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ONTOGENETIC STRUCTURE AND SEED PRODUCTIVITY OF *ARNICA MONTANA* L. IN THE UKRAINIAN CARPATHIANS

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Abstract: The article examines the ontogenetic structure and seed productivity of *Arnica montana* L. in the natural conditions of the Ukrainian Carpathians, which are key aspects for understanding the dynamics of its populations and ecological adaptations. The main factors affecting population viability have been identified, including climatic conditions, altitudinal zonation, phytocenotic state, and the intensity of anthropogenic impact. An analysis of the spatial distribution and age structure of populations has been conducted, allowing for an assessment of the species' adaptive potential and its capacity for natural regeneration. The relationship between altitudinal zonation, plant community structure, and seed renewal indicators has been studied. The obtained data confirm that the presence of favorable environmental conditions is a determining factor in ensuring the successful regeneration of the species. It has been established that in the conditions of mid-mountain meadows and the subalpine zone, *Arnica montana* L. exhibits a higher level of seed productivity compared to high-mountain areas, where a gradual decline in potential seed productivity is observed due to ecological constraints. The phase development of *Arnica montana* L. individuals at different ontogenetic stages has been analyzed. A quantitative analysis of potential and actual seed productivity indicators, as well as seed regeneration levels in different ecological niches, has been conducted. A set of measures for the conservation of natural populations of *Arnica montana* L. in the region has been proposed. These measures include limiting livestock grazing, regulating recreational impact, prohibiting the collection of medicinal raw materials in natural habitats, and protecting key populations in protected areas. The possibility of creating artificial populations and restoring the species in areas of its historical distribution is also considered.

Keywords: *Arnica montana* L., ontogenetic structure, seed productivity, ecological factors, Ukrainian Carpathians, species conservation.

1. INTRODUCTION

Arnica montana L. (*Asteraceae*) is classified as a species with relatively undisturbed populations, which are commonly found in the Ukrainian Carpathians over large areas (Leoni, 2021). It reproduces satisfactorily but requires conservation as morphological isolates (Kriplani, 2017). The main reasons for the decline in the population of *Arnica montana* L. include significant harvesting for decorative purposes, collection of medicinal raw materials, and the destruction of growth conditions due to trampling or livestock grazing.

Arnica montana L. is a perennial herbaceous plant with glandular pubescence. It is a heliophilous species, capable of blooming and fruiting only in open or lightly shaded areas. Vegetative plants can tolerate significant shading (on forest edges). For optimal vital activity, the species requires loose sodding or moss cover, due to the need for constant moisture. *Arnica montana* is very sensitive to the drying out of its root system and reacts negatively to soil exposure caused by excessive grazing, mechanical trampling, or soil erosion. Drought is particularly detrimental to seedlings, so on exposed soil, generative regeneration practically does not occur. It is also absent in areas with excessive sodding and a significant amount of dead plant material.

The vegetation of *Arnica montana* begins in the first or second decade of April, after the snow melts. In the mid-mountain regions, mass flowering is observed in the second half of June, while in the subalpine zone, it takes place in the second decade of August.

Arnica montana is a mesophyte, an indifferent species. It is widespread in the subalpine, and less commonly in the alpine zone, at elevations of 1200-1300 meters above sea level. It is found in meadows and shrub thickets, in scrub forests, and on fresh, acidic, humus-rich, and clayey soils that are low in lime (Flórez-Fernández, 2021).

The reproductive biology of the species includes the biology and ecology of its reproduction, regeneration, and the maintenance of population homeostasis. In natural conditions, most plants have the ability to reproduce both vegetatively and by seeds (Pljevljakuši´c, 2012).

Arnica montana L. is one of the key representatives of the alpine flora of the Ukrainian Carpathians, which requires careful study due to the threat of extinction and its importance in conservation programmes. In the international context, the species is studied mainly for its ecological, medical and population significance. Studies published in the Web of Science and Scopus databases highlight the adaptation of the species to different environmental conditions, as well as the problems of conserving its natural habitats. For example, studies in the Alps and Pyrenees focus on the impact of climate change and anthropogenic factors on the viability of *Arnica montana* L. populations (Kimel, 2020, Jakubowicz-Gil, 2017).

A review of current publications demonstrates that one of the central aspects of the species' study is its seed productivity and ability to generate and reproduce vegetatively. In particular, research results confirm a significant dependence of the success of seed renewal on the altitude zone, phytocoenotic conditions and anthropogenic load (Sugier, 2020, Duthen, 2022).

In addition, attention is paid to the analysis of the ontogenetic structure of populations, which allows to assess the adaptive potential of the species in different environmental conditions. Such research contributes to the development of recommendations for effective population management and preservation of their stability in natural conditions.

2. RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The habitats of *Arnica montana* in the Ukrainian Carpathians belong to the continental spatial category. We focused on the ecological and biological, population characteristics, and specific aspects of the species' life and behavior in various ecological conditions. Observations were conducted using a route method, and the population density and age structure were determined along transects measuring 1x1 m². The aim of the study is to investigate the ontogenetic structure and seed productivity of *Arnica montana* L. in the Ukrainian Carpathians in order to assess its adaptive potential and develop measures for the conservation of the species.

The methodology included route observations, analysis of the number and age structure of populations in 1×1 m² transects. Methods of variation statistics were used to estimate quantitative indicators of seed production. Data were collected in different phytocoenoses at altitudes from 700 to 1300 m above sea level. The analysis used indicators of potential and actual seed productivity, as well as the seeding rate.

The quantitative indicators were processed using methods of variation statistics. For all indicators, the following basic statistical characteristics were determined: the arithmetic mean (X for potential seed productivity – PSP, Y for actual seed productivity – ASP), the standard error of the mean (Sx and Sy, respectively), the coefficient of variation (Cv, %), the t-test for mean validity (t), and the experiment accuracy indicator (P, %). The significance of the difference between the arithmetic means of individual populations of the studied species was determined using the validity criterion.

The data used were based on field studies conducted in 2023-2024 and literature sources included in the Web of Science and Scopus databases.

3. RESULTS AND DISCUSSION

The ecotypic tolerance of *Arnica montana* L. covers areas from the foothills to the subalpine zone, where it occurs in meadows and shrub thickets. In the alpine zone of the Chornohora mountain, populations of *Arnica montana* L. can be found up to the highest points of the main watershed ridge. The phytocenotic amplitude of the species is quite broad, occurring in the *Nordetum*, *Vaccinietum*, and *Festucetum* communities. The highest density is observed in post-forest meadows in the middle mountain zone (600-1200 m), both in the highland pastures and in river valleys, where *Arnica montana* often acts as a subdominant in low-grass formations (*Festuceta rubrae, Nardeta, Agrostideta, Anthoxanthieta*). Among these communities, fragments of the *Arnicetum montanae* association are occasionally found, where the projective cover of *Arnica montana* L. reaches about 65% (Babyna Yama locality). Associated species: *Nardus stricta*, *Festuca rubra*, *Achyrophorus uniflorus*, *Leontodon croceus*, *Scorzonera rosea*. A characteristic feature of the species' distribution is spatial fragmentation and significant variation in population density, even in adjacent habitats. This is due to the species' high demands for several ecological factors, as well as the prior condition of the plant communities.

Ontogenetic features determine the population structure of *Arnica montana*. Table 1 presents data on the age structure and population density of the species under favorable mowing conditions and the absence of anthropogenic influence. Populations of *Arnica montana* in protected areas are characterized by a high level of species vitality and low variability in population indicators.

Table 1. Indicators of density and age structure of the *Arnica montana* L. populations

№	Habitat of communities	Altitude above sea level	Age structure, %						Density, individuals/m²		
			j	im	v	g	ss	s	Individuals	Rosettes	Generative shoots
1.	Babyna Yama locality, *Arnicetum montanae*	950	2	8	70	14	4	2	55	85	15
2.	Highland pasture Vesnarka *Festucetum rubrae*	1300	1	2	77	14	5	1	7	24	4
3.	Highland pasture Svynianka, *Nardetum*	800	2	7	70	13	4	4	66	82	19

4.	Pechnivske locality, *Festucetum agrostidosum*	1380	1	6	64	20	6	3	13	41	7

Ontogenetic indicators of the age structure and density of *Arnica montana* are characteristic of the middle mountain zone with a conservation regime. The percentage of generative individuals ranges from 14% to 20%. There is a significant predominance of virgin individuals (64%-77%), which is a result of a high rate of vegetative reproduction. The low number of post-generative individuals is due to the relatively short subsenile and senile periods.

The results of quantitative analysis of *Arnica montana* seed productivity are presented in Table 2. They reflect the pattern of change in the number of ovules and seeds depending on the habitat conditions.

Table 2. Average number of ovules and seeds per elementary unit of seed productivity (fruit)

Collection site, community	Cenotic conditions	Elevation, m a.s.l.	Ovules			Seeds			Seed-setting efficiency
			$Y \pm S_y$	C_v	Lim	$X \pm S_x$	C_v	Lim	
Babyna Yama locality, *Arnicetum montanae*	Meadow	950	117±3	18,5	55-159	93,6±21,0	22,4	45-160	80,0
Highland pasture Vesnarka, *Festucetum rubrae*	Alpine Meadow	1300	105±2	16,4	74-145	94,3±15,7	16,6	70-148	89,5
Highland pasture Svynianka, *Nardetum*	Pasture	800	157±4,0	26,0	74-121	95,8±12,1	12,6	60-125	54,5
Pechnivske locality, *Festucetum agrostidosum*	Pasture	700	121±2	19,3	76-196	95,5±10,1	10,6	69-119	78,8

The number of ovules varies less than the number of seeds. Based on this, the accuracy of the study of actual seed productivity (ASP) is higher than the 5% significance level, whereas for all data on potential seed productivity (PSP), this level is below 5%. However, the sufficient number of accounting units (n=50) ensured the necessary reliability of the arithmetic means (t=3).

Based on the number of ovules (NO) per elemental unit of seed productivity (SP), *Arnica montana* L. can be classified into the group of species where the number of ovules ranges from 51 to 100. Regarding the number of seeds, it belongs to the group where the number ranges from 40 to 96.

For most of the studied populations, the seed productivity coefficient (SPC) is high, exceeding 60% (Table 3). A high SPC indicates satisfactory seed regeneration of the species. Seed regeneration varies over the years, and accordingly, the seed yield in individual populations will also change. This yield depends not only on seed productivity but also on the number of generative shoots per unit area.

Table 3. Average number of fruits per individual, PSP and ASP of *Arnica montana* L.

Association	Fruits			PSP	ASP	SPC
	$X \pm S_x$	C_v	Lim	U±Su	$Z \pm S_z$	
Babyna Yama locality	1,65±0,02	49,69	1-4	173,75±8,89	151,63±8,21	87,27
Highland pasture Vesnarka	2,40±0,12	49,17	1-5	62,96±3,14	44,39±3,12	70,50
Highland pasture Svynianka	1,59±0,07	42,14	1-3	214,25±22,65	166,14±10,55	78,48
Pechnivske locality	2,54±0,18	70,86	1-11	106,05±8,96	90,93±7,67	85,74

The comparison of potential seed productivity, actual seed productivity, and the seed productivity coefficient of populations from different altitudinal zones revealed some differences. The values of potential seed productivity in high-mountain populations are, on average, 15% lower than those in the mid-mountain zone.

The level of seed productivity in *Arnica montana* L. ranges from satisfactory (85.74–87.27%) to moderate (70%) in high-altitude habitats. Along with a significant percentage of seed setting, this

indicates a satisfactory level of adaptation of the species to its current living conditions. The self-maintenance of *Arnica montana* L. populations occurs through both seed and vegetative reproduction.

4. CONCLUSIONS

Arnica montana L. is an important component of the flora of the Ukrainian Carpathians, exhibiting a wide phytocenotic amplitude but requiring favorable ecological conditions for optimal vitality.The populations of this species exhibit significant dependence on environmental conditions, particularly moisture levels, soil structure, and the degree of anthropogenic impact. The highest plant abundance and viability are observed in mid-mountain areas with moderate anthropogenic pressure. The seed productivity of *Arnica montana* L. varies depending on the altitudinal zone, reflecting its adaptation to different growth conditions. However, a slight decrease in potential seed productivity is observed in high-altitude populations. A high seed-setting coefficient indicates the species' capacity for effective seed regeneration, which supports population maintenance, provided that negative factors are minimized. The conservation of *Arnica montana* L. requires the implementation of protective measures, such as limiting livestock grazing, controlling the collection of medicinal raw materials, and preserving natural habitats, which will contribute to the stability of its populations in the Ukrainian Carpathians.

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Андрій Дубляк, Надія Різничук, Вікторія Гнєзділова. Онтогенетична структура та насіннєва продуктивність Arnica montana L. в умовах Українських Карпат. Журнал Прикарпатського національного університету імені Василя Стефаника. Біологія, 11 (2024), С.168-176.

Анотація. У статті розглянуто особливості онтогенетичної структури та насіннєвої продуктивності *Arnica montana* L. у природних умовах Українських Карпат, що є ключовими аспектами для розуміння динаміки її популяцій і екологічних адаптацій. Визначено основні фактори, які впливають на життєздатність популяцій, включаючи кліматичні умови, висотну поясність, стан фітоценозів та інтенсивність антропогенного впливу. Здійснено аналіз просторового розподілу та вікової структури популяцій, що дозволяє оцінити рівень адаптивного потенціалу виду та його здатність до природного відтворення. Досліджено

взаємозв'язок між висотною поясністю, структурою рослинного угруповання та показниками насіннєвого оновлення. Отримані дані засвідчують, що наявність сприятливих екологічних умов є визначальним фактором для забезпечення успішної регенерації виду. Встановлено, що в умовах середньогірних лук і субальпійської зони *Arnica montana* L. демонструє вищий рівень насіннєвої продуктивності порівняно з високогірними територіями, де спостерігається поступове зниження потенційної насіннєвої продуктивності внаслідок екологічних обмежень. Проаналізовано фазовий розвиток особин *Arnica montana* L. на різних онтогенетичних стадіях. Здійснено кількісний аналіз показників потенційної та актуальної насіннєвої продуктивності, а також рівня насіннєвого відтворення у різних екологічних нішах. Запропоновано комплекс заходів для збереження природних популяцій *Arnica montana* L. у регіоні. До таких заходів належать обмеження випасу худоби, регулювання рекреаційного навантаження, заборона збору лікарської сировини у природних місцях зростання та охорона ключових популяцій у заповідних територіях.

Ключові слова: *Arnica montana* L., онтогенетична структура, насіннєва продуктивність, екологічні фактори, Українські Карпати, охорона видів.