CHAPTER 6

Comprehensive population analysis as a framework for sustainable management of medicinal plant resources

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Abstract

The section considers the possibilities of using complex population analysis as a scientific and methodological basis for sustainable management of medicinal plant resources and the introduction of innovative approaches into the agricultural system. The study was conducted on the example of populations of nine species of medicinal plants distributed in floodplain meadow ecosystems of the Krolevets-Glukhiv geobotanical region of the Forest-Steppe of Ukraine. The methodological basis of the work was a complex analysis that included determining the area of population fields, population density, morphometric characteristics of plants, ontogenetic and vitality structure of populations. Significant interspecific and intraspecific variability of parameters of medicinal plant populations was established, which reflects the peculiarities of their adaptation to environmental conditions and anthropogenic impact. Populations with high resource potential were identified, which can be used as centers of regulated procurement of medicinal raw materials, as well as populations that require priority protection. It is shown that the most informative criteria for assessing the prospects for the economic use of medicinal plants are the area of the population field, population density, characteristics of the ontogenetic structure, including indices of renewal and aging of populations, as well as the value of the quality index *Q* as a reflection of the level of vitality of populations.

The feasibility of using population indicators as a tool to support management decisions in the field of rational nature management and agroecological management is substantiated. A conceptual model of adaptive management of medicinal plant resources is proposed, based on a combination of complex population analysis, system monitoring and mechanisms for adjusting economic use regimes depending on the state of populations. Particular attention is paid to population

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monitoring as an informative tool for early detection of negative trends and prevention of depletion of phytoresources.

It is shown that the integration of the population approach into the practice of natural resource management creates the prerequisites for increasing the efficiency of medicinal plants, preserving their adaptive potential and maintaining the biodiversity of meadow ecosystems. The results obtained can be used to form innovative natural resource management systems in agriculture, improve phytodiversity protection programs, develop environmentally friendly production of medicinal plant raw materials and implement the principles of sustainable development of agricultural landscapes.

Keywords

Medicinal plants, population analysis, population monitoring, sustainable resource management, ecosystem approach, innovations in agriculture, agroecology, biodiversity, meadow ecosystems, ontogenetic structure, vitality structure, cultivation of medicinal plants.

6.1 Introduction

In modern conditions, agriculture is considered not only as a sector of management that ensures food security, but also as a factor in the transformation of ecosystems and changes in biodiversity. The intensification of agricultural production is often accompanied by the degradation and even destruction of natural habitats, fragmentation of vegetation cover and a decrease in floristic and cenotic diversity [1, 2]. In response to these challenges, modern agroecology is increasingly paying attention to the sustainable development of agriculture and the introduction of management based on ecosystem and environmental solutions that combine the economic use of natural complexes with their conservation [3, 4].

Important components of agrolandscapes are meadows, which simultaneously perform productive, regulatory and environmental functions, supporting a high level of floristic diversity [5, 6]. Meadow ecosystems also require the introduction of sustainable management and scientifically based regulation of resource use, capable of combining their exploitation with the preservation of biodiversity and ensuring sustainability [7, 8]. This fully applies to medicinal plants [9–12], which are widely represented in meadow cenoses. In turn, this makes it relevant to study the features and patterns of functioning of medicinal plant populations, which are a real form of species existence and link the structures of the genetic, organismal, and cenotic levels. It is in populations that a number of processes are implemented that are crucial for ensuring the sustainable and long-term existence of bio- and ecosystems. In this case, the use of complex population analysis becomes important, the most important components of which are usually the assessment of the structure of populations and their population fields [13, 14].

Taking into account the above, the purpose of this publication was determined: to investigate and substantiate the possibility of using complex population analysis of medicinal plants of floodplain meadow ecosystems as a component of an innovative system of management of plant resources of the agrosphere, aimed at ensuring their sustainable use, preserving phytodiversity and achieving the sustainability of agricultural landscapes.

6.2 Study region and methodological framework

The presented materials are based on the results of the study conducted within the Krolevets-Hlukhiv geobotanical district, located in the northern part of the Sumy slope-upland region of the Forest-steppe zone of Ukraine. The study covered the ecosystems of floodplain meadows along the rivers Seim, Kleven, Esman, Ret, etc., which are characterized by significant floristic diversity and a wide representation of medicinal plants, traditionally used by the local population as sources of medicinal raw materials. Studies were conducted for *Althaea officinalis* L., *Potentilla erecta* (L.) Raeusch., *Sanguisorba officinalis* L. (five populations of each species were studied), *Centaurium erythraea* Rafn., *Melilotus officinalis* (L.) Pall. (six populations each), *Arctium lappa* L., *Leonurus villosus* Desf. ex Spreng, *Polygonum aviculare* L., *Saponaria officinalis* L. (seven each).

To establish the state, composition and structure of phytocenoses in which these populations grow, generally accepted geobotanical approaches and methods were used [15]. In general, the study covered phytocenoses of both natural vegetation in the rank of "associations" (according to the dominant classification), and ruderal, anthropogenically transformed, which represent serial groups of demutations (mostly of the second and third stages) of the plant cover. The names of natural vegetation associations are given in accordance with the "Prodromus of Vegetation of Ukraine" [16].

The work was based on the use of the methodology of complex population analysis [17] for nine selected species of medicinal plants, the components of which were the determination of the area of population fields, population density (number of plants per unit area), ontogenetic and vitality structure of populations.

To establish the population density within the studied populations, 30–50 small accounting plots of 0.25 m^2 in size were randomly located (*Saponaria officinalis*, *Centaurium erythraea*, *Potentilla erecta*, *Polygonum aviculare*) or 1 m^2 (*Arctium lappa*, *Melilotus officinalis*, *Leonurus villosus*, *Althaea officinalis*, *Sanguisorba officinalis*) on which the total number of plants was counted. Depending on the characteristics of the implementation of certain types of reproduction by the studied species, genets were used as accounting units in five of them (*Polygonum aviculare*, *Melilotus officinalis*, *Centaurium erythraea*, *Arctium lappa*, *Leonurus villosus*), and ramets in four (*Saponaria officinalis*, *Potentilla erecta*, *Sanguisorba officinalis*, *Althaea officinalis*).

In the process of working with small accounting plots, plants of the studied species were also differentiated according to their belonging to a certain ontogenetic state and, accordingly, the number of plants of each of them was determined. At the same time, several ontogenetic states were distinguished in plants of the studied species: seedlings (p), juveniles (j), immatures (im), virginal (v), generative (g, with division into g_1, g_2, g_3), subsenile (ss), senile (s).

Establishing the number of plants of each ontogenetic state on small accounting plots for each species made it possible to determine the ontogenetic structure and ontogenetic spectra of populations. At the same time, the following were assessed for each of them:

1. Completeness of spectra. If there were representatives of all ontogenetic states in the population, the population was characterized as complete in terms of the ontogenetic spectrum, and in the absence of plants of a particular state – as incomplete.

2. Symmetry of spectra: left-sided spectra (characterized by the predominance of pregenerative individuals), centered (characterized by a significant proportion of generative individuals), right-sided (characterized by a significant proportion of senile individuals), bimodal (have two peaks).

A number of integral ontogenetic indices were determined. In particular, the indices proposed by I. Kovalenko [18]: regenerativeness, aging and generativity and a generalizing indicator – the population age index. With age index values greater than 1, populations were characterized as those in which degradation processes prevail, and with values less than 1, as those for which invasive processes are characteristic.

At the final stage of the study of the ontogenetic structure, the population's belonging to one of three categories was established: invasive, which is characterized by the predominance of individuals of pre-generative states; generative (normal) – characterized by the predominance of generative individuals; regressive – characterized by the predominance of post-generative individuals.

Taking into account the values Δ and ω, it was established that each of the studied populations belonged to one of the six types according to L. Zhivotovsky [17]: young: $\Delta < 0.35$, $\omega < 0.60$; transitional: Δ 0.35–0.54, $\omega < 0.70$; maturing: $\Delta < 0.35$, $\omega > 0.60$; mature: Δ 0.35–0.54, $\omega > 0.70$; senescent: $\Delta > 0.55$, $\omega > 0.60$; old: $\Delta > 0.55$, $\omega < 0.60$.

In order to determine the dimensional parameters of plants, morphometric analysis was used. For this purpose, 25–50 plants of each of the studied species were randomly selected from phytocenoses. They evaluated 15–22 morphoparameters: total phytomass of plants and their height, phytomass of leaves and stems, number of leaves and leaf surface area, number and mass of generative organs, reproductive effort, etc.

The results of morphometric analysis served as the basic basis for assessing the vitality (vitality) of plants and the vitality structure of populations in general. These studies were implemented according to the methodology of Y. Zlobin [17]. As a result, based on the assessment of the values of the most informative in terms of reflecting the level of vitality (key) morphoparameters, the proportion of plants of different vitality levels (the lowest (class "c"), intermediate (class "b") and the highest (class "a")) was established in each population and the value of the quality index Q was calculated for each population

$$Q = 1/2(a + b),$$

where a – the proportion of plants with the highest level of vitality (in fractions of a unit); b – the proportion of plants with an intermediate level of vitality (in fractions of a unit).

According to the values of the quality index Q, the population was classified as belonging to one of the quality types: depressed ($Q < 0.16667$), balanced (Q from 0.16667 to 0.3333), thriving ($Q > 0.3333$).

The use of a combination of these methods allowed obtaining objective comprehensive information about the parameters of the habitats of the studied medicinal plant species, the state of their populations, as well as the features and patterns of their functioning.

6.3 Population organization of medicinal plants

According to the results of the conducted study, it was established that in the plant species covered by the study, the indicators of the area of the population field vary widely: from 12 to 1106 m^2. According to the predominant density indicators, the populations are differentiated into five groups:

1) values mostly do not exceed 5 plants/m^2 (in *Arctium lappa* populations);

2) 5–10 plants/m^2 (*Leonurus villosus*, *Centaurium erythraea*, *Althaea officinalis*, *Potentilla erecta*, *Sanguisorba officinalis*);

3) 10–15 plants/m^2 (*Melilotus officinalis*);

4) 15–25 plants/m^2 (*Saponaria officinalis*);

5) 45–70 plants/m^2 (*Polygonum aviculare*).

All studied species are characterized by a wide representation of incomplete ontogenetic spectra, which most often lack seedlings and senile plants (**Fig. 6.1**). The most incomplete ontogenetic spectra were recorded in the populations of *Polygonum aviculare* and *Arctium lappa*, and the most complete in *Melilotus officinalis*, *Sanguisorba officinalis*, and *Saponaria officinalis*. Virginal and generative (g_1 and g_2) plants are distinguished by the highest degree of constancy in the spectra.

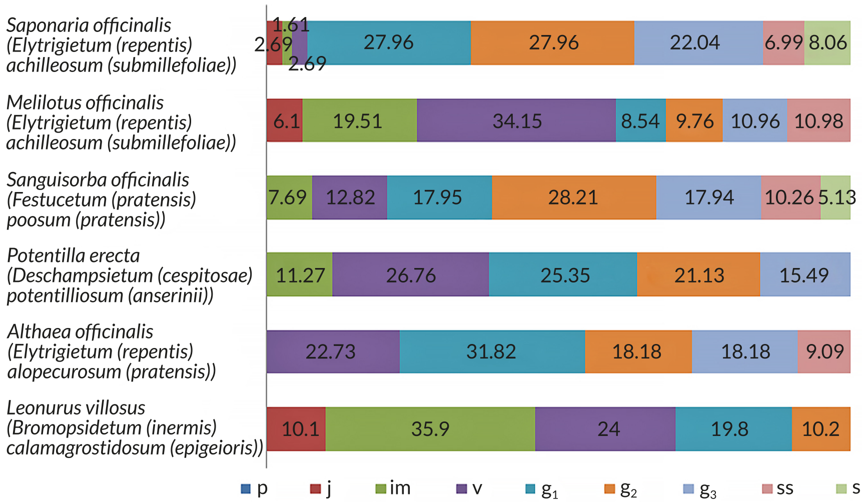

Fig. 6.1 Ontogenetic spectra and proportion (%) of plants of different ontogenetic states in populations of model species in the studied phytocenoses

The ontogenetic spectra of almost all populations are monomodal. Only in one population in *Arctium lappa* and *Centaurium erythraea* were spectra registered that were close to bimodal in their features. Monomodal spectra are differentiated as follows: in *Melilotus officinalis* they are only left-sided, in *Saponaria officinalis, Centaurium erythraea, Potentilla erecta, Sanguisorba officinalis* – exclusively centered, in *Arctium lappa, Leonurus villosus, Althaea officinalis, Polygonum aviculare* – both left-sided and centered.

It was established that the populations clearly differ among themselves in the values of generalizing ontogenetic indices and, as a result, in belonging to certain types (**Table 6.1**). In all species, populations of the "normal" category are constantly represented, the share of which varies from 16.7 to 100%. According to the values of the age index of I. Kovalenko, populations are differentiated into three groups:

a) with a predominance of populations characterized by invasive processes (*Althaea officinalis*, *Melilotus officinalis*, *Polygonum aviculare*, *Potentilla erecta*);

b) with a predominance of populations characterized by degradation processes (*Sanguisorba officinalis*);

c) with an almost equal representation of populations with a predominance of invasive or degradation phenomena (*Arctium lappa*, *Centaurium erythraea*, *Leonurus villosus*, *Saponaria officinalis*).

Table 6.1 Generalized ontogenetic characteristics of medicinal plant populations in floodplain meadow ecosystems

Plant species	Population type, %	Dominant population processes (according to I. Kovalenko), %	Population category (L. Zhivotovsky), %
Melilotus officinalis	83.3 – invasive; 16.7 – normal	100.0 – invasive	100 – young
Centaurium erythraea	66.7 – normal; 33.3 – regressive	50.0 – invasive; 50.0 – degradation	50.0 – transitional; 33.3 – mature; 16.7 – aging
Arctium lappa	71.4 – normal; 28.6 – regressive	57.1 – invasive; 42.9 – degradation	57.1 – maturing; 28.6 – transitional; 14.3 – aging
Leonurus villosus	57.1 – normal; 28.6 – invasive; 14.3 – regressive	57.1 – invasive; 42.9 – degradation	42.9 – young, 42.5 – transitional; 14.6 – mature
Saponaria officinalis	85.7 – normal; 14.3 – regressive	57.1 – degradation; 42.9 – invasive	57.1 – mature; 28.6 – maturing; 14.3 – aging
Potentilla erecta	100.0 – normal	100.0 – invasive	80.0 – maturing; 20.0 – transitional
Sanguisorba officinalis	100.0 – normal	100.0 – degradation	60.0 – mature; 40.0 – transitional
Althaea officinalis	60.0 – invasive; 40.0 – normal	80.0 – invasive; 20.0 – degradation	80.0 – young; 20.0 – mature
Polygonum aviculare	57.1– invasive; 42.9 – normal	71.4 – invasive; 28.6 – degradation	57.1 – young; 28.6 – mature; 14.3 –maturing

Source: authors' research

In the division into six types species individuality was more clearly manifested with a wide representation in the region of "transitional", "maturing" and "young" populations. In species which populations are self-sustaining (exclusively or to a large extent) through generative reproduction (*Polygonum aviculare*, *Melilotus officinalis*, *Leonurus villosus*), there is a tendency towards a greater representation of populations of the "young" category. The same tendency is observed in species in which the above-ground part is harvested to obtain medicinal raw materials. At the same time, no statistically significant differences were found in the values of the leading ontogenetic characteristics of populations depending on whether the species belong to annuals, biennials or perennials.

According to the results of the vitality analysis, it was found that the populations of the studied species are characterized by significant diversity in terms of the representation of the proportion of plants of different classes (lowest, intermediate, highest) vitality in their composition. As a result, the values of the quality index *Q* vary in a fairly wide range of values, including from the lowest (0) to the highest (0.5) possible (in *Saponaria officinalis*) (**Table 6.2**). In *Arctium lappa*, *Leonurus villosus*, *Melilotus officinalis*, *Polygonum avicular, Potentilla erecta*, populations of all three types of vitality were found, and in *Althaea officinalis*, *Centaurium erythraea*, *Sanguisorba officinalis*, *Saponaria officinalis* – two (depressive and thriving).

Table 6.2 Final results of the vitality analysis

Plant species	Range of values of the quality index *Q*	Proportion of populations (%) belonging to a certain qualitative type
Melilotus officinalis	0.1000–0.5000	33.3 – prosperous; 33.3 – balanced; 33.4 – depressed
Centaurium erythraea	0.0–0.4667	66.6 – prosperous; 33.4 – depressed
Arctium lappa	0.1333–0.4000	42.8 – prosperous; 42.8 – balanced; 14.4 – depressed
Leonurus villosus	0.1667–0.4000	57.1 – depressed; 28.6 – prosperous; 14.3 – balanced
Saponaria officinalis	0.0–0.5000	57.1 – prosperous; 42.9 – depressed
Potentilla erecta	0.0667–0.4667	40.0 – prosperous; 40.0 – depressed; 20.0 – balanced
Sanguisorba officinalis	0.0667–0.4667	60.0 – prosperous; 40.0 – depressed
Althaea officinalis	0.0334–0.4667	60.0 – prosperous; 40.0 – depressed
Polygonum aviculare	0.0667–0.4000	42.8 – depressed; 28.6 – prosperous; 28.6 – balanced

The established differences in the characteristics of population fields and the structure (ontogenetic, vitality) structure objectively demonstrate the high adaptive diversity of medicinal plants and, accordingly, demonstrate the importance of the study at the population level of organization for understanding the mechanisms of adaptation and resistance of species under anthropogenic pressure and economic use.

6.4 Population indicators as criteria for sustainable use of medicinal plants

According to the results of a comprehensive study, it was established that the populations of the studied species have significant differences in both quantitative and qualitative characteristics. Among the studied species, the populations of *Sanguisorba officinalis* and *Centaurium erythraea* are distinguished by a low frequency of occurrence and the size of the population field. In addition, all the studied populations of *Sanguisorba officinalis* by the signs of ontogenetic structure are distinguished by the predominance of degradation processes. The same feature is inherent in half of the *Centaurium erythraea* populations covered by the study. In addition, *Sanguisorba officinalis* is a species included in the "IUCN Red List", although with a low conservation category (LC level). Taking into account the specified set of features, at the present stage in the region it is inappropriate to carry out the procurement of medicinal raw materials of these species. On the contrary, the introduction of protection measures is a priority for them.

Populations of *Potentilla erecta*, unlike populations of *Sanguisorba officinalis* and *Centaurium erythrea*, have a slightly higher frequency of occurrence. It is also positive that populations of *Potentilla erecta* are characterized by the predominance of invasive processes, with most of them belonging to maturing and to all three qualitative types in terms of vitality structure. At the same time, in the absolute majority of cases, populations of *Potentilla erecta* have insignificant indicators of the area of the population field. This, in particular, is one of the consequences of the long-term unregulated use of resources of this species in the region. In general, for the region of research on *Potentilla erecta*, the priority is the implementation of active protection measures aimed at increasing the centers of distribution and the formation of high-quality (with a significant area of the population field, population density, pronounced invasive processes and belonging to the category of thriving) populations capable of sustainable existence and self-sustainability. When implementing active protection measures, the source of planting material can be populations from the groups *Deschampsietum (cespitosae) potentilliosum (anserini)* and *Deschampsietum (cespitosae) arostidosum (stoloniferea)*, and peaty meadows should be used as centers of formation of new populations.

Compared with the populations of *Sanguisorba officinalis*, *Centaurium erythraea*, *Potentilla erecta*, the populations of *Saponaria officinalis*, *Arctium lappa*, *Melilotus officinalis*, *Leonurus villosus*, *Althaea officinalis*, *Polygonum aviculare* are more promising for their use as centers of regulated harvesting of medicinal raw materials. In this case, the informative criteria for determining the suitability of populations for regulated harvesting and long-term use of resources are primarily such indicators as population density, population area, ontogenetic and vitality structure, and the actual value of the quality index *Q*.

Populations with high density, sufficiently large population fields, the predominance of pregenerative and generative individuals, active renewal processes and a high level of vitality (vitality) demonstrate the highest resource potential and adaptive stability and can be considered suitable for regulated harvesting under conditions of constant environmental monitoring. In contrast, populations characterized by widespread degradation processes, incomplete ontogenetic spectrum, low representation of pregenerative individuals, or depressed vitality structure should be separated from intensive resource use or significant restrictions on their harvesting should be imposed. In general, population-based approaches provide greater opportunities for assessing the sustainability of medicinal plant use compared to traditional resource assessment methods that focus primarily on biomass stocks or harvest volumes.

Populations from the *Elytrigietum (repentis) poosum (pratensis)* association and the *Elytrigia repens* + *Artemisia absinthium*, *Elytrigia repens* + *Artemisia vulgaris* groups can be considered as centers of regulated harvesting of medicinal raw materials of *Saponaria officinalis*. Populations formed in these phytocenoses are thriving ($Q = 0.4–0.5$), have a fairly significant population density (21.4–23.9 plants/m^2). In all of them, the proportion of pregenerative and generative plants is high (at the level of 80–90%). At the same time, populations from the last two groups require more careful monitoring in the process of economic use: they have one of the highest values of the aging index (26.85–37.10%) with a general tendency to the dominance of degradation processes.

In *Arctium lappa*, populations from *the Urtica dioica* + *Rumex confertus – Trifolium repens* and *Urtica dioica* + *Arctium lappa* groups may be promising in terms of resources. These two populations are thriving (Q = 0.3667–0.4000), have a fairly significant population density (about 2.0–3.4 plants/m^2). They have a high (at 100%) proportion of pregenerative and generative plants, invasive processes prevail, and the populations belong to the category of "maturing".

In *Melilotus officinalis*, populations from the phytocenoses *Elytrigietum (repentis) achilleosum (submillefoliae)* and *Elytrigia repens* + *Artemisia vulgaris* can primarily be considered as potential centers of regulated procurement of medicinal raw materials. They are thriving (with *Q* reaching the maximum possible values of 0.5), have fairly high population density (on average at the level of 11.7–12.5 plants/m^2), and according to their ontogenetic structure, invasive processes prevail with fairly high recovery index indicators (within 58.67–59.76%) and the populations are young. Considering that the populations of *Melilotus officinalis* from the phytocenoses *Festucetum (pratensis) elytrigiosum (repenstis)* and *Chelidonium majus – Convolvulus arvensis*, although balanced in terms of vitality structure (Q is 0.2000 and 0.2333, respectively), are distinguished by rather high population density indicators (at the level of 9.4–10.1 plants/m^2), the predominance of invasive processes and belonging to the category of young plants, they can also be considered as potential centers for the procurement of medicinal raw materials of *Melilotus officinalis*. However, during economic use, these two populations require particularly careful monitoring of the level of plant vitality and, in general, the vitality structure, in particular. In the event of a tendency to decrease in the values of the quality index Q, their use should be stopped (just as in the case of deterioration of other population characteristics and signs of population structure).

In *Leonurus villosus*, the populations of the associations *Bromopsidetum (inermis) elytrigiosum (repentis)* and *Dactyletum (glomeratae) festucosum (pratensis)* are promising from a resource point of view. The populations formed in these phytocenoses are prosperous ($Q = 0.3333–0.4000$), have a fairly significant population density (about 7 plants/m^2). They have a high (at the level of 83–88%) share of pregenerative and generative plants. At the same time, populations from these two groups in the process of economic use require more detailed monitoring: they have one of the highest values of the aging index (27.78–32.56%) with a general tendency to the dominance of degradation processes and their belonging to the category of "transitional".

In *Althaea officinalis*, three populations can be considered as potential foci of regulated harvesting of medicinal raw materials: from the associations *Scirpetum (sylvatici) ranunculosum (acris)*, *Scirpetum (sylvatici) lycoposum (europaei)*, *Caricetum (acutae) agrostidosum (stoloniferae)*. They are distinguished not only by belonging to the category of thriving ($Q = 0.4667$), but also by rather high values of population density (about 7–8 plants/m^2), significant values of renewal indices (within 45.45–62.16%) and relatively high values of generativity index (32.43–51.52%) and, as a result, by belonging to the category of young with a general predominance of invasive processes.

In *Polygonum aviculare*, the promising centers of regulated harvesting of medicinal raw materials are primarily population No. 1 and, to some extent, population No. 2 (both from the *Polygonum aviculare* group), which grow against a background of relatively insignificant recreational impact. These populations, respectively, are prosperous and balanced in terms of vitality structure. The *Polygonum aviculare* plants represented in their composition are some of the largest in size and have a fairly well-developed leaf surface, and the populations themselves are distinguished by one of the highest population density indicators.

Thus, the results of a comprehensive analysis of the state of populations indicate that the characteristics of populations can serve as effective indicators for determining the prospects for the sustainable use of medicinal plants in meadow ecosystems. At the same time, a comprehensive analysis of populations should be considered as an effective scientific basis for sustainable management of medicinal plant resources in meadow ecosystems. Its application creates opportunities for the implementation of adaptive approaches aimed at balancing the economic use of medicinal plants with the long-term preservation of biodiversity and maintaining ecosystem stability.

6.5 Population monitoring as a management tool

For populations that are identified as potential centers for the procurement of medicinal raw materials, it is relevant to conduct resource studies in order to determine the available reserves and possible volumes and procurement regimes. To maintain and increase the resource potential of *Saponaria officinalis*, *Arctium lappa*, *Melilotus officinalis*, *Leonurus villosus*, *Althaea officinalis*, *Polygonum aviculare*, as well as for *Sanguisorba officinalis*, *Centaurium erythraea*, *Potentilla erecta*, it is possible to apply active protection measures aimed at increasing the number of growth centers of these species in the region, as well as expanding population fields and optimizing the structure of existing populations.

An equally relevant issue is the introduction of systematic monitoring of the state of medicinal plant populations. First of all, it should cover populations of species that represent a rare component of phytodiversity or are not among the most common in the region. For populations that will be involved in the economic use system, the implementation of monitoring studies is also mandatory.

It is believed that when implementing monitoring of medicinal plants, it is necessary to adhere to the following algorithm:

1. Select parameters (characteristics) for monitoring.
2. Select monitoring objects.
3. Determine the frequency of data collection.
4. Form a database based on the monitoring results.
5. Based on the monitoring data, form recommendations aimed at promoting the sustainable existence of populations.
6. Provide monitoring results and recommendations to interested institutions (organizations).
7. Promote the implementation of recommendations formed based on the monitoring results.

In the course of the study, a number of negative signs were identified regarding the sustainable existence of populations of the studied species: incompleteness of ontogenetic spectra, a rather significant representation of populations with a dominance (according to the signs of ontogenetic structure) of degradation processes, the presence of populations in which plants of low (class "c") vitality prevail. Taking into account the above-mentioned features, it is believed that an important component of the monitoring of medicinal plants should be population monitoring. It should include:

1. Determination of the complex of leading ecological and cenotic signs of the phytocenosis in which the population – the object of monitoring – grows.
2. Determination of the area of the population field for the selected object of monitoring.
3. Establishment of population density values.
4. Determination of the ontogenetic structure and its comprehensive assessment based on the use of a set of generalizing indices.
5. Conduction of a morphometric analysis (damaging or non-damaging) of plants forming the population.
6. Establishment of the vitality structure of populations.
7. Identification of the main stress factors that are dangerous for the population.
8. Establishment of the signs of ecological, cenotic and complex ecological-cenotic optimums for the population.
9. Provision of a forecast of the future state of the population subject to the further implementation of the selected protection regime (or economic use).
10. Assessment of the effectiveness of the selected protection regime (or economic use) of the population. If negative trends are identified in the signs reflecting its state – presenting updated proposals for improving the protection regime or economic use of phytoresources of the population.

When implementing the last stage, it is necessary to take into account that objective signs of population deterioration are: a decrease in the area of the population field, indicators of population density and plant size, an increase in the values of the aging index when the dominance (according to the signs of the ontogenetic structure) of invasive processes changes to the dominance of degradation processes, an increase in the proportion of plants with low vitality in the population while reducing the values of the *Q* index, especially when reducing its categorical status (for example, transformation from balanced to depressed).

Particular attention should be paid to plant populations which medicinal raw materials are underground organs, in particular *Arctium lappa*, *Potentilla erecta*, *Saponaria officinalis* and *Sanguisorba officinalis*. The collection of underground organs directly affects the survival of individuals and limits the natural processes of regeneration. Under such circumstances, the value of the area of the population field, ontogenetic and vitality structure, and the level of vitality of populations becomes especially significant for determining permissible levels of harvesting and frequency of resource use.

An important component of ensuring the rational use of medicinal plant resources should be the assessment of qualitative and quantitative characteristics of raw materials. It should be carried out by specialized, certified institutions (laboratories). The results of such an assessment can also influence the final decisions on the feasibility, volumes, and modes of using medicinal plant resources.

Therefore, the use of population monitoring creates opportunities for early detection of negative trends in their dynamics and helps prevent resource depletion before irreversible degradation processes occur. Population monitoring can be effectively combined with geobotanical assessment, habitat analysis and assessment of anthropogenic impact, forming a comprehensive scientific basis for effective resource management.

6.6 Conservation-oriented cultivation of medicinal plants

In modern conditions, as a result of the negative transformation of plant communities under the influence of various anthropogenic factors, traditional environmental protection measures (regulation of collection, allocation of territories with nature conservation status, planting and replanting plants in places of natural growth, etc.) are not always effective. In addition, the use of natural populations as a source of medicinal raw materials, even if all recommendations aimed at ensuring rational nature management are followed, still creates a potential danger of deterioration of their quantitative and qualitative characteristics. This primarily concerns species in which the underground part is removed during the harvesting process.

Accordingly, long-term preservation of medicinal plant resources in meadow ecosystems requires not only conventional nature conservation measures, but also the development of cultivation systems capable of reducing the burden on natural populations in the process of harvesting medicinal plants. In this case, cultivation focused on nature conservation should be considered as an important component of sustainable management of medicinal plant resources, aimed at combining the preservation of biodiversity with the stable production of high-quality medicinal raw materials.

At the same time, the introduction of plants into culture is a long and laborious process, and one of the components of ensuring the successful cultivation of autochthonous species of medicinal plants is an in-depth analysis of the biological and ecological properties of medicinal plants and the study of the features and patterns of functioning of their natural populations, which can act as a source of seeds and (or) planting material.

Based on the results of population studies in the floodplains of the rivers of the Krolevets-Hlukhiv geobotanical region, it is believed that natural populations of medicinal plants that can become a source of seeds for introducing a particular species into culture should primarily have the following characteristics (in decreasing order of importance): the predominance of invasive processes (by the complex of characteristics of the ontogenetic structure and by the values of the age index), a relatively significant proportion of medium-generative (g_2) plants with pronounced centered ontogenetic spectra, belonging of populations to the category of thriving or balanced, but with values of the quality index *Q* greater than 0.30 and, preferably, high values of population density and area of the population field. At the same time, the plants from which seeds (fruits) will be collected must also have high vitality (classes "a" or "b"), a sign of which is higher than the average population values of key morphological parameters, as well as higher than the average population values of reproductive effort and other quantitative characteristics of the generative sphere (length of reproductive shoots, size of fruits, etc.). For example, in *Saponaria officinalis*, the characteristics of populations from the phytocenoses *Elytrigietum (repentis) poosum (pratensis)* and *Elytrigia repens + Artemisia absinthium* most closely correspond to these requirements, in *Arctium lappa* – populations from the groups *Trifolium repens – Persicaria hydropiper*, *Urtica dioica + Rumex confertus – Trifolium repens*, *Urtica dioica + Arctium lappa*, in *Melilotus officinalis* – from *Elytrigietum (repentis) achilleosum (submillefoliae)* and *Elytrigia repens + Artemisia vulgaris*, in *Leonurus villosus* – from the associations *Dactyletum (glomeratae) festucosum (pratensis) and Elytrigietum (repentis) dactyleto (glomeratae) – festucosum (pratensis)*, in *Centaurium erythraea* – from the groups *Trifolium repens – Daucus carota – Achillea submillefolium* and *Trifolium repens – Tanacetum vulgare*, in *Althaea officinalis* – from the associations *Scirpetum (sylvatici) lycoposum (europaei)* and *Caricetum (acutae) agrostidosum (stoloniferae)*, in *Potentilla erecta* – from the associations *Deschampsietum (cespitosae) potentilliosum (anserini)* and *Deschampsietum (cespitosae) agrostidosum (stoloniferae)*, in *Sanguisorba officinalis* – from the groups *Poetum (angustifoliae) alopecurosum (pratensis)*, *Festucetum (pratensis) poosum (pratensis)*. In-depth studies should also be conducted in the indicated populations, aimed at studying the complex of traits that reflect quantitative and qualitative indicators of reproduction, generative propagation (seed productivity, reproductive success, seed germination indicators and factors that influence it, etc.), and in production conditions – agrotechnological aspects of this method of forming crops of medicinal plants should be investigated.

In the case when the introduction into the culture will be carried out on the basis of the use of structures that participate in vegetative reproduction or the movement of the plants themselves (genets or ramets), the populations from which the selection of planting material will be carried out must meet the following requirements (in order of decreasing importance): have high indicators of population density and area of the population field, left-sided or centered ontogenetic spectra with reduced indicators of the proportion of plants of older ontogenetic groups (old generative (g_3), subsenile (ss) and senile (s)), it is also desirable that they be thriving or balanced in terms of vitality structure. In this case, plants that will be used for transplantation or for obtaining planting material must have high vitality (classes "a" or "b"). Among the studied species, the complex of the specified requirements, for example, are most closely matched by the characteristics of the populations of *Saponaria officinalis* from the phytocenoses *Elytrigietum (repentis) poosum (pratensis)*, *Elytrigia repens + Artemisia absinthium* and *Elytrigia repens + Artemisia vulgaris*, in *Arctium lappa* – from the group *Urtica dioica + Rumex confertus – Trifolium repens* and, especially, from *Urtica dioica + Arctium lappa*, in *Melilotus officinalis* – from the phytocenoses *Elytrigietum (repentis) achilleosum (submillefoliae)* and *Elytrigia repens + Artemisia vulgaris*, in *Leonurus villosus* – from the associations *Elytrigietum (repentis) festucosum (pratensis)* and *Elytrigietum (repentis) dactyleto (glomeratae) – festucosum (pratensis)*, in *Centaurium erythraea* – from the group *Trifolium pratensis + Achillea submillefolia*, in *Althaea officinalis* – from the associations *Scirpetum (sylvatici) ranunculosum (acris)*, *Scirpetum (sylvatici) lycoposum (europaei)* and *Caricetum (acutae) agrostidosum (stoloniferae)*, in *Potentilla erecta* – from the associations *Deschampsietum (cespitosae) potentilliosum (anserini)* and *Deschampsietum (cespitosae) agrostidosum (stoloniferae)*. The practical application of this method of introduction into culture requires additional study aimed primarily at clarifying the physiological, biochemical and agrotechnological means that ensure successful plant survival and the formation of productive agrocenoses by them.

The analysis conducted allows to identify populations that, when introducing plants of the appropriate species into the culture, can be a source of high-quality seed and planting material. In particular, in *Saponaria officinalis* these are populations from the phytocenoses *Elytrigietum (repentis) poosum (pratensis)* and *Elytrigia repens + Artemisia absinthium*, in *Arctium lappa* – from the groups *Urtica dioica + Rumex confertus – Trifolium repens* and *Urtica dioica + Arctium lappa*, in *Melilotus officinalis* – from the phytocenoses *Elytrigietum (repentis) achilleosum (submillefoliae)* and *Elytrigia repens + Artemisia vulgaris*, in *Leonurus villosus* – from the association *Elytrigietum (repentis) dactyleto (glomeratae) – festucosum (pratensis)*, in *Althaea officinalis* – from the association *Scirpetum (sylvatici) lycoposum (europaei)* and *Caricetum (acutae) agrostidosum (stoloniferae)*, in *Potentilla erecta* – from the association *Deschampsietum (cespitosae) rotentilliosum (anserini)* and *Deschampsietum (cespitosae) agrostidosum (stoloniferae)*.

Therefore, natural populations are not only sources of medicinal raw materials, but also foci of valuable phytodiversity necessary for the long-term sustainability of medicinal plant cultivation systems. Integration of population approaches into cultivation programs creates opportunities for preserving the adaptive potential of populations and reducing the pressure on them from the harvesting process. This, in turn, will contribute to the preservation of the biodiversity of meadow ecosystems and maintaining their ecological stability.

As a result, based on the study conducted, it was formed a generalizing conceptual model that demonstrates the integration of complex population analysis into systems for sustainable management of medicinal plant resources in meadow ecosystems (**Fig. 6.2**).

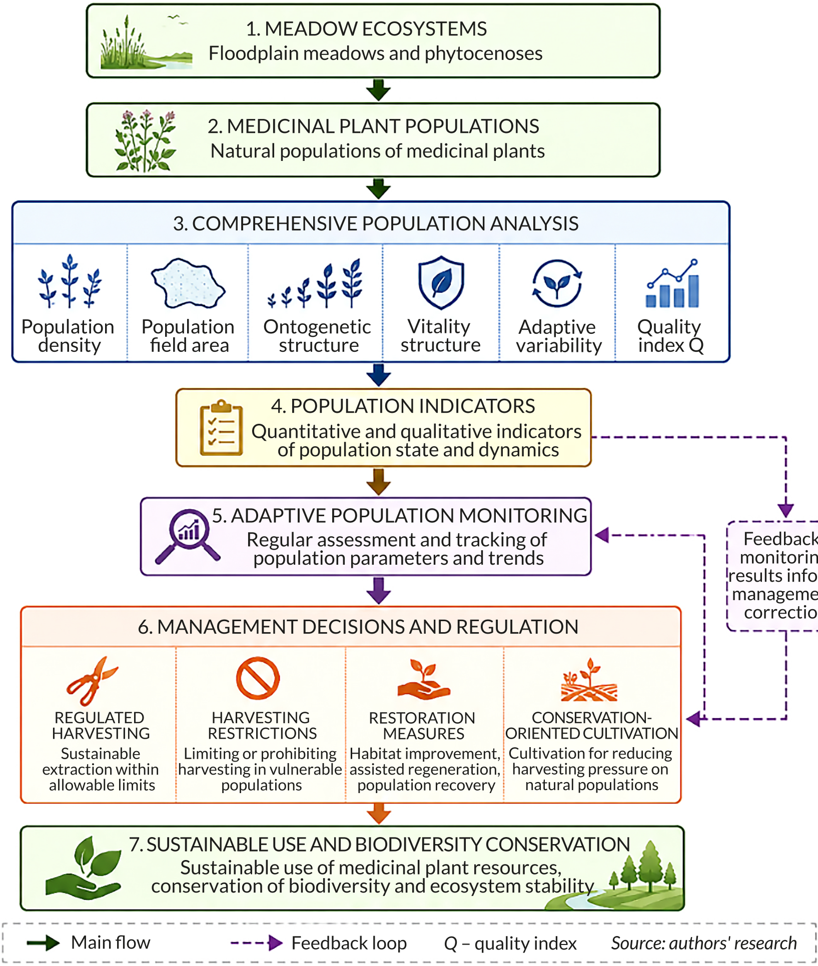

Fig. 2 Conceptual framework of population-based sustainable management of medicinal plant resources in meadow ecosystems
Source: imagined with AI

It is directly related to adaptive management measures, in which the results of population studies and their monitoring were used as a basis for further adjustment of management decisions aimed at balancing the economic use of medicinal plants with the preservation of biodiversity and maintaining ecosystem stability.

6.7 Conclusions

Populations of medicinal plants of floodplain meadows show statistically significant interspecific and intraspecific differences in spatial organization and structure, which reflects both species biological features and high ecological diversity of meadow habitats. At the same time, indicators of population density, their area, ontogenetic and vitality structure serve as informative criteria for assessing their actual state, adaptive capacity, expectations for further dynamics and determining the possibility and regimes of economic use. Accordingly, the conducted study showed that a comprehensive population analysis provides an effective scientific and methodological basis for sustainable management of medicinal plant resources in floodplain meadow ecosystems. It is shown that population monitoring should be considered as an important tool for effective and sustainable management of the meadow ecosystem. Systematic tracking of the state of populations ensures early detection of negative trends, timely correction of harvesting regimes and prevention of resource depletion. The integration of population monitoring results into the natural resource management system contributes to the implementation of scientifically based adaptive approaches to the rational inexhaustible use of medicinal plants.

Scientific results also revealed the importance of conservation-oriented cultivation as a component of sustainable management of medicinal plant resources. The development of cultivation systems based on the use of the adaptive and reproductive potential of natural populations contributes to reducing the pressure of harvesting on natural habitats, preserving biodiversity, stabilizing the supply of raw materials and optimizing production technologies. At the same time, a comprehensive analysis of populations creates a scientific basis for identifying populations with high adaptive and reproductive potential, suitable for inclusion in breeding and cultivation programs.

The results obtained confirmed the practical value of the population approach for differentiating medicinal plant populations according to the prospects of economic use, the need for protective measures and suitability for introduction into culture.

This creates the prerequisites for the implementation of innovative models of plant resource management, based on taking into account the demographic state, viability and adaptive potential of populations and contributing to increasing the efficiency of nature use and ecological sustainability of agrolandscapes. Integration of population ecology approaches, monitoring systems and conservation-oriented cultivation strategies creates opportunities for balancing the economic use of medicinal plant resources with the preservation of biodiversity and maintaining the ecological stability of meadow ecosystems. Increasing the effectiveness of such measures also requires the development of an administration system that will include measures for planning, organizing, and controlling phytoresources and their use.

The issue of developing the principles of administration is a prospect for our further scientific research.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published results of the study, including the financial aspects of conducting the study, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Manuscript has associated data in a data repository.

Use of artificial intelligence statement

The authors have used artificial intelligence technologies (ChatGPT artificial intelligence system from OpenAI, based on the GPT-5.5 model, AI was used to create a graphic figures).

Authors' contributions

Inna Zubtsova: Formal Analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft.

Viktoriia Skliar: Conceptualization, Data Curation Project Administration, Resources, Supervision, Validation, Writing – review & editing.

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