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RESEARCH ARTICLE

Structure of coenopopulations and phytocoenotic confinement of *Paeonia tenuifolia* L. in floristic complexes of Oka-Don lowland

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ABSTRACT
Paeonia tenuifolia L. is a rare and protected plant of Saratov region classified as 2 (V) vulnerable species. It has been established that in Kalininsky district, Saratov region, this plant is characterized by narrow environmental amplitude and is exerted to anthropogenic impacts, the coenopopulations are isolated from each other. Existence of the species in communities of the meadow–steppe floristic complexes of Kalininsky district has confirmed that peony is heliophyte, xeromesophyte, eutrophic plant and calcicole. Photophily of *P. tenuifolia*is confirmed first of all by its high abundance and occurrence in open steppe communities. In both coenopopulations of *P.tenuifolia*, the indices of recovery have been higher than 1 (CP 1 I_{rec} = 3.38, CP 2 I_{rec} = 1.67), that is, the coenopopulations are relatively steady, numerous seeds are generated giving birth to viable individuals. The index of replacement showing the ratio of the density of regrowth to total mature fraction of the population has been higher in CP 1 (I_{repl} = 0.80) and lower in CP 2 (I_{repl} = 0.67). Moderate index of maturing evidence long-term existence of the species in the generative state.

Introduction

Preservation of biological variety is an urgent problem of the present scenario, which should be solved first of all at the regional level since the state of ecosystems and biosphere of earth depends on environmental stability of regions. Therefore, inventory of regional floras as well as single species and their populations is highly important and necessary (1, 2).

Paeonia tenuifolia L. (Paeoniaceae family) is Balkan-Asia Minor-Eastern European species. It is forest-steppe herbaceous perennial plant up to 50 cm tall. It has compound, deeply lobed leaves with lobes up to 1–2 mm wide. The flower is solitary, large, up to 7 cm in diameter dark red colored with follicular fruits. The underground part is comprised of short rhizome with thickened roots. The plant blooms in May and is propagated by seeds (3). The areal of *P. tenuifolia* is as follows: Ukraine, Transcaucasia, Asia Minor, Balkan peninsula. In European Russia, it is found in all areas of the Central Black Earth Region; plants spread to the east up to the Samara Trans-Volga Region. It is a protected plant in 15 regions of Russia, including adjacent ones: Voronezh, Penza, Tambov, Volgograd (4, 5).

Paeonia tenuifolia is classified as 2b category, threatened species, in the Red Data Book of the Russian Federation, and as 2(V) vulnerable species, in the Red Data Book of Saratov region. It is not included in the IUCN Redlist (6, 7).

The species rareness is determined by the destruction of steppes due to recreational loading, wide-scale collection for bouquets and digging of roots. In Saratov region, *P. tenuifolia* can be occasionally met in Atkarsky, Balashovsky, Volsky, Kalininsky, Krasnoarmeisky, Saratovsky, Samoilovsky, Khvalynsky, Tatishchevsky districts. It exists in steppe meadows, forb–feather grass steppes, edges of light oak forests, shrubberies, on gulch slopes. The plant is photophilic and cannot stand overwetted soils and water stagnation. It is a facultative calcicole (8). The main limiting factors for the species are as follows: its use as ornamental plant, haying, burning dry grass on natural hayfields and pastures, deforestation, digression of natural plant communities when grazing farm animals.

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Its use as a medicinal plant is another limiting factor, although the chemical composition of *Paeonia tenuifolia* is not well understood. Decoctions and tinctures of *P. tenuifolia* exert smoothing effect on the central nervous system, the spasmolytic effect on smooth muscles of internal organs and vessels (9, 10).

Methods

In 2017–2019, due to the stories of local residents, the authors discovered the coenopopulations of *Paeonia tenuifolia* in Kalininsky district, Saratov region, during expeditions to study the resources of medicinal plants. Previously, this area was not mentioned in botanical reports as a habitat of *P. tenuifolia* and was not studied. The study area was located at the junction of the Oka-Don Plain and the Volga Upland. In Vasilkovyi Les Stow (geographical coordinates 51°34'23'' N, 44°21'12'' E, 170 m above the sea level), CP 1 was located. This stow was a high oak forest, 2 km from Akhtuba Village. The habitat was a sparse undergrowth of the oak forest. *P. tenuifolia* plants descended in the shape of a tongue along the upland fringe of the Olshanka River. The slope was south-facing with steepness of 15º. Spread of the population was 2 km (according to the speedometer). The number of species per 1 m^2 ranged from 3 to 6. The soil was represented by ordinary chernozem, thin, eroded with access to the surface of crushed stone, which corresponded to the ecological characteristics of the species. In spring, fires and grazing of small cattle were observed.

In the vicinity of Simonovka Village (51°22'15" N, 44°45'05" E; 120 m above sea level), CP 2 was located. The area of population was 200 m^2. The village was situated near the east boundary of the district on the right bank of the Balanda River (a right-bank tributary of the Medveditsa river, Don basin). In the west, the village bordered on agricultural land and the right tributary of the Balanda – the Izbukha river, in the east on floodplain forests (Fig. 1 & 2). Habitat of *P. tenuifolia* was on the southern slope and bottom of the ravine on the trail of carbonate and calcium ions outflow from ordinary, highly eroded chernozem. The length of the small flat-bottom valley was 1.7 km. The number of species per 1 m^2 ranged from 5 to 10. The anthropogenic impact included the collection for bouquets by the people and collecting them to grow as a garden plant.

Common geobotanic descriptions were used during the work (11). To obtain phytocoenotic properties, 15 random test sites, 10 m^2 each, were arranged. Specific names were given according to Cherepanov (12).

While detecting the ratio of mature and other parts of the natural coenopopulations and forecasting the state of vulnerable *Paeonia tenuifolia* species, the ontogenetic spectra were plotted. In *P. tenuifolia* cenopopulations, the age state of plants was determined visually (by the number of old and young shoots), by the state of the generative and vegetative spheres of plants, by the number and nature of leaf development on shoots, and also by the diagnoses and keys described by Serikova, Lepeshkina, Voronin (13). Ontogenetic states were determined in accordance with the ontogenesis periodization proposed by Rabotnov (14) and adjusted by Uranov (15). In order to analyze ontogenetic structure in each of the studied coenopopulations, 1 m^2 test sites were arranged randomly. All specimens were counted, and all age states were recorded (16). While analyzing the age structure of coenopopulations, the indices of recovery (I_{rec}), of generativity (I_{gener}), of replacement (I_{repl}), of age (Δ), and of efficiency (ω) were calculated. The type of coenopopulations was determined using classification by Rabotnov, as well as on the basis of combined use of maturity and efficiency criteria: Δ-ω by Zhivotovskii (17).

Results and Discussion

Despite the fact that this species is recorded in regional and federal Red Data Books, no specialized coenopopulation-related studies of this species were carried out in Volga Upland. According to data of various researchers in Russia and Volga Upland, in recent decades, its area has decreased due to negative economic activities (1, 3, 18-21). Analysis of the environmental state of such vulnerable species as *Paeonia tenuifolia* is important and is required to

Fig. 1. Map showing the location of *Paeonia tenuifolia* populations (compiled by the authors).

Fig. 2. General view of the population and a map of the area (Source: Google Maps).

detect strategy and tactics of protection and recovery of this species as well as to retain its surrounding populations of steppe and forest-steppe ecosystems of Middle Volga region.

The authors studied the coenopopulations of *Paeonia tenuifolia* in steppe areas near Akhtuba and Simonovka villages, Kalininsky district.

The performed studies revealed that in surrounding phytocenosis of *Paeonia tenuifolia*, the main dominant species determining the community type were *Bromus riparius*, *Stipa capillata*, *S. pennata, Festuca valesiaca* in most cases their codominant species was *P. tenuifolia*. The natural coenopopulations are located as components of forb-fescue-feather grass steppe, brome-feather grass steppe and feather-brome grass steppe, that is, in interrelated open steppe communities forming a complex landscape. In these communities, together with *P. tenuifolia* in the early spring synusia such rare species as *S. pennata*, *Adonis volgensis*, *Anemone sylvestris,* having similar requirements to habitat, can be met with (Table 1). Fifty-seven species were determined in total in the floristic surrounding of *P. tenuifolia* in the two populations: 37 species in CP 1 and 47 species in CP 2. The species were referred to 22 families. The most numerous were: Asteraceae – 12 species; Poaceae – 7 species; Lamiaceae – 6 species; Scrophulariaceae, Rosaceae, Ranunculaceae – by four species each. The other families were represented by 1–2 species. In both cenopopulations located in different habitats, *Elytrigia repens, Stipa capillata, Festuca valesiaca, Prunus tenella, Fragaria viridis* etc. were found as associated species.

Analysis of environmental features and occurrence of *Paeonia tenuifolia* in the communities of meadow–steppe floristic complexes in Kalininsky district confirmed that *P. tenuifolia* was heliophyte, xeromesophyte, eutrophic plant, calcicole, coenophil and erosiophobe. Photophily of *P. tenuifolia* was first of all confirmed by its abundancy and occurrence in open steppe communities. Even in the edges of light forests, it occurred mainly in light edges and glades; it did not grow in the centre of forest communities with lower illumination.

In the ontogenetic spectrum of CP 1, pregenerative plants were dominant: 80.0% of the total number of analyzed specimens, sprouts were the maximum fraction (30.9%). The second local maximum was observed for the virginile plants (20.0%). A high fraction of pregenerative plants evidences the ability of the population to self-reproduction.

Among the plants of generative fraction, young generative species dominated (7.3%). The coenopopulation was normal, complete, leftward. In CP 2, the fraction of sprouts was 25.0%, high content of virginal (16.7%) and juvenile (13.8%) fractions were observed. The fraction of subsenile plants was low (2.8%). According to the ratio of age states by the Bodenheimer classification, cenopopulations were stationary i.e. with a natural ratio of species of different age groups.

The coenopopulation was normal, complete, leftward (Fig. 3 & 4). According to the classification by Zhivotovskii, types of studied coenopopulations of *Paeonia tenuifolia* were young (CP 1 Δ = 0,14, ω = 0.27, CP 2 Δ = 0.30, ω = 0.33) (Table 2).

In both coenopopulations of *Paeonia tenuifolia,* the indices of replacement were higher than 1 (CP 1 I_{rec}= 3.38, CP 2 I_{rec}= 1.67) i.e., the coenopopulations were relatively steady, numerous seeds were generated giving birth to viable individuals.

Pregenerative plants of these coenopopulations could completely replace the species of the generative fraction.

The index of replacement showing the ratio of the density of regrowth to total mature fraction of the population was higher in CP 1 (I_{repl} = 0.80) and lower in CP 2 (I_{repl} = 0.67). Moderate index of maturing evidence long-term existence of the species in generative state (Table 2).

The index of age was the lowest in CP 1 (I_{age}= 0.09), and the highest in CP 2 (I_{age}= 0.21), the number of specimens of generative and post-generative fractions gradually increased according to this trend. The efficiency varied indignantly. Therefore, young populations consumed high energy and exerted high load on environmental energy resources.

Table 1. Species composition of coenopopulations with *Paeonia tenuifolia*.

Taxa	Family	CP1	CP2
1. *Colchicum bulbocodium* subsp. *versicolor* (Ker Gawl.) K.Perss.	Colchicaceae	-	+
2. *Salix triandra* L.	Salicaceae	-	+
3. *Bromus riparius* Rehmann.	Poaceae	+	+
4. *Elytrigia repens* (L.) Nevski.	Poaceae	+	+
5. *Phleum pratense* L.	Poaceae	-	+
6. *Stipa capillata* L.	Poaceae	+	+
7. *S. pennata* L.	Poaceae	-	+
8. *Poa angustifolia* L.	Poaceae	-	+
9. *Festuca valesiaca* Schleich. ex Gaudin.	Poaceae	+	+
10. *Rumex confertus* Willd.	Polygonaceae	+	+
11. *Campanula patula* L.	Campanulaceae	-	+
12. *Phlomis herba-venti* subsp. *pungens* (Willd.) Maire ex DeFilipps.	Lamiaceae	+	+
13. *Phlomoides tuberosa* (L.) Moench.	Lamiaceae	+	+
14. *Salvia tesquicola* Klokov. & Pobed.	Lamiaceae	+	+
15. *S. nutans* L.	Lamiaceae	-	+
16. *Stachys recta* L.	Lamiaceae	+	-
17. *Origanum vulgare* L.	Lamiaceae	+	-
18. *Galium aparine* L.	Rubiaceae	+	-
19. *G. verum* L.	Rubiaceae	+	+
20. *Pedicularis kaufmannii* Pinzger.	Orobanchaceae	-	+
21. *Veronica longifolia* L.	Scrophulariaceae	+	-
22. *V. spicata* subsp. *incana* (L.) Walters	Plantaginaceae	+	+
23. *Verbascum lychnitis* L.	Scrophulariaceae	-	+
24. *Euphorbia esula* subsp. *tommasiniana* (Bertol.) Kuzmanov.	Euphorbiaceae	-	+
25. *Silene wolgensis* (Hornem.) Besser ex Spreng.	Caryophyllaceae	-	+
26. *Nonea pulla* (L.) DC.	Boraginaceae	-	+
27. *Urtica dioica* L.	Urticaceae	+	-
28. *Hypericum perforatum* L.	Hypericaceae	+	+
29. *Plantago lanceolata* L.	Plantaginaceae	-	+
30. *Vincetoxicum hirundinaria* Medik.	Apocynaceae	-	+
31. *Carex praecox* Schreb.	Cyperaceae	+	+
32. *Erysimum canescens* Roth.	Brassicaceae	+	+
33. *Goniolimon elatum* (Fisch. ex Spreng.) Boiss.	Plumbaginaceae	-	+
34. *Securigera varia* (L.) Lassen.	Leguminosae	+	+
35. *Chamaecytisus ruthenicus* (Fischer ex Woloszczak) Klásk.	Leguminosae	+	+
36. Genista tinctoria L.	Leguminosae	+	+
37. *Lathyrus tuberosus* L.	Leguminosae	+	+
38. *Rosa majalis* Herrm.	Rosaceae	+	-
39. *Prunus tenella* Batsch.	Rosaceae	+	+
40. *Fragaria viridis* Weston.	Rosaceae	+	+
41. *Filipendula vulgaris* Moench.	Rosaceae	-	+
42. *Artemisia vulgaris* L.	Compositae	+	+
43. *A. austriaca* Jacq.	Compositae	-	+
44. *Inula britannica* L.	Compositae	-	+
45. *Achillea millefolium* L.	Compositae	+	+
46. *Cichorium intybus* L.	Compositae	+	+
47. *Aster amellus* L.	Compositae	-	+
48. *Senecio schwetzowii* Korsh.	Compositae	+	+
49. *Echinops sphaerocephalus* L.	Compositae	+	+
50. *Carduus crispus* L.	Compositae	+	+
51. *Centaurea scabiosa* L.	Compositae	+	-
52. *Podospermum purpureum* (L.) W.D.J.Koch & Ziz.	Compositae	+	-
53. *Taraxacum campylodes* G.E.Haglund.	Compositae	+	+
54. *Thalictrum minus* L.	Ranunculaceae	+	+
55. *Adonis volgensis* Steven ex DC.	Ranunculaceae	+	+
56. *Anemone sylvestris* L.	Ranunculaceae	-	+
57. *A. patens* L.	Ranunculaceae	+	+

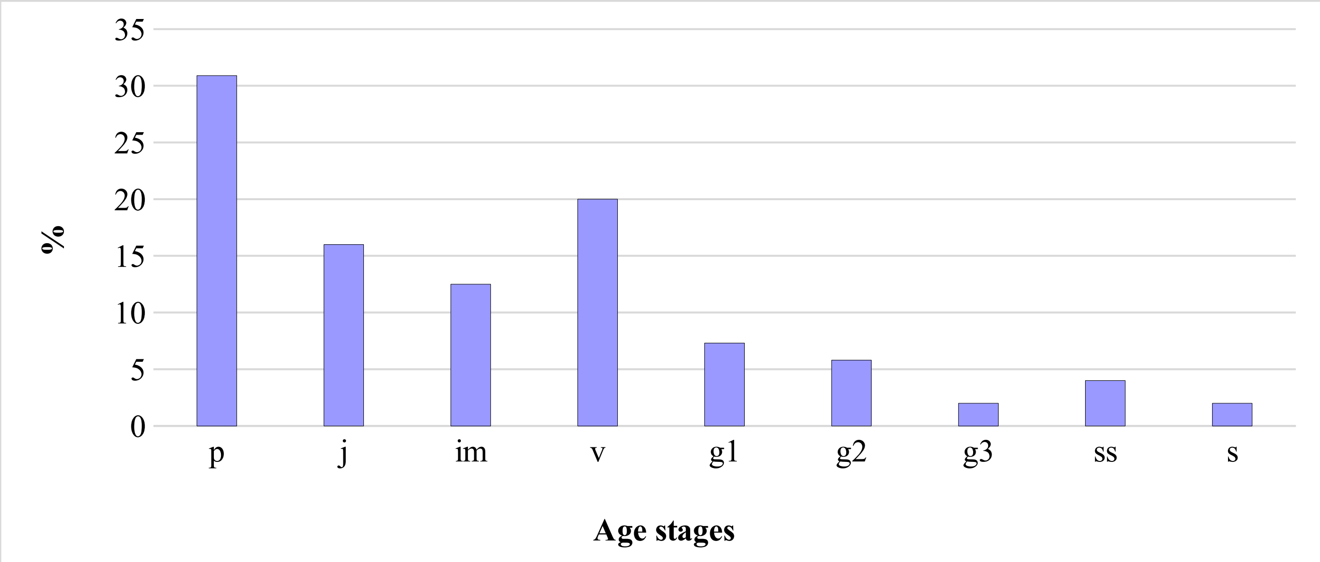

Fig. 3. The ontogenetic spectrum of CP 1 of *Paeonia tenuifolia*. X-axis: ontogenetic states (p - seedlings, j - juvenile, im - immature, v - virginile, g - generative, ss - subsenile, s - senile); Y-axis: percentage of species of different ontogenetic groups in CP,%.

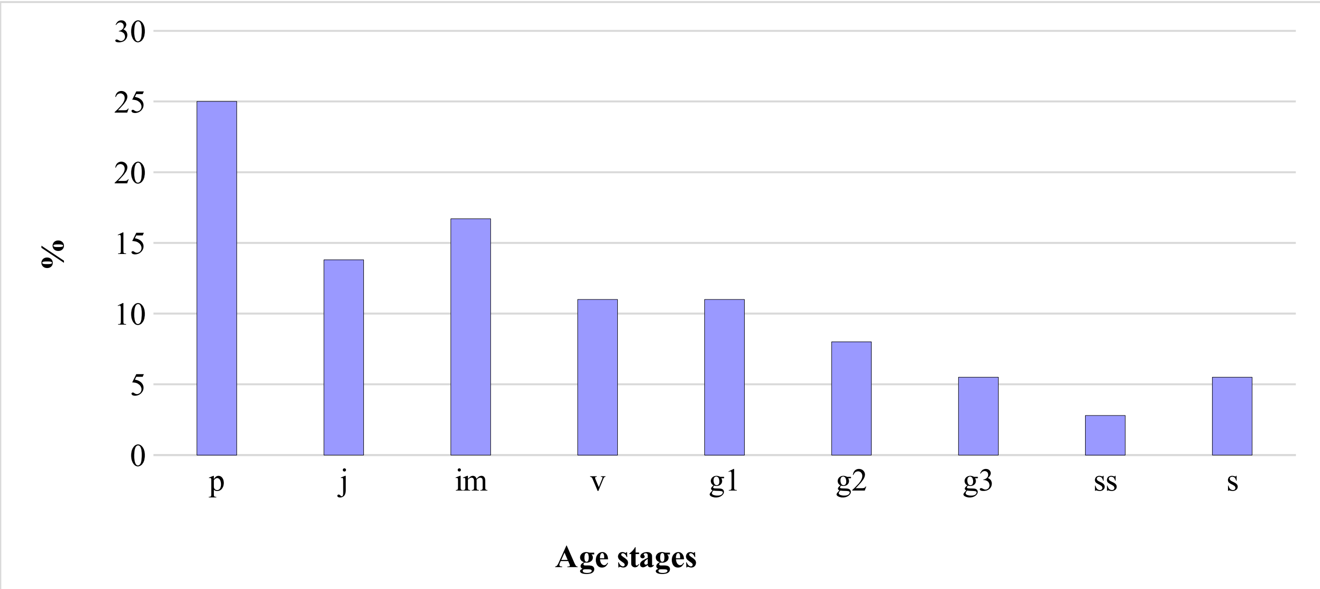

Fig. 4. The ontogenetic spectrum of CP 2 of *Paeonia tenuifolia*. X-axis: ontogenetic states (p - seedlings, j - juvenile, im - immature, v - virginile, g - generative, ss - subsenile, s - senile); Y-axis: percentage of species of different ontogenetic groups in CP,%.

Table 2. Demographic indices of coenopopulations of *Paeonia tenuifolia*.

CP No.	I_{rec}	I_{repl}	I_{gener}	I_{mat}	I_{age}	Δ	Ω	Type of population in terms of Δ-Ω
CP 1	3.38	0.80	0.15	0.07	0.09	0.14	0.27	Young
CP 2	1.67	0.67	0.25	0.14	0.21	0.30	0.33	Young

Conclusion

The performed studies have demonstrated that the state of natural coenopopulations of *Paeonia tenuifolia* is quite steady; however, the increasing anthropogenic impact (gathering of both decorative and medicinal plants by inhabitants, ploughing up, uncontrolled burning, pasturing) in its habitats can destruct their stability in time.

Paeonia tenuifolia is characterized by narrow environmental amplitude (heliophyte, xeromesophyte, eutrophic plant, calciphile, cenophile and erosiophobe). The populations are vulnerable since they are exerted to anthropogenic impact. *P. tenuifolia* is a medicinal plant, which is another limiting factor. The type of cenopopulations, according to the delta-omega criterion, is normal, full-membered, left-sided and young. According to the Bodenheimer classification, they are stationary.

Monitoring populations of rare species allows determining trends in their development and proposing measures for their conservation. Protective measures should be based on studies of biology, environment, the geography of the species in the region, state of the populations, dynamics of age structure. It is necessary to create micro-reserves in these habitats, prohibiting business activities in them, and the recreational load should be controlled. New habitats should be identified within the Oka-Don lowland.

Authors' contributions

All authors contributed equally; read and approved the final manuscript.

Conflict of interests

Authors do not have any conflict of interests to declare.

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