Current state, population structure and population dynamics of rare plants under economic and recreational use of natural-territorial complexes in the Middle Volga basin (Russia)

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Abstract. The article summarizes the results of studies on the population structure and population dynamics of rare plants of the steppe and forest-steppe zones of the European part of Russia. Conservation of representatives is mainly ensured by the creation of protected areas and the inclusion in the Red Books. Four groups of species by peculiarities of ontogenetic structure and type of cenopopulations according to the “delta-omega” criterion were determined. Most species are characterized by a mature type of cenopopulations with a predominance of generative individuals. Long-term studies allowed us to establish that most of the rare species of the region have maintained their numbers. However, 30 representatives, the number of which has noticeably decreased, need to strengthen the conservation measures. The studies are of interest in the development of conservation measures, identifying the current ecological state of natural-territorial complexes under economic and recreational pressure, determining the categories of rarity of species, justifying the inclusion or exclusion of them from the Red Books.

1. Introduction
The Volga Basin covers an area of 1,360 square kilometres and accounts for more than 30% of the Russian Plain and 8% of the total Russian territory. It plays an important role in the country's economy and the lives of Russia's population. The Middle Volga Region is one of the most densely populated, industrially and agriculturally developed parts of the Volga Basin, so the problem of preserving the integrity of the natural environment in this area has not lost its urgency over the past decades.

The basin principle of area study is relevant at the current stage of biological sciences development. Acquisition of original data, analysis and generalisation of accumulated materials on the flora and vegetation of the Middle Volga Basin are far from being completed. Our team has done a great deal of work to study the spatial and functional organisation of the region's vegetation cover at the organism, population and phytocoenotic levels of organisation. The scientific and practical importance of research and data analysis lies in the possibility of offering scientifically sound solutions in the sphere of preserving biological and landscape diversity. In this regard, the biogeographic aspect of the work acquires particular importance (including the study of bioecology and geography of regional real estate species, relics, endemics, economically significant and resource representatives).

Natural-territorial complexes in the Middle Volga region are characterized by a variety of vegetation cover. This is due to the geographical location of the territory on the border of two natural zones - forest-steppe and steppe. The Volga as a natural biogeographical barrier divides the region into
two parts, differing in their natural and climatic characteristics. As a result, they differ in terms of their
geobotanical and floral composition. All of the above determines the availability of habitats that are
diverse in terms of ecological and phytocoenotic parameters, a wide range of plant communities and
the floral richness of various natural sites that require careful study.

Due to the high degree of development and the constantly increasing economic and recreational use
of this territory, a significant number of plant species are on the verge of extinction and are protected
at the federal and regional level [1-11]. Some representatives of the flora require protection on a global
scale. The main direction of conservation activities in Russia is the creation of Red Books and
specially protected natural areas of various ranks (nature reserves, national parks, natural monuments,
etc.).

The study of the vegetation cover makes it possible to determine the totality of external
environmental conditions and the main dynamic processes of indigenous, conditionally indigenous and
disturbed communities under anthropogenic pressure.

Identifying and analysing the structure and dynamics of plant price populations is an important area
of biology and ecology. The population method looks at the prospects of conserving phytodiversity
with the increasing economic exploitation of ecosystems. The demography and condition of natural
plant populations is also studied by foreign scientists. For representatives with a narrow range, the data
on population structure and possible population dynamics are more original and are of value for the
conservation of stenobiont species [1; 2; 6; 7].

This type of research is necessary to establish the degree of correlation between the different
characteristics of natural and territorial complexes and environmental parameters using modern data
analysis tools and to identify the most important determinants of species diversity of vascular plants.
Systematization of information in the format of electronic databases will provide an opportunity to
compare floral and cenotic features of natural complexes at both federal and global levels.

2. Materials and methods

An important aspect of the study is the study of biology, ecology, distribution, identification of
limiting factors and assessment of the condition of populations of rare, relict and endemic species of
vascular plants, which is important for the development of theoretical foundations for environmental
monitoring of vegetation cover and assessment of the condition of biological resources.

The following age states were considered when determining ontogenetic structure of populations
according to the standard criteria [3-5; 8-9; 12-20]. Ontogenetic (age) spectrum of populations was
created from the obtained data. The state of conopopulations was estimated using the “delta-omega”
criterion by Zhivotovsky L.A. [20]; it was used to determine which of the following types particular
conopopulation belongs to: young, maturing, mature, transitional, aging, old. In any case, the object of
study is not a single plant, but a cenotic population of plants. A plant cenopopulation includes all
individuals of a species within the same plant community. Its size and boundaries are determined by
the boundaries of this phytocenosis.

Herbarium material was collected in nature, detailed floristic lists were compiled, and field
descriptions of plant communities in the natural-territorial complexes under study were performed.
Plant communities were studied using the methods developed by Russian (Soviet) scientists based on
the dominant component [13]. When describing the vegetation, the effect of human economic activity
on it was necessarily indicated. Along with the description of the sample plots and the description of
the location, the geobotanical profiles were also described. In the cameral period, the collected data
were analyzed, plant species were clarified, and the earlier herbarium collections were analyzed.

The study of rare and vulnerable plant species of the Middle Volga flora, determination of their
present status, limiting the development of cenotic populations, successional processes in plant
communities were carried out in 2000-2020 in Samara and neighboring regions (Middle Volga basin).

In the course of monitoring studies of rare and vulnerable plant species, cenotic populations and
accompanying phytocenoses were examined for the following representatives: Bupleurum aureum
Fisch. ex Hoffm, Cicuta virosa L., Ferula caspica M. Bieb., Ferula tatarica Fisch. ex Spreng., Laser
trilobum (L.) Borkh., Pleurosporum uralense Hoffm., Calla palustris L., Anthemis trotzkiana Claus, Artemisia salsoloides Willd., Jurinea ledebouri Bunge, Onosma polychroma Klokov ex M. Popov [incl. O. iricolor Klokov], Rinderia tetrasis Pall. [Cynoglossum tetrasis (Pall.) W. Greuter et Burdet], Alyssum lenense Adams, Claudia aprica (Stephan) Korn.-Tr., Crambe tataria Sebek, Schiveereckia hyperborea (L.) Berkutenko [S. podolica (Besser) Andrz. ex DC.], Adenophora liliifolia (L.) A. DC., Campanula latifolia L., Helianthemum nummularium (L.) Mill., Helianthemum zheguliense Juz. ex Tzvelev, Maianthemum bifolium (L.) F.W. Schmidt, Cephaleria uralensis (Murr.) Schrad. ex Roem. et Schult., Knautia tatarica (L.) Szabo, Scabiosa isetensis L. [Lomelosia isetensis (L.) J. Sojak], Drosera rotundifolia L., Astragalus cornutus Pall., Astragalus helmii Fisch. ex DC., Astragalus macropus Bunge, Astragalus sulcatus L., Astragalus temirensis Popov, Astragalus tenuifolius L. [A. scopaeformis Ledeb.], Astragalus ucrainicus Popov et Klokov, Astragalus volgensis Bunge, Astragalus zingeri Korsh., Hedysarum gmelini Ledebr., Hedysarum grandiflorum Pall., Hedysarum razoumovianum Fisch. et Helm, Lathyrus litvinovii Iljin, Medicago cancellata M. Biebr., Oxytropis floribunda (Pall.) DC., Oxytropis hippolyti Boriss., Oxytropis knjazevii Vasjukov [O. spicata (Pall.) O. et B. Fedtsch.], Corydalis intermedia (L.) Merat, Gentiana pneumonanthe L., Globularia punctata Lapeyr., Gladiolus tenuis M. Biebr., Iris pumilia L., Iris sibirica L., Fritillaria meleagroides Patrin ex Schult et Schult. fil., Fritillaria ruthenica Wikstr., Lilium pilosiusculum (Frey) Miscz. [L. martagon auct. non L.], Ornithogalum fischeranum Krasch., Tulipa biebersteiniana Schult. et Schult.fil., Tulipa schrenkii Regel, Goniolimon elatum (Fisch. ex Spreng.) Boiss., Limonium caspium (Willd.) Gams, Linum flavum L., Linum perenne L., Linum uralense Juz., Cephalanthera rubra (L.) Rich., Cyripedium calceolus L., Dactylorhiza fuchsii (Druce) Soo, Dactylorhiza incarnata (L.) Soo, Dactylorhiza maculata (L.) Soo, Epipactis atrorubens (Hoffm. ex Bernh.) Besser, Epipactis palustris (L.) Crantz, Epipogium aphyllum (F.W. Schmidt) Sw., Gymnadenia conopsea (L.) R. Br., Herminium monorchis (L.) R. Br., Liparis loeselii (L.) Rich., Neottianthe cucullata (L.) Schlechter, Orchis militaris L., Polemonium caeruleum L., Polygala sibirica L., Atraphaxis frutescens (L.) K. Koch, Primula macrocalyx Bunge, Trientalis europaea L., Moneses uniflora (L.) A. Gray, Pyrola chlorantha Sw., Pyrola minor L., Pyrola rotundifolia L., Adonanthe vernalis (L.) Spach [Adonis vernalis L.; Chrysocymathus vernalis (L.) Holub], Adonanthe volgensis (Steven ex DC.) Chrték et Slavíková [Adonis volgensis Steven ex DC.; Chrysocymathus volgensis (Steven ex DC.) Holub], Anemonoides alata (C.A. Mey.) Holub [Anemone alata Fisch. ex C.A. Mey.], Clematis integrifolia L., Delphinium subcuneatum Tzvelev, Pulsatilla patens (L.) Mill., Ranunculus polystylii Waldst. et Kit. ex Willd., Ranunculus polychisis Stephan, Trollius europaeus L., Potentilla erecta (L.) Raetsch., Asperula petraea V.I. Krecz. ex Klokov, Dictamus caucasicus (Fisch. et C.A. Mey.) Grossh., Veronica officinalis L., Valeriana tuberosa L., Ephedra distachya L.

3. Results
When writing this article, a random sample of 5-10 cenopopulations for each species was made, and population parameters were analyzed. Some parameters (predominant group of individuals in the populations, type of cenopopulations according to the "delta omega" criterion) are given in table 1.

4. Discussion
Peculiarities of the population structure in different plant species depend on a variety of factors. The ranking of the examined cenopopulations, given in Table 1, shows that only 7 representatives in the ontogenetic spectra are dominated by virginal individuals. Old generative individuals prevail in cenopopulations of 9 representatives of rare flora. Young generative plants predominate in the populations of 23 representatives. In a significant number of species (57 taxa), mature generative individuals predominate in the ontogenetic spectra. The peculiarities of the ontogenetic structure determine the type of cenopopulations (defined by the "delta-omega" criterion).

The authors lengthy research allowed them to determine the dynamics of the number of individuals of rare and vulnerable species.
Table 1. Population characteristics of the studied rare and vulnerable species.

| Representatives                                                                 | Prevailing ontogenetic group | Prevailing types of cenopopulations |
|---------------------------------------------------------------------------------|------------------------------|-------------------------------------|
| 1. Ferula caspica, Ferula tatarica, Laser trilobum, Pleurosporellum uralense, Pyrola chlorantha, Pyrola minor, Pyrola rotundifolia [7 species]. | virginile                    | young, maturing                     |
| 2. Calla palustris, Clausia aprica, Crambe tataria, Adenophora liliifolia, Campanula latifolia, Maianthemum bifolium, Scabiosa isetensis, Hedysarum gmelinii, Hedysarum grandiflorum, Hedysarum razoumovianum, Oxytropis hippolyti, Oxytropis knjazevii, Globularia punctata, Gladiolus tenuis, Iris pumila, Iris sibirica, Fritillaria meleagroides, Fritillaria ruthenica, Lilium pilosiusculum, Liparis loeselii, Neottianthe cucullata, Orchis militaris, Ranunculus polyrhizos [23 species]. | young generative              | maturing, mature                   |
| 3. Cicuta virosa, Anthemis trotzkiana, Artemisia salsoloides, Jurinea ledebourii, Onosma polychroma, Rinderet tetraspis, Cephalaria uralensis, Knautia tatarica, Astragalus cornutus, Astragalus helmii, Astragalus macropus, Astragalus sulcatus, Astragalus temirensis, Astragalus tenuifolius, Astragalus ucrainicus, Astragalus volgensis, Astragalus zingeri, Medicago cancellata, Oxytropis floribunda, Gentiana pneumonanthe, Ornithogalum fischaranum, Tulipa biebersteiniana, Tulipa schrenkii, Goniolimon elatum, Limonium caspium, Linum flavum, Linum perenne, Linum uralense, Cephalanthera rubra, Cypripedium calceolus, Dactylorhiza fuchsii, Dactylorhiza incarnata, Dactylorhiza maculata, Epipactis atrorubens, Epipactis palustris, Epipogium aphyllum, Gymnadenia conopsea, Herminium monorchis, Polemonium caeruleum, Polygala sibirica, Atraphaxis frutescens, Primula macrocalyx, Tristentis europaea, Moneses uniflora, Adonanthe vernalis, Adonanthe volgensis, Anemonoides altaica, Clematis integrifolia, Delphinium subcuneatum, Pulsatilla patens, Ranunculus polyphyllus, Potentilla erecta, Asperula petraea, Dictamnus caucasicus, Veronica officinalis, Valeriana tuberosa, Trollius europaeus [57 species]. | mature generative              | mature, transitional               |
| 4. Bupleurum aureum, Alyssum lenense, Schivereckia hyperborea, Helianthemum nummularium, Helianthemum zheguliense, Drosera rotundifolia, Lathyrus litvinovii, Corydalis intermedia, Ephedra distachya [9 species]. | old generative                 | aging, old                         |
The group of species whose numbers have increased over the past 20 years includes 26 species: *Laser trilobum*, *Calla palustris*, *Alyssum lenense*, *Crambe tataria*, *Schivereckia hyperborea*, *Adenophora lilijofila*, *Campanula latifolia*, *Cephalaria uralensis*, *Scabiosa isetensis*, *Astragalus helnii*, *Astragalus macropus*, *Astragalus sulcatus*, *Astragalus zingeri*, *Hedysarum grandiflorum*, *Hedysarum razoumovianum*, *Oxytropis floribunda*, *Oxytropis hippolyti*, *Oxytropis knjazevii*, *Globularia punctata*, *Iris pumila*, *Iris sibirica*, *Fritillaria ruthenica*, *Tulipa biebersteiniana*, *Linum flavum*, *Linum perenne*, and *Adonanthe volgensis*.

The group of species whose numbers did not undergo significant changes and remained approximately at the same level includes 44 species: *Dictamnus caucasicus*, *Linum uralense*, *Artemisia salsoleoides*, *Jurinea ledebouri*, *Onosma polychroma*, *Bupleurum aureum*, *Cicuta virosa*, *Pleurospermum uralense*, *Anthemis trozktiana*, *Rindera tetraspis*, *Clausia aprica*, *Helianthemum nummularium*, *Helianthemum zheguliense*, *Knautia tatarica*, *Astragalus temirensis*, *Astragalus tenuifolius*, *Astragalus ucrainicus*, *Astragalus wolgensis*, *Lathyrus livinovii*, *Bipetrica cancellata*, *Corydalis intermedia*, *Gentiana pneumonanthe*, *Lilium pilosiusculum*, *Ornithogalum fischeranum*, *Gonioilimon elatum*, *Limonium caspium*, *Atraphaxis frutescens*, *Trientalis europaea*, *Moneses uniflora*, *Pyrola rotundifolia*, *Adonanthe vernalis*, *Anemonoides altaica*, *Clematis integrifrula*, *Delphinium subcuneatum*, *Pulsatilla patens*, *Hedysarum gmelinii*, *Ranunculus polyphyllus*, *Ranunculus polyrhizos*, *Epipactis atrorubens*, and *Veronica officialis*.

A decrease in the number of individuals over the past 20 years has been observed in 30 species: *Polygala sibirica*, *Ferula caspica*, *Ferula tatarica*, *Maianthemum bifolium*, *Drosera rotundifolia*, *Astragalus cornutus*, *Gladiolus tenuis*, *Fritillaria meleagroids*, *Tulipa schrenkii*, *Cephalaria uralensis*, *Dactylorhiza fuchsii*, *Dactylorhiza incarnata*, *Orchis militaris*, *Polemonium caeruleum*, *Adonanthe volgensis*, *Liparis loeselii*, *Neottianthe cucullata*, *Herminium monorchis*, *Trientalis europaea*, *Moneses uniflora*, *Astragalus temirensis*, *Ranunculus gmelinii*, *Ranunculus polyphyllus*, *Ranunculus polyrhizos*, and *Lathyrus litvinovii*.

5. Conclusion

The study of rare species of the Middle Volga basin revealed the most frequent types of age spectra of their cenopopulations. The predominant type of cenopopulations is mature, in which the survival rate of seedlings is low and generative plants account for the main share due to long ontogenesis. Such populations are not highly labile and are sensitive to even the slightest changes in habitat conditions.

The study of the dynamics of the number of individuals allowed us to distinguish three groups of species. In general, the number remained unchanged (in 40 species); increased, although mostly insignificantly (due to reduced grazing pressure), in 26 species; decreased in 30 species (for representatives of orchids, a decrease in the number of individuals in most cases is critical).

Thus, the results of many years of field research and analysis allowed us to identify a group of species requiring enhanced conservation measures.

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