhat lower, but relatively high, diversity is typical of the pine forests of the Karkaraly and Burabay NPs. The smallest values of diversity are typical of the pine forests of the Naurzum Reserve and the Kanonersky Forestry. The generic coefficient, the ratio of the number of plant species to the number of genera, shows how evenly the species are distributed over the genera (Tolmachev, 1974). A high generic coefficient for a certain territory may be due to the fact that its ecological conditions are favorable for the development of some systematic groups. A low generic coefficient can be interpreted as an indicator of high intraspecific competition (Elumeeva, 2007). The highest indices of the generic coefficient are observed for the flora of the pine forests of the Buzuluk pine forest, the Burlinsky ribbon-like pine forest, and the Naurzum Reserve (more than 1.5), which indicates that their diversity is achieved largely due to multispecies genera.

Rank analysis of family representation showed a significant similarity between pine forests. Representatives of the Compositae family predominate. The second place is occupied by *cereals*, the proportion of which is maximal in the arid conditions of the Naurzum Reserve and Kanonersky Forestry. The third place is occupied by Rosaceae, the proportion of which is usually close to grasses; it significantly decreases only in the pine forests of sandy hillocks (Naurzum Reserve and Kanonersky Forestry; Fig. 2).

The Kendall's rank correlation coefficients (Table 2) make it possible to judge the similarities and differences between the floristic composition of individual pine stands. Data on the species number in the 23 most numerous genera in terms of the number of species

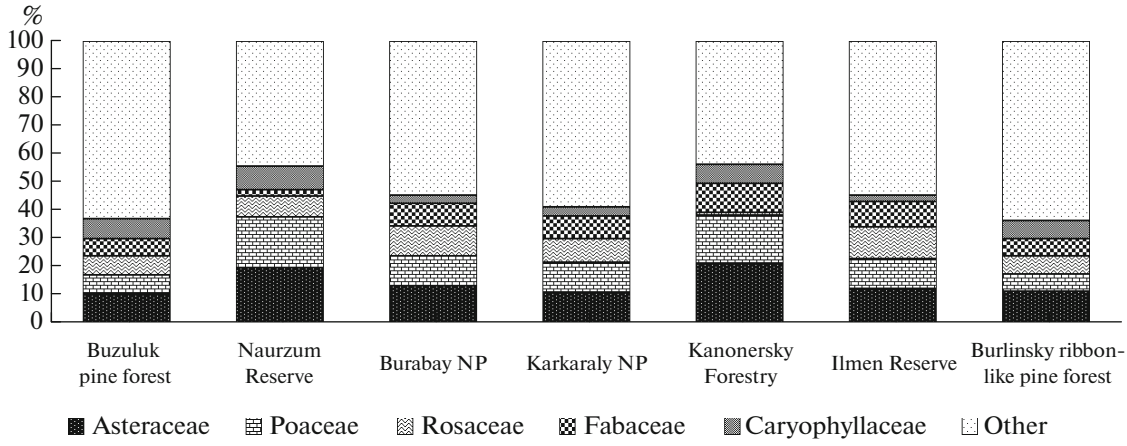

Fig. 2. Taxonomic spectra of pine forests of the TVKP and adjacent forest–steppe regions.

Table 2. Kendall's rank correlation coefficients for floristic lists of insular pine forests

		Bz*	Nz	Burab	Kark	Kanon	Ilm	Burl
Bz	1**		–0.20	0.03	–0.11	-0.15	0.08	0.25
	2		0.26	0.85	0.51	0.40	0.67	0.14
Nz	1	–0.20		0.04	–0.02	0.56	–0.10	–0.08
	2	0.26		0.84	0.93	0.002	0.59	0.63
Burab	1	0.03	0.04		0.41	0.15	0.39	0.25
	2	0.85	0.84		0.02	0.387	0.03	0.14
Kark	1	–0.11	–0.02	0.41		0.12	0.36	0.21
	2	0.51	0.928	0.02		0.495	0.047	0.21
Kanon	1	–0.15	0.56	0.15	0.12		–0.08	0.16
	2	0.40	0.002	0.39	0.50		0.678	0.35
Ilm	1	0.08	–0.10	0.39	0.36	–0.08		0.06
	2	0.67	0.59	0.03	0.05	0.68		0.76
Burl	1	0.25	–0.08	0.25	0.21	0.16	0.06	
	2	0.14	0.63	0.14	0.21	0.35	0.76	

* Bz, Buzuluk pine forest, Nz, Naurzum R; Burab, Burabay NP; Kark, Karkaraly NP; Kanon, Kanonersky Forestry; Ilm, Ilmen Reserve; Burl, pine forest; ** 1, correlation coefficient; 2, significance (two-way). Darker tone indicates coefficients of significance less than 0.05 (two-way).

characteristic of all massifs were used for the calculation. Correlation links were found between the ancestral lists of pine forests of the Karkaraly NP, Burabai NP, and the Ilmen Reserve. A closer connection was found between the lists of the Naurzum Reserve and the Kanonersky Forestry. This suggests that the flora of the forest areas of the TVKP has a high level of originality. However, some similarities are found between some pine forests due to the similarity of historical development and modern forest-growing conditions. Insignificant correlation coefficients are observed for Buzuluk and Burlinsky pine forests, which may be explained by their remoteness.

To identify the similarity between the floristic composition of the considered pine forests, cluster analysis was also carried out with the Biodiversity-Pro software according to Bray-Curtis (Fig. 3). The pine forests of the Karkaraly and Burabay NPs have the greatest similarity. The next group includes the pine forests of the Buzuluk pine forest and the pine forests of the forest–steppe zone (Burlinsky ribbon-like forest and Ilmen nature reserve). The pine forests of sandy massifs (pine forests of the Naurzum Reserve and the Kanonersky Forestry) stand apart.

Geographic analysis. The pine forests of the TVKP are dominated by species with a wide range: Eurasian

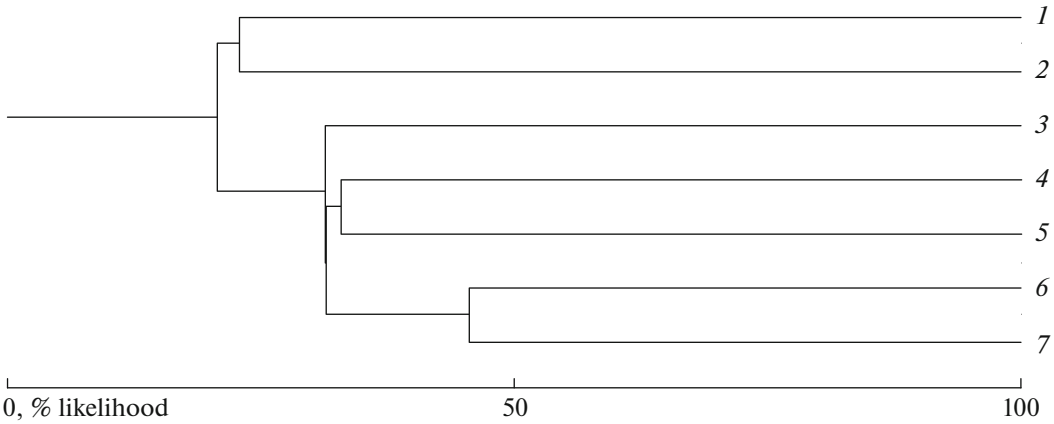

Fig. 3. Cluster analysis of TVKP pine forests and forest–steppe zone. (*1*) Kanonersky Forestry; (*2*) Naurzum Reserve; (*3*) Ilmen Reserve; (*4*) Burlinsky pine forest; (*5*) Buzuluk pine forest; (*6*) Burabay NP; (*7*) Karkaraly NP.

Table 3. Distribution of the number of species of vascular plants in pine forests by area type

Areas	1*	2	3	4	5	6	7	8	9	Total
Arctoalpine	0	4	0	0	0	0	0	0	0	**4**
Tundra forest	0	2	0	2	0	0	0	0	0	**4**
Boreal	0	21	14	9	2	6	1	0	1	**54**
Boreal-nemoral	0	18	**40**	19	0	14	0	0	0	**91**
Nemoral	0	20	**55**	26	0	**41**	0	0	0	**142**
Large-leaved	0	1	6	4	2	1	4	1	0	**19**
Boreal-nemoral-steppe	0	10	**48**	14	3	15	0	0	0	**90**
Steppe	0	15	**166**	30	**37**	**41**	9	12	9	**317**
Plurizonal	8	21	**48**	2	0	2	0	0	0	**81**
Synanthropic	1	2	0	0	1	0	0	0	0	**4**
Total by group	**9**	**116**	**377**	**106**	**45**	**120**	**14**	**13**	**10**	

* Longitudinal confinement of areas: 1, hemicosmopolitan; 2, Holarctic; 3, Eurasian; 4, Euro-Siberia; 5, Asian; 6, European, 7, Siberian; 8, Black Sea–Kazakh; 9, Trans-Volga–Kazakh (Kin, 2009; Sultangazina, 2015; *Flora USSR*, 1934–1964; Plantarium..., 2007; Online catalogue..., 2001; *Interactive Agricultural*..., 2008).

(47%), Holarctic (14%), Euro-Siberian (13%), and European (15%; Table 3). The predominance of species with European ranges is probably associated with their increased number in the Buzuluk pine forest, as well as with historical links: some of the species are noted in different pine forests.

Steppe species predominate in terms of the latitudinal distribution of areas (39%). A smaller but significant number is represented by species with a nemoral type of range (18%), boreal–nemoral (11%) and plurizonal species (10%), taiga (boreal) species (7%). The penetration of the forests by such a large number of steppe species indicates links with the surrounding steppe spaces and the gradual steppe formation of forests. The forest species found in the forests of the TVKP mainly have wide ranges that cover the boreal and large-leaved zones and extend to the south beyond it. An increased number of nemoral species is associated with the Buzuluk pine forests, which are in direct contact with deciduous forests, often forming mixed deciduous-pine stands. Eleven species endemic to the TVKP are found in the TVKP forests. These are mainly steppe species, but there is a species among them that is characteristic directly of pine forests—*Betula kirghisorum*.

Analysis of life forms according to the classification of (Serebryakov, 1962) revealed a significant similarity in the distribution of species according to the classification of life forms between pine forests of different subprovinces. The tree tier contains one representative of evergreen trees *Pinus sylvestris* L. and deciduous *Betula pubescens, Populus tremula*, while the others comprise only 1–5% of the floristic composition. All of the considered pine forests have more deciduous shrubs than evergreens (*Cerasus fruticosa, Crataegus sanguinea*, etc.). The smallest proportions of woody and shrub plants are observed in the pine forests of the Kanonersky Forestry, while the highest proportions are in the Buzuluk pine forest. The herb–dwarf shrub layer is dominated by rhizome (31–45%), root (18–25%), and turf (6–12%) perennials.

Ecological–coenotic analysis showed that steppe and meadow species predominate in all considered pine forests. Their number is practically equal in the Naurzum Reserve, and steppe species clearly predominate in the Kanonersky Forestry. In addition, both pine forests have a high proportion of petrophytic and psammophytic steppe species due to edaphic conditions. The forest species (boreal, nemoral, and upland) are next in terms of importance in communities. The largest number of species of these groups is naturally observed in the more northern pine forests of the forest–steppe zone: in the Burlinsky pine forest and in the Ilmen Reserve. The share of forest nemoral species is significantly increased in the Buzuluk pine forest. Their participation in dry pine forests on the sands of the Naurzum Reserve and the Kanonersky Forestry is, on the contrary, reduced. The pine forests of granite low mountains (Karkaraly and Burabay NPs) occupy an intermediate position in terms of the number of forest species. In contrast to Buzuluk pine forest, forest species are represented by boreal elements in all other insular pine forests of the botanical–geographical TVKP.

CONCLUSIONS

Studies of the floristic composition of communities of relict pine forests, which are widespread across insular massifs in the TVKP, found a number of common features and differences in their phytodiversity that were due to which features of the physical and geographical conditions.

The floristic diversity of the TVKP pine forests decreases from north to south due to climate aridization and distance from the main forest area. The maximum values of species diversity are typical of the Buzuluk and Burlinsky pine forests, while the minimum values are typical of the forests of the Naurzum Reserve and Kanonersky Forestry.

Taxonomic analysis showed a significant similarity of spectra in different parts of the province: representatives of the Asteraceae, Gramineae, Rosaceae, and Fabaceae families predominate. The spectra differ in the Naurzum nature reserve and the Kanonersky Forestry, where the share of grasses is increased. Analysis of the Kendall's rank correlation for genera and cluster analysis for species showed that (a) the pine forests of the Karkaraly and Burabay NPs and (b) the Naurzum nature reserve and Kanonersky Forestry have the greatest similarity in floristic composition.

Analysis of the ranges of vascular plant species revealed the predominance of species with wide Eurasian, Holarctic, Euro-Siberian, and European ranges.

The predominant life forms are represented rather uniformly in the pine forests of the province: the arboreal and shrub tier have a similar composition, and the rhizome, root, and turf perennials prevail among the grasses.

Species of meadow and steppe ecological–coenotic groups prevail in the pine forests of the province. An important role in the composition of communities is played by forest species, including boreal, boreal-nemoral, nemoral, and upland species: their largest share is observed in the Buzuluk and Burlinsky pine forests, and the minimum share is observed in the Kanonersky Forestry and the Naurzum Reserve, where they grow in flat conditions on sand.

In general, three groups of pine forests that are similar in phytodiversity have been identified: (a) pine forests of the Naurzum Reserve and the Kanonersky Forestry, which have low indicators of floristic diversity, the most xerophilic appearance of communities, a predominance of steppe species, and the maximum distribution of turf grasses; (b) pine forests of the Karkaraly NP, Burabay NP, and Ilmen nature reserve, which are confined to the hills and are characterized by an average species diversity and a transitional composition of taxonomic and typological spectra; (c) Buzuluk and Burlinsky pine forests, which occupy a border position in the province and have high floristic diversity and increased participation of forest species.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that they have no conflicts of interest.

Statement on animal welfare. This article does not contain any studies involving animals performed by any of the authors.

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