Thus, the most accurate assessment of the state of populations of rare plant species can be provided by a combination of three multi-criteria methods:

- Vitality analysis based on a multi-criteria evaluation of the condition of plant individuals forming the population.
- Multi-criteria assessment of population structure as an independent biosystem.
- Assessment of ontogenetic state of the population using the Uranov-Zhivotovsky method, which takes into account two features: relative energy efficiency (Uranov's delta) and efficiency index (Zhivotovsky's omega) of individuals that make up the population.

We set the task of analyzing the state of ten populations of two rare protected plant species using a complex of multi-criteria methods for assessing individuals and populations.

Materials and Methods

Two rare protected species of plants were taken as objects for testing the method of assessing individuals and populations of plants as multi-feature biological systems: *Lilium martagon* L. (Liliaceae) and *Pulsatilla patens* (L.) Mill. s.l. (Ranunculaceae), which grow in the territory of Desnyansko-Starogutsky National Nature Park in Ukraine.

Five populations of *Lilium martagon* were analyzed:

- Ecotone between Betuletum corylosa and Pinetum corylosa-convallariosum,
- From Pinetum corylosa-convallariosum communities,
- From Pinetum corylosa-sparsiherbosum,
- From Pinetum coryloso-maianthemosum, and
- From Fraxinetum corylosa-convallariosum.

Five populations of *Pulsatilla patens* were also evaluated:

- From the Querceto-Pinetum corylosa-luzulosum community,
- From the Querceto-Pinetum frangulosa-festucosum,
- From Pinetum callunosa-hylocomiosum in the Starogutsky forest area,
- From Pinetum callunoso-hylocomiosum in the Desnyansky part of the national park, and
- Also from Pinetum callunosa-hylocomiosum in the Desnyansky part of the park, but the conditions of growth for *P. patens* in this population are significantly different from all the others and from population 4 because it is located in a recently cut area that is just starting to grow back into a forest.

A morphometric analysis of more than 700 plant specimens was conducted within these populations. The traits of individuals and populations were recorded over three consecutive growing seasons, which allowed for the characterization of their annual variability.

The following morphometric parameters were used to assess the condition of the individuals: plant height, number of leaves, number of leaflets, length and width of leaves, average area of individual leaves, total leaf surface, number of generative structures, weight of flowers and fruits, as well as ontogenetic stage (from "r" to "ss").

To assess populations as biological entities, the following parameters were taken into account: number of individuals in the population, population density, renewability index, generativity index, age index (Kovalenko, 2015), population vitality index Q (Zlobin, 1989), delta (Uranov, 1975), and omega (Zivtovsky, 2001).

Classification of plant individuals and populations as multivariate biosystems was performed using the method of discriminant analysis (Zlobin et al., 2022), which allows the degree of similarity between objects in a multidimensional space to be evaluated. Distances between groups of individuals or between populations were determined by the values of Mahalanobis distance squared. The Wilks lambda served as a metric of classification reliability, with values ranging from 0 to 1, where smaller values indicate more accurate classification and more reliable groups of similar objects - individuals or populations. The found value of Wilks lambda was evaluated by the Fisher criterion with a significance level of p. In combination with canonical analysis, the results of classification are presented in the form of two-dimensional graphs.

Results and Discussion

Table 1. **. Results of discriminant analysis for populations of L. martagon over three consecutive growing seasons**

	Based on morphometric parameters of individuals	Based on population parameters
Wilks' lambda	0.019	0.0000193
Fisher's criterion and significance level	2.38/ p<0.0082	5.95 p<0.0041
Values of Mahalanobis distance squares between groups of individuals and populations and their statistical significance.	P1-P2=33.18/p<0.20	P1-P2=171.79/p<0.23
	P1-P3=36.63/p<0.20	P1-P3=5.25/p<0.15
	P1-P4=8.75/p<0.20	P1-P4=409.17/p<0.23
	P1-P5=20.62/p<0.20	P1-P5=372.04/p<0.23
	P2-P3=118.11/p<0.30	P2-P3=193.08/p<0.15
	P2-P4=44.61/p<0.30	P2-P4=90.61/p<0.23
	P2-P5=24.96/p<0.30	P2-P5=176.33/p<0.23
	P3-P4=38.66/p<0.15	P3-P4=408.20/p<0.23
	P3-P5=80.95/p<0.15	P3-P5=380.89/p<0.23
	P4-P5=40.22/p<0.15	P4-P5=99.53/p<0.23

Populations of *L. martagon* either increase their population size and density (populations 4 and 5) or maintain it steadily. This phenomenon is explained by the analysis of the ontogenetic structure of the populations. According to the Uranov-Zhivotovsky criterion, all five populations of *L. martagon* are considered young (Fig. 3). The value of the Uranov delta does not exceed 0.25, and the Zhivotovsky omega -0.55.

Thus, the comprehensive multi-feature analysis of *L. martagon* populations allowed for the most complete, comprehensive, and accurate assessment of their status.

The comparison of five *Pulsatilla patens* populations by the discriminant analysis method based on the traits of the plants comprising them showed (Fig. 4) that individual populations were almost identical in their complex of these traits, while others were quite distinctive. Populations 1, 2, and 3 were similar to each other. Populations 4 and 5 (both from the Pinetum callunosa-hylocomiosum association but from different parts of the National Park) differed significantly from them and from each other. The classification accuracy was quite high, with a Wilks' lambda of 0.5. All these differences were statistically significant (p<0.000) (Tab. 2).

Figure 2. **Discrimination of *L. martagon* populations based on a set of population characteristics in the space of the first and second canonical roots during three consecutive vegetation periods. Populations 1-5 are numbered**

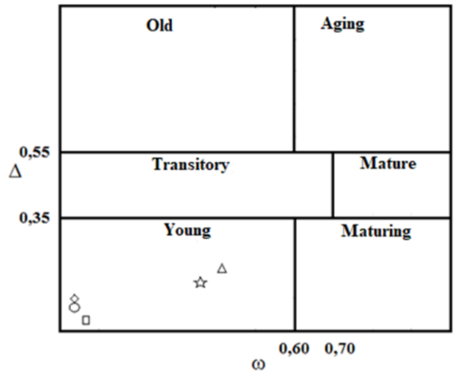

Figure 3. **Position of *Lilium martagon* populations in the Δ/ω plane. P1-circle, P2-diamond, P3-square, P4-star, P5-triangle**

The isolated position of population 5 is related to the fact that, unlike other forest populations, this population is located on a clearcut area that is only being overgrown by the forest. The age of the forest stand here is 50 years-60 years, while populations 1-4 are located in phytocenoses with a forest stand age of 80 years-100 years. It has been previously shown (Panchenko & Klimenko, 2013) that the ecological discomfort index for *P. patens* is the highest here. Population 5 stands out in terms of its ontogenetic status, as it is transitional, while the other populations belong to the categories of young, maturing, or mature (Fig. 6). It should be noted that, in combination, this indicates the high effectiveness of discriminant and canonical analysis in the study of plant populations.

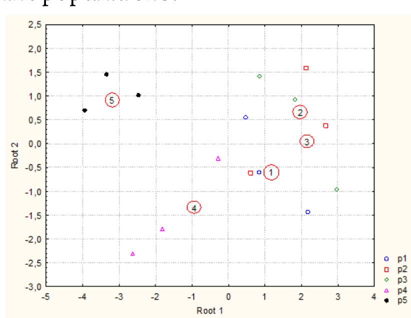

Figure 4. **Discrimination of *P. patens* populations based on a set of morphometric characteristics of individuals in the space of the first and second canonical roots. 1-5 -population numbers**

Like with *L. martagon*, a displacement of population centroids over the years was detected in the space of canonical roots for *P. patens* populations (Fig 4). The magnitude of this displacement is even greater than that observed for *L. martagon*, reflecting significant changes in morphostructural parameters of individuals depending on changes in weather conditions during the vegetation period, primarily precipitation and temperature, as noted above. Changes in the morphostructure of individuals depending on weather conditions during the vegetation period were most pronounced in population 4 of Pinetum callunoso-hylocomiosum in the foothills of the national park.

Table 2. Discriminant analysis results for *P. patens* populations over three consecutive vegetation periods

	Based on morphometric parameters of individuals	On the basis of population parameters
Wilks' lambda	0.5	0.00017
Fisher's criterion and its significance	3.62/p<0.000	5.73/p<0.0003
Values of Mahalanobis distance squares between groups of individuals or populations and their statistical significance	P1-P2=9.15/p<0.08	P1-P2=30.06/p<0.14
	P1-P3=7.67/p<0.08	P1-P3=524.73/p<0.001
	P1-P4=16.45/p<0.00	P1-P4=303.98/p<0.004
	P1-P5=19.55/p<0.04	P1-P5=36.60/p<0.13
	P2-P3=6.96/p<0.00	P2-P3=828.31/p<0.0005
	P2-P4=25.46/p<0.00	P2-P4=517.27/p<0.001
	P2-P5=36.01/p<0.01	P2-P5=141.81/p<0.02
	P3-P4=22.11/p<0.00	P3-P4=62.98/p<0.08
	P3-P5=35.20/p<0.05	P3-P5=356.40/p<0.002
	P4-P5=16.94/p<0.18	P4-P5=215.16/p<0.009

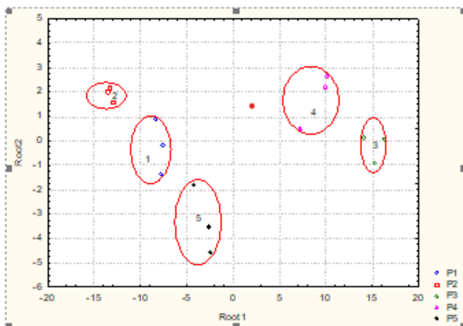

Figure 5. Discrimination of *Pulsatilla patens* populations based on a set of population characteristics in the space of the first and second canonical roots for three consecutive vegetation periods. 1-5 -population numbers

A comparative analysis of *P. patens* populations based on their population characteristics revealed significant differences between the five studied populations (Fig. 5). The classification accuracy in this case was very high, with Wilks' lambda equal to 0.00017. The differences between populations are statistically significant, with p<0.0003 (Table 2).

Based on the population characteristics, populations 3 and 4 were found to be the most similar to each other, while the largest differences were observed between populations 2 (from Querceto-Pinetum frangulosa-festucosum) and 3 (from Pinetum callunosa-hylocomiosum of the Starogutsky forest area). These differences reflect the different population densities and ontogenetic states of the populations. Among the five *P. patens* populations, one is young, two are maturing, one is mature, and one is transitional (Fig. 6). This fact largely explains the differences between *P. patens* populations, primarily in the state of their forming plant individuals, which in turn affects the population density and level of generativity.

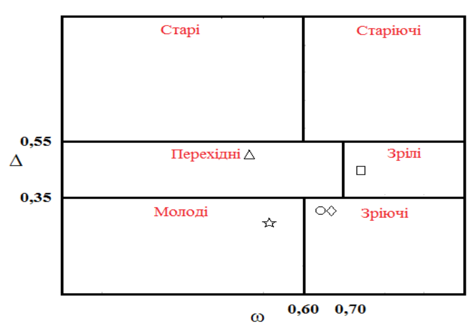

Figure 6. The position of *Pulsatilla patens* populations in the Δ/ω plane. P1 -circle, P2 -diamond, P3 -square, P4 -star, P5 –triangle

Using the example of five populations of *L. martagon* and five populations of *P. patens*, it was shown that populations of the same plant species with similar structures of their forming individuals can significantly differ in their own population characteristics, and vice versa. Both studied rare plant species exhibit morphological variability in vegetative and generative organs (Klymenko, 2013). It was found that the scales of this variability in different ecologically-phytocenotic conditions are not the same.

Based on individual characteristics, populations of *L. martagon* were found to be more distinctive compared to populations of *P. patens*. The average Mahalanobis distance between populations of *L. martagon* is 44.66, while between populations of *P. patens* it is only 19.55. In the conditions of the National Park, individuals of *L. martagon* were found to be more morphologically variable than individuals of *P. patens*.

Data on the state of plant populations obtained on the basis of multi-feature assessments allow for predicting the dynamics of phytocenoses of rare plant species, which we emphasized earlier (Klymenko & Zlobin, 2014).

Conclusions

Based on the principle of hierarchical organization of biosystems, a classification of methods for assessing the state of plant populations was developed, with a subdivision into methods based on accounting for a single feature of individuals or the population as a whole, or on accounting for a complex of features of both individuals and populations. The use of discriminant analysis showed that the most informative methods are two main multi-feature methods: the first is the assessment of the population based on the characteristics of the individuals that form it, and the second is the assessment of the population based on its own population parameters. The combination of these two methods multi-feature assessment of individuals and multi-feature assessment of populations -characterizes them most fully and comprehensively.

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