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FLOWERING AND GENERATIVE REPRODUCTION IN ISOLATED POPULATIONS OF ENDANGERED SPECIES *CARLINA ONOPORDIFOLIA* BESSER (ASTERACEAE) IN POLAND

ABSTRACT: *Carlina onopordifolia* is long-lived monocarpic perennial plant, which reproduces only generatively, however, it flowers and fruits only once in lifespan (10–20 yrs) and after seeds development it dies. Due to this type of reproduction the abundance of population depends on amount of produced seeds, moreover the plant flowers more abundantly every 2–3 years. The plant is highly specialized in respect to habitat and micro-climate conditions. It grows on calcareous and sun-heated slopes, where xerothermic grasslands grow with contribution of species typical for steppe vegetation. In Poland it is a very rare species known only from seven isolated natural stands in south and east part of the country. Differences and year-to-year fluctuations in the frequency and the abundance of generative and vegetative specimens in natural stands were studied in 2006 and 2007 years. The regional differences in leaf rosette size and size of inflorescences were examined. The abundance of population in all stands increased from *ca*. 13600 plants in 2006 to ca. 31950 in 2007. The G test revealed significant decrease in frequency of flowering plants vs. barren plants between the years in four of all seven stands. The significant differences in mean diameter of leaf rosettes (45; 49; 52 cm) and mean diameter of anthodium of generative specimens (7.17; 7.74; 8.27 cm) were observed in three the most geographically distinct and the most abundant populations. The mean values of leave rosette (44.20; 49.31 cm) and sizes of anthodiums (6.05; 7.61 cm) also changed significantly between the years 2006 and 2007, respectively for all data. It can be concluded that in all stands of the thistle in Poland the synchronization of blooming phase takes place. The observations implicate conclusions important for practice of monitoring which must be conducted at least for two vegetative seasons covering the whole phenology of the species in order to prevent the artifacts.

KEY WORDS: *Carlina onopordifolia*, monocarpic perennial plant, semelparic plants, population dynamics

1. INTRODUCTION

Amongst rare and endangered species, represented by small and isolated populations thistle *Carlina onopordifolia* Besser is important plant. It is an endemic plant, known in Poland only in 7 natural stands located in two regions – Małopolska Upland (South Poland) and Lublin Upland (East Poland) (Poznańska 1988, 1991b, Bzdon and Ciosek 2007, Denisiuk *et al.* 2008) of which only three can be considered as abundant (more than 1000 specimens) – in Miechów Upland (50°20'23"N, 20°13'41"E), Pińczów Hummock (50°32'33"N; 20°29'50"E) (Małopolska Upland) and in surroundings

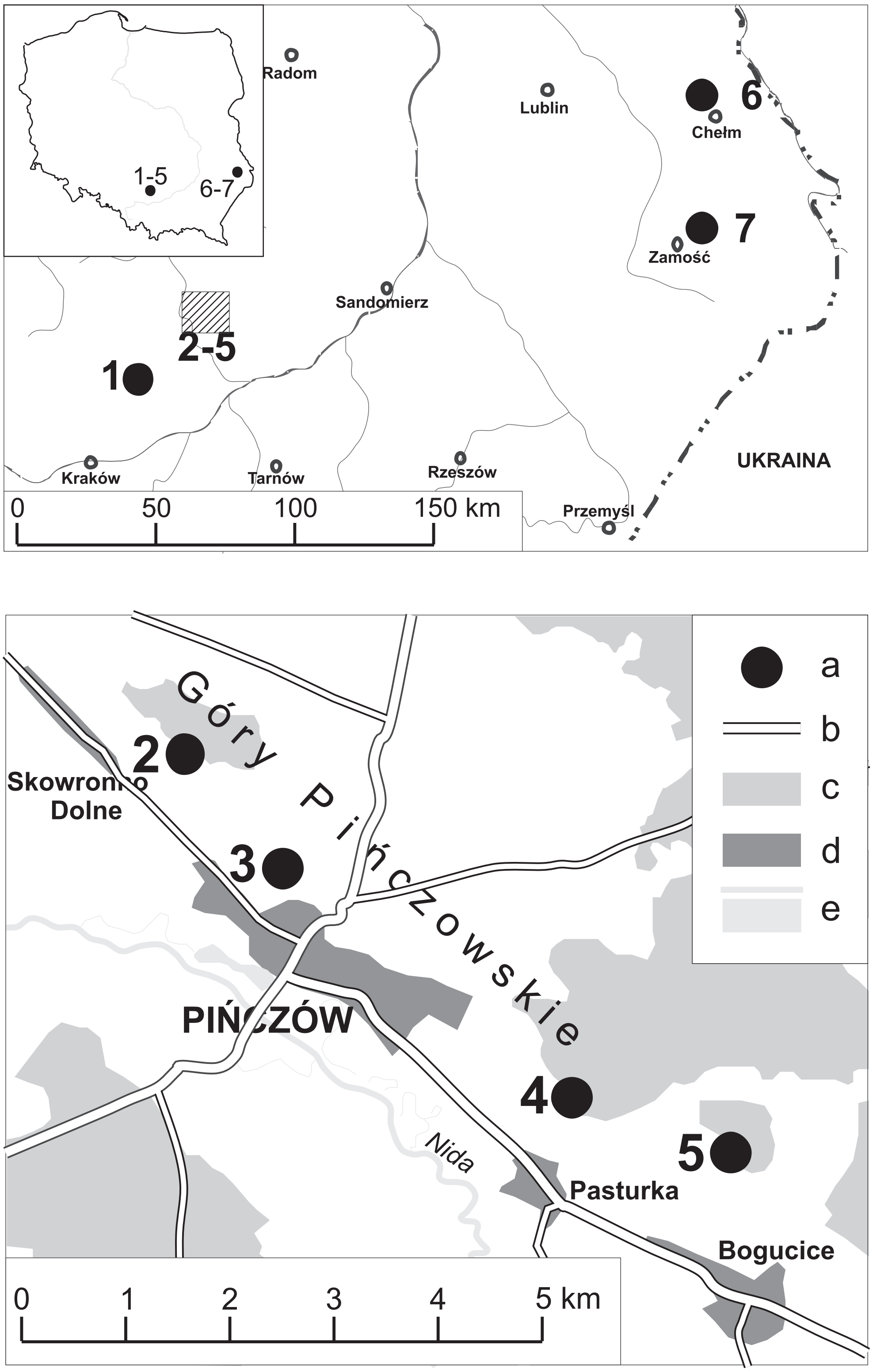

Fig.1. Localization of natural stands of the thistle *Carlina onopordifolia* Besser in Poland.
Explanations: a – stands:1– nature reserve "Wały", 2 – Skowronno, 3 – Pińczów, 4 – Pasturka, 5 – Bogucice, 6 – nat. res. "Stawska Góra", 7 – nat. res. "Rogów"; b – roads; c – forests; d – settlements; e – waters.

Table 1. Numbers of flowering and barren specimens of *Carlina onopordifolia* in natural stands in the years 2006–2007 (in the brackets percentage of flowering plants are given). Test G, * *P* <0.05; ** *P* <0.01; *** *P* <0.001; ns – non-significant. (see Fig. 1.).

Stand No.	Locality	Area (ha)	2006				2007				
			Barren	Flowering	Total	Number per ha	Barren	Flowering	Total	Number per ha	*P*
1	Res. “Wały”	5.81	7350	640 (8)	7990	1375	25180	160 (1)	25340	4361	***
2	Skowronno	1.50	490	22 (4)	512	341	518	7 (1)	525	350	**
3	Pińczów	2.50	1110	135 (11)	1245	498	1618	57 (3)	1675	670	***
4	Pasturka	0.25	470	34 (7)	504	2016	306	13 (4)	319	1276	ns
5	Bogucice	0.05	59	11 (16)	70	1400	2	0 (0)	2	40	ns
6	Res. “Stawska Góra”	4.00	3130	154 (5)	3284	821	4001	54 (1)	4055	1014	***
7	Res. “Rogów”	0.95	29	0 (0)	29	31	33	0 (0)	33	35	ns
	total	15.06	12638	996 (7.3)	13634	905.3	31670	290(0.9)	31960	2122.2	***

of Chełm (51°12’24”N, 23°24’10”E) (Lublin Upland) (Fig. 1). It occurs also in the West Ukraine. In Poland the species is included into list of vulnerable plants (V) – endangered species believed likely to move into the declining – critically endangered category in the near future if the casual factors continue to operate (Zarzycki and Szeląg 2006). Due to small number of stands with decreasing abundance of population the thistle was enlisted in Polish Red Data Book (Kaźmierczakowa and Zarzycki, eds. 2001). It has similar status in the Red Data Book of Ukraine (Szeljag-Sosonko 1996).

It is a plant of high specialization in relation to habitat and climate. It grows on south- and western-facing, sunny calcareous hills and slopes where thermophilous vegetation is formed with contribution of species typical for steppe biotopes (Izdebski 1959, Fijałkowski 1970, Poznańska 1991a). In the vascular flora the thistle represents Pannonian element (Piękoś-Mirkowa and Mirek 2003). On the territory of Poland the species reaches northern-western border of its range.

Amongst mentioned stands of *Carlina onopordifolia* three ones are under legal protection as nature reserves: “Wały” (established in 1957), “Stawska Góra”(1957) and “Rogów” (1965) (Denisiuk *et al.* 2008) (Fig. 1). Of the seven natural stands three populations are very abundant (more than 1000 specimens). These are nature reserves: “Wały” and “Stawska Gora” and “Pińczów” population (Bzdon and Ciosek 2007, Denisiuk *et al.* 2008). The remaining ones are much poorer and some (e.g. “Bogucice” and “Rogów”) are only remnants of bigger populations in the past and probably declined (Fig. 1).

Carlina onopordifolia is a monocarpic long-lived, perennial plant, classified also as semelparic one because it blooms and fruits only once in lifespan and dies after seeds production. The plant reproduces only generatively. Because of such type of reproduction, the abundance of population is dependant on the intensity of flowering and the number of produced and propagated seeds. It turns out that the thistle flowers periodically, thus there are years with low percentage of flowering specimens or with no flowering plants at all (e.g. 2005) and years where blooming specimens are numerous e.g. 2006 (Fijałkowski 1970, Denisiuk *et al.* 2008). As Kaźmierczakowa (2004) reports year to year changes in the abundance of populations are not considerable. The consequence of breaks in flowering is the decrease in number of seedlings in successive years and the increase in its numbers after year abundant in generative specimens. Flowering and fruiting begins in August and after decaying, seeds produced in a given vegetation season (August–September) ripen in late autumn (October–November) and may propagate only next year.

The objectives of this work were: 1) to evaluate the abundance and frequency of generative and vegetative specimens on stands and seasons, 2) to evaluate the regional differences in leaf rosette size and size of inflorescences, 3) to assess the relationship between abundance and reproduction of *Carlina onopordiflora*.

2. STUDY AREA

The research on the dynamics of flowering and fruiting of *Carlina onopordifolia* was carried out in the years 2005–2007 in all 7 known in Poland natural stands of the total area about 15 ha. These are nature reserves and localities which local names are as follows: 1st stand – nature reserve "Wały", 2st – Skowronno, 3rd – Pińczów, 4th – Pasturka, 5th – Bogucice, 6th – reserve "Stawska Góra" and 7th – reserve "Rogów" (Fig. 1). The border of the stand was marked by area inhabited by plants. The above mentioned localities were recorded and described by different botanists in the period of 1880–1997 (Denisiuk *et al* 2008). The detailed inventory studies have conducted since 2005 but in the first year there were no flowering plants. However, in next two years both generative and barren plants were noted (Table 1).

3. MATERIAL AND METHODS

In each natural stand the abundance of populations, selected morphological traits and frequency of flowering and fruiting were examined. The biometrical studies were conducted in the period of optimal development and flowering of plants (second half of July and beginning of August). The size (diameter) of leaf rosette and two parameters of inflorescences (anthodia): external diameter i.e. diameter of upper surface with protruding involucres and internal diameter i.e. surface of anthodium filled with flowers, were measured. Also material of more than ten anthodia, (2–5 from the stand where plant flowered) for counting number of flowers in whole anthodium were collected.

To recognize reproductive potential i.e. the seed number per plant (Bissuel-Belaygue *et al*. 2002) and selected reproductive traits (Bisht *et al*. 2008) we studied the morphological properties of anthodiums which represented single plants i.e. number of florets per anthodium, number of fruits (achenes) per anthodium, and weight and length of fruits.

At the late autumn when vegetation season has finished (November–December) a few randomly chosen anthodia were sampled in order to count number and weight of fruits and seeds. Fruits (achenes) taken from anthodia with a pappus were measured by a caliper with accuracy of 0.0001 g. In winter when there was no snow cover, seeds were sown in sites they were taken from.

In order to compare the frequency of generative and vegetative specimens of *Carlina onopordifolia* between populations and within the years 2006–2007 contingency analysis (test G) was performed. The differences in biometrical traits were tested by non-parametric ANOVA Kruskal-test, and Siegel-Castellan post-hoc test was employed for multiple comparisons. The seasonal differences (beginning and the end of September) for chosen biometrical features, in the three most abundant populations (stands 1st, 6th and 3rd), were analysed using *U* Mann-Whitney test (there were no matched pairs). All statistical analyses were performed using R software (R Development Core 2007).

4. RESULTS

The abundance of population in some stands increased in 2007 in comparison with 2006, among others in the 1st, 6th as well as in 3rd stand. In stands 4th and 5th considerable decrease in number of plants was observed (Table 1). The significant increase in the abundance of total number of plants between the years in all stands was revealed and amounted to 31950 in 2007 when compared to 13600 plants in 2006 ($G = 1386.216$, $P < 0.001$). The number and % frequency of flowering and barren plants changed significantly in majority of populations, too (Table 1). The generative specimens of *Carlina ono-*

Table 2. The average values (± SD) of (A) the diameter of leaf rosette (cm), (B) internal diameter of anthodium (cm), (C) external diameter of anthodium (cm) between three the biggest populations (Kruskal-Wallis test, followed by Siegel-Castellan test) (values differing at the level *P* <0.05 were marked by different letters).

No of stand*	A		B		C	
3rd	45.61±7.6	a	7.74±1.67	a	12.8±2.48	
6th	52.85±9.76	b	8.27±1.74	a	12.3±2.6	ns
1st	49.75±7.98	b	7.17±1.72	b	12.5±1.97	

*see Fig. 1.

Table 3. The average values (± SD) of (A) diameter of leaf rosette (cm), (B) internal diameter of anthodium (cm), (C) external diameter of anthodium (cm) within the flowering period (beginning and end of August). U Mann-Whitney test: * *P* <0.05; ** *P* <0.01; *** *P* <0.001; ns – non-significant. All data for 1–7 stands. (see Fig.1).

Period	A	B	C
Beginning of August	49.25±8.99	7.37±1.81	12.2±2.36
	ns	***	**
End of August	49.41±8.6	8.13±1.54	13.14±2.19

Table 4. The average values (± SD) of (A) diameter of leaf rosette (cm), (B) internal diameter of anthodium (cm), (C) external diameter of anthodium (cm) between the years 2006–2007. U Mann-Whitney test: * *P* <0.05; ** *P* <0.01; *** *P* <0.001; ns –non-significant. All data for 1–7 stands. (see Fig. 1).

Year	A	B	C
2006	44.20± 8.43	6.05±1.30	12.98±2.17
	***	***	ns
2007	49.31±8.84	7.61±1.76	12.55±2.34

Table 5. Variations in biometrical traits of generative parts in *Carlina onopordifolia*. All data for 1–7 stands (Fig. 1) in 2007.

Biometrical trait	Min	Max	$\bar{X}$	SD
Number of flowers in anthodium	648	1412	924.1	300.2
Number of achenes in anthodium	438	905	722.6	179.7
% of mature fruits	71	99	88	11
Weight of 1000 ripen achenes (g)	6.52	12.33	8.67	1.99
Weight of 1000 immature achenes (g)	0.05	0.6	0.21	0.18
Weight of 1000 seeds (g)	0.40	0.88	0.52	0.16
Weight of 1000 pappus (g)	9.67	17.91	13.85	3.56
Weight of 1000 achenes with pappus (g)	16.38	30.42	22.74	4.62
Length of fruits (mm)	6.04	7.85	6.97	0.78
Thickness of fruits (mm)	0.98	1.59	1.25	0.23

pordifolia on the average have the biggest leaf rosettes in stand 6th (more than 50 cm) and a bit lower in stand 1st. However, in stand 3rd they are distinctly smaller (Table 2). In relation to external diameter of anthodium specimens in population of stand 1st were characterized by smaller values compared to specimens in stands 3rd and 6th. No significant differences were revealed in internal diameter of anthodium (Table 2).

There are no significant differences in diameter of leaf rosette between the beginning and the end of August but statistical analyses yielded significant differences in external and internal diameter of anthodia (Table 3). In 2007 higher values of external diameter of anthodium and diameter of leaf rosette were observed compared to 2006. However, there is no such difference in internal diameter of anthodium (Table 4).

The mean number of flowers on anthodium is estimated at *ca*. 920 and ranges from more than 700 to almost 1300. The number of fruits is smaller and on the average amounts to *ca*. 720. The mean weight of 1000 air-dried seeds with pappus varies between 16 and 30 g (Table 5).

5. DISCUSSION

The cyclic appearance of periods of more abundant flowering of specimens and a phase of considerable decrease of generative plants is very characteristic in population dynamics of the studied species. It was first Fijałkowski (1970) who observed in the stand 7st (Rogów), that every year only single plants flowered or no of them, but in 1968 when the population counted 70 plants there were 24 flowering specimens (*ca*. 35% of total population). Also in the stand 6th ("Stawska Góra") this author observed the increase in number of flowering plants. Thus high frequency of flowering plants in the stand 7th and similar intensity of flowering in 6th stand can be connected with favorable environmental factors in a preceding season Fijałkowski (1970). Our results confirm this statement. In 2005 the thistle population was in a lag phase because in all stands of this species in Poland only few weakly developed blooming plants were found. However, in 2006 in all stands (except of 6th stand) the fraction composed by blooming specimens consists large part of the population. The percentage of flowering plants was lower than this reported by Fijałkowski (1970) and contributed to *ca*. 5–16% (Table 1). In 2007 percentage of flowering plants contributed to only 1% (Table 1).

In monocarpic perennial plants, in which reproduction is strongly limited there is a mechanism enhancing the reproductive success. Among others it is delayed reproduction and seed dormancy (Rees *et al*. 2006). Under favorable conditions monocarpic species can flower as soon as it is possible. For instance in *Carlina vulgaris* some individuals can start flowering in the second year, however, reproduction can be delayed by 1 to 8 years (Rose *et al*. 2002, Rees *et al*. 2006). The latter one i.e. the seed bank, is almost typical for short-lived monocarpic species. *Carlina onopordifolia* seems to have short-lived seed bank because – as Poznańska (1988) showed – under laboratory conditions, seeds are vital and capable to germinate within three years after harvest but later their vitality rapidly decreases. It can be inferred that *Carlina onopordifolia* has the evolutionary developed reproductive strategy similar to *Carlina vulgaris*; the rosette bank of this species is higher but the seed bank is low (Rees *et al*. 2006). Other research showed that the probability of flowering is related to plant size not to age (Klinkhamer *et al*. 1991, 1996). At the beginning of life span the plant allocates resources mainly to vegetative parts and later when it reaches critical size for development of generative parts changes the allocation. In our study the young plants have short leaves (15–25 cm), whereas the leaves of mature specimens but not flowering – are longer than 25 cm and even longer than 45 cm. Plants with leaves longer than 50 cm are extremely rare and they occur only on vegetative specimens. For instance, the exceptional population in this regard is the population introduced near 2nd stand by Poznańska in 1987 (1991a, b) in locality Skowronno, where the vegetative plant having two 52 cm-leaves was found. Such long leaves never occur in generative specimens resembling vegetative plants and representing mature, older generation with leaves of mean length 30–45 cm. Moreover, we observed significant increase in size of anthodium within blooming period whereas changes in leaf rosette were insignificant. Probably plants of *Carlina onopordifolia* preparing for flowering and seed production use more resources in generative parts reducing energy for development of vegetative parts. It is well-known phenomenon that plants use different strategies allocating resources for growth, development and reproduction (Harper 1977, Bell and Koufopanou 1986, Falińska 1991, 1998, Stearns 1992). However, the year-to year significant increase in sizes of vegetative parts and generative parts (Table 4) can be the consequences of more favorable climatic conditions for growth and development in successive year.

The differences in anthodium size and leaf rosette between populations can result from the plasticity of the species to local conditions or the existence of regionally adapted genotypes which was demonstrated by Becker *et al* (2006) in related species *Carlina vulgaris*.

The study demonstrates that mean number of flowers amounted to *ca*. 925 and minimum number is lower than 650 (Table 5). Of them at least 70%, but on the average more than 80%, are capable to set seeds. It can be assumed that minimum number of propagated seeds in 2007 can be estimated at *ca*. 150 000 and mean number *ca*. 215 000 in all Polish stands. Taking into account that under natural conditions only 20% of seeds can germinate (Poznańska 1991a, b) then reproductive potential of whole population in Poland amounts to above 40 000 viable seeds (minimum 30 000). However, the amount of new seedlings in every year is not so much as it could be inferred from reproductive potential. Even in 2007 an increase by *ca*. 18000 specimens was observed in total abundance of this species in Poland.

Seed propagation is affected by seed weight. It was observed that seeds of *Carlina onopordifolia* are heavy and therefore their dispersal is hampered (Motyka 1947, Poznańska 1991c). As it was shown the weight of fruits is high (Table 5), especially pappus contributes a lot to total weight of the thistle achenes. Fruits of *Carlina onopordifolia* are relatively heavy when compared to fruits of other species. However, the weight of its seeds in comparison with seeds of *Poa* sp. and *Agrostis* sp. are comparable, whereas such species like *Bromus* sp., and *Hordemus* sp. are much heavier than of thistle (Baker 1972, Thompson and Grime 1983, Grime *et al*. 2007). The high weight and large size of pappus may not be a critical factor in achene dispersal in the species studied. It is shown that the efficiency of dispersal is determined more by pappus geometry, which directly affects its aerodynamic properties, than by the size ratio of pappus to achene. The dispersal of many composites is hampered by the pappus response to humidity (Sheldon and Burrows 1973).

In the light of above-mentioned facts it can be concluded that in all 7 stands of the thistle in Poland the synchronization of blooming phase takes place. Our data do not permit to answer if differences in generative activity may be also the result of cyclic fluctuations of vegetative specimens too. The observations implicate conclusions important for practice of monitoring which must be conducted at least for two vegetative seasons covering the whole phenology of the species in order to prevent the artifacts.

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