Biodiv. Res. Conserv. 32: 45-52, 2013

BRC
www.brc.amu.edu.pl

DOI 10.2478/biorc-2013-0017

Submitted 15.05.2013, Accepted 22.11.2013

The influence of neighbouring species on ecological variation of the selected subpopulations of *Iris sibirica* L.

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Abstract: Ecological variation of the selected subpopulations of *Iris sibirica* L. were studied in the years 2011-2012, in the abandoned patches of *Molinietum caeruleae* dominated by small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), shrubs (Patch IV), as well as shrubs and trees (Patch V). The abundance of subpopulations and dimensions of aggregations of ramet clusters increased gradually from Patch I to Patch IV and subsequently declined in Patch V. During the whole study period, all subpopulations showed signs of senility due to the absence of individuals in pre-reproductive stages. The share of generative ramet clusters diminished, while contribution of senile and fragmentised ramet clusters increased substantially in consecutive patches. The dimensions of ramet clusters increased significantly in successive plots and years. The number and height of generative stems and production of flowers and fruits did not show the temporal variability. The abundance of generative stems was considerably lower in the plots dominated by small meadow species, than in the sites dominated by large-tussock grasses, shrubs or overgrown shrubs and trees. Both the height of flowering stems and production of flowers and fruits increased gradually from Patch I, *via* Patches II, III and IV, to Patch V. The augmentation of flower production might contribute to better visibility of inflorescences for pollinators, whereas an increase in the production of fruits may increase the chances for successful seed dispersal to new sites.

This study results show that the *I. sibirica* subpopulations occurring in the site dominated by small meadow species and macroforbs were in unsatisfactory condition, those inhabiting the sites dominated by large-tussock grasses and shrubs were in a quite good condition, while the subpopulation inhabiting the plot overgrown by shrubs and trees showed the worst condition.

Key words: abundance, cluster of ramet, flower, fruit, *Iris sibirica*, *Molinietum caeruleae*, structure

1. Introduction

Iris sibirica is a long-living, rhizomatous, clonal plant, characterized by the iterative growth of individuals resulting from the processes of proliferation, dying and regeneration occurring at variable intensities in subsequent stages of development. Individuals consist of numerous leaf rosettes and generative shoots bearing flowers pollinated by bumblebees. The fruit is an oblongate capsule containing several seeds. Siberian iris is native to central and eastern Europe and ranges from north-eastern Turkey, European Russia and western Siberia, to northern Italy (Den Virtuella Floran 1996). Nowadays, *I. sibirica* belongs to rare taxa in entire Europe. It is classified as extinct (EX) in Schleswig-Holstein (Ingelög *et al.* 1993), endangered (EN) in Kaliningrad and Mecklenburg (Ingelög *et al.* 1993), as well as vulnerable (VU) in Lithuania (Ingelög *et al.* 1993), Croatia (State Institute for Nature Protection 2004) and Switzerland (Moser *et al.* 2002). In Poland, *I. sibirica* is a strictly protected (Regulation 2012), endangered species (Zarzycki & Szeląg 2006), included in the regional Red Lists of threatened plants in Gdańsk Pomerania (Markowski & Buliński 2004; Olszewski & Markowski 2006), South Podlasie Lowland (Głowacki *et al.* 2003), Wielkopolska region (Jackowiak *et al.* 2007), Opole Province (Kącki 2002), Lower Silesia (Kącki *et. al.* 2003), as well as the Carpathians (Witkowski *et al.* 2003).

The very useful tool for conservation and management of rare and endangered species seems to be the evaluation of abundance and structure of populations considered as an indicator of their vitality, as well as a base for successful conservation programs (Hutchings 1991; Owen & Rosentrer 1992). Up to now, the studies of abundance and structure of populations of *I. sibirica* have been performed by Ishmuratova and Mullabaeva (2002), Sporek and Rombel-Bryzek (2005), as well as Kostrakiewicz (2007, 2008). Despite of growing interest in population biology of this species the further investigations are still strongly needed. Considering the insufficient state of knowledge, the investigations of habitat conditions on variability of the selected characteristics of subpopulations of *I. sibirica* inhabiting patches of *Molinietum caeruleae* with the diverse height of standing vegetation were performed. The specific aims focused on: (1) abundance of subpopulations, (2) structure of subpopulations, (3) the number and height of generative stems, (4) flower and fruit production.

2. The study area

The studies were carried out in the Kostrze district located on the western edge of Kraków, south of the Vistula River (Fig. 1). The research area was located on a low flood terrace of the Vistula, covered by unmanaged *Molinietum caeruleae* patches characterized by presence of *Betonica officinalis, Dianthus superbus, Galium boreale, Gentiana pneumonanthe, Gladiolus imbricatus*, *Inula salicina, Iris sibirica*, *Selinum carvifolia* and *Succisa pratensis* (Dubiel 1991, 1996, 2005 and pers. obs.).

Patch I measured *ca* 1400 m^2 and was unmanaged for 10 years. It was dominated by taxa presenting minor competitive abilities such as small-tussock grasses (i.e. *Briza media*) and short rosette-forb species (i.e. *Lychnis flos-cuculi*). The average height of plant cover achieved 54.8 cm.

Patch II covered *ca* 1200 m^2 and was abandoned for 15 years. It was dominated by tall-growing macroforbs producing robust, wide spreading rhizomes (i.e. *Lysimachia vulgaris*, *Solidago gigantea, Filipendula ulmaria*). The average height of plant cover achieved 77.2 cm.

Patch III had *ca* 1300 m^2 in area and was not used for 15 years. It was dominated by tall grasses forming large tussocks (i.e. *Molinia caerulea* and *Deschampsia cespitosa*). The mean height of standing vegetation reached 97.9 cm.

Patch IV measured *ca* 1450 m^2 and was unmanaged for at least 18 years. It was overgrown by shrubs (i.e. *Salix repens* ssp. *rosmarinifolia* and *Crategus* sp.). The average height of plant cover was 116.7 cm.

Patch V covered *ca* 1450 m^2 and was abandoned for at least 25 years. It was overgrown by bushes (i.e. *Salix repens* ssp. *rosmarinifolia*, *S. cinerea*, *S. aurita* and *Crategus* sp.) and trees (i.e. *Populus tremula* and *Betula pendula*). The average height of plant canopy attained 156.7 cm.

3. Material and methods

On the basis of the preliminary studies, a cluster of ramets (understood as an aggregation of generative stems and leaf rosettes formed in the course of vegetative proliferation of an individual or individuals) was adopted as a basic demographic unit. In the year 2011,

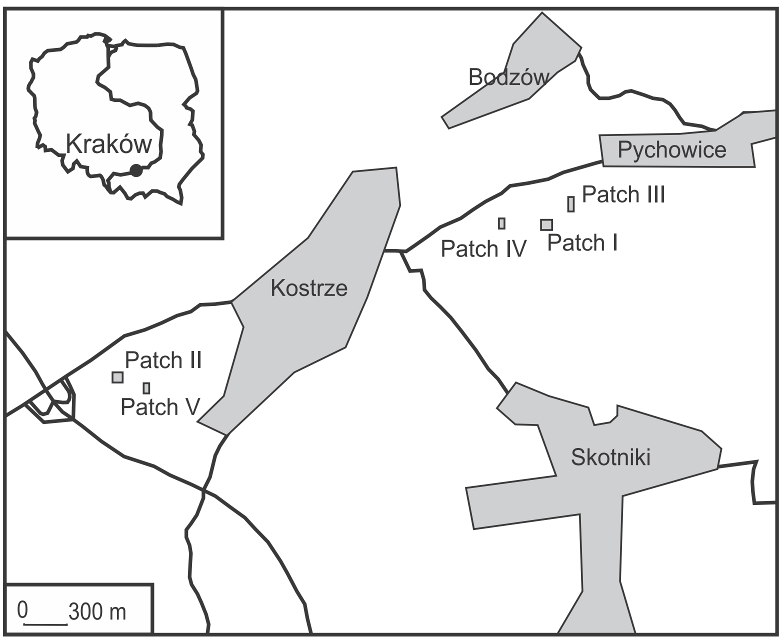

Fig. 1. The localization of *Iris sibirica* subpopulations in the abandoned *Molinietum caeruleae* patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V)

all ramet clusters of *I. sibirica* that occurred in the study area were marked with plastic pegs. The observations were carried out in the years 2011-2012. The abundance of subpopulations was estimated on the basis of the number of ramet clusters, as well as the total number of ramets. The spatial structure of subpopulations was evaluated on the basis of distribution of ramet clusters in individual plots. The structure of developmental stages determined by Kostrakiewicz (2007) and the structure of size based on the total number of ramets per clusters were studied as well. Additionally, each year the following parameters were observed: (1) number of generative stems per each ramet cluster, (2) height of each generative stem, (3) production of flowers and fruits per generative stem and per ramet cluster.

The chi-square statistics was applied to check whether the structure of developmental stages and the structure of size present significant spatial and temporal variability. The H Kruskal-Wallis test was used to test if there were significant differences among subpopulations in the number of generative stems, their height, as well as flower and fruit production. The U Mann-Whitney test was applied to test whether there were significant differences among years in the number and height of generative stems, as well as the number of flowers and fruits noted in particular subpopulations.

4. Results

The abundance of ramet clusters, as well as the total number of ramets increased gradually from Patches I and II, via Patch III, to Patch IV, while in Patch V both parameters declined. The abundance of ramet clusters in individual patches was constant during the whole study period, while the total number of ramets exhibited temporal variability (Table 1). All subpopulations showed the identical clumped spatial structure during the whole study period. The number of aggregations, as well as the number of ramet clusters per aggregation raised gradually from Patches I and II, via Patch III, to Patch IV, while in Patch V both aforementioned traits decreased slightly (Fig. 2). All subpopulations showed signs of senility due to lack of individuals in pre-reproductive

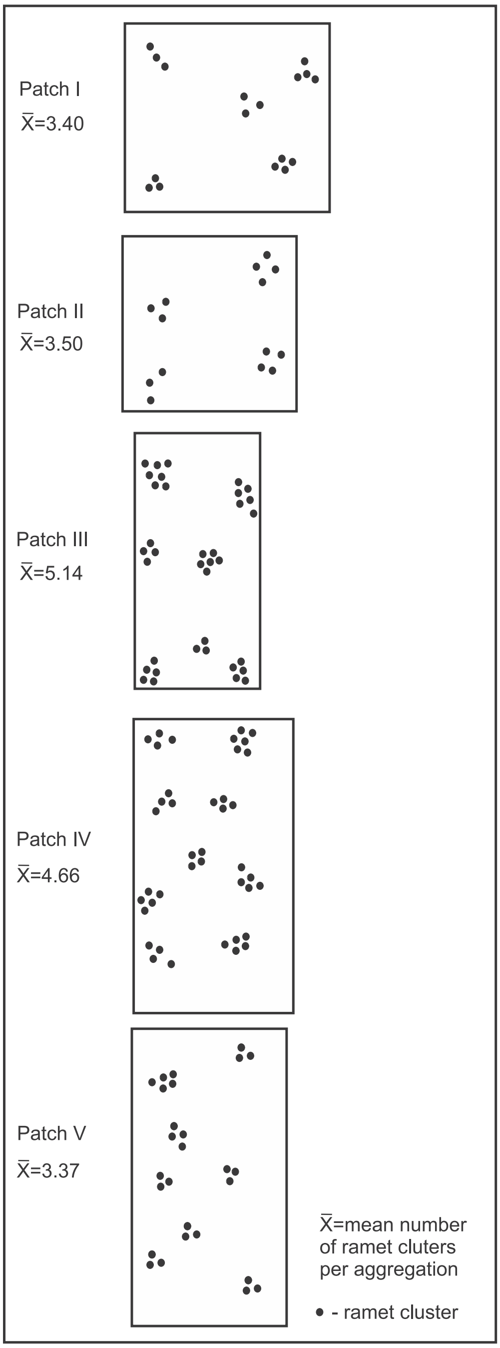

Fig. 2. The spatial structure of *Iris sibirica* subpopulations in the abandoned *Molinietum caeruleae* patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V) in the whole study period in the years 2011-2012

Table 1. Abundance of *Iris sibirica* subpopulations established in the patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V)

Patch	The number of ramet clusters in the years 2011-2012	The total number of ramets	
		Year 2011	Year 2012
I	17	903	1308
II	14	835	1104
III	36	2586	3257
IV	41	3169	4114
V	27	1870	1857

Table 2. The number and height of generative stems in the subpopulations of *Iris sibirica* established in the patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V)

	The number of generative stems per ramet cluster		The height of generative stems	
	Year 2011	Year 2012	Year 2011	Year 2012
	The mean (range)	The mean (range)	The mean (range)	The mean (range)
Patch I	2.00 (1-5)	1.74 (1-5)	62.21 (40-77)	61.15 (38-79)
Patch II	3.23 (1-9)	2.69 (1-6)	79.92 (64-101)	78.34 (63-110)
Patch III	4.58 (1-15)	4.30 (1-14)	83.72 (67-117)	84.68 (67-123)
Patch IV	4.65 (1-10)	3.91 (1-9)	84.72 (59-125)	86.15 (63-113)
Patch V	4.40 (2-7)	4.20 (2-9)	90.20 (70-106)	91.48 (76-127)
The statistical significance level	B*; C*; D*	B*; C*; D**	A**; B***; C***; D***; E***; F***; G***; I***; J***	A**; B***; C***; D***; E*; F**; G***; I***; J***

Explanations: asterisks denote significant statistical differences (H Kruskal-Wallis test) in the number/height of generative stems among subpopulations established in the Patches, I and II (A), I and III (B), I and IV (C), I and V (D), II and III (E), II and IV (F), II and V (G), III and IV (H), III and V (I), IV and V (J) at the level < 0.05 (*), < 0.01 (**), < 0.001 (***)

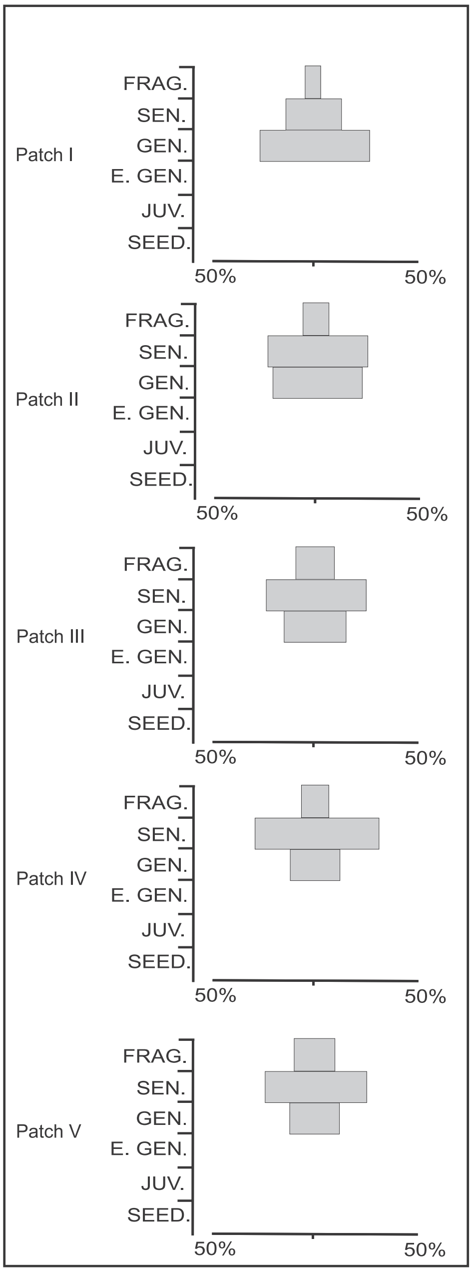

Fig. 3. The structure of developmental stages of *Iris sibirica* subpopulations in the abandoned *Molinietum caeruleae* patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V) in the whole study period in the years 2011-2012. The developmental stages: SEED. – seedlings, JUV. – juvenile, E.GEN. – early generative, GEN. – generative, SEN. – senile, FRAG. – fragmentation

stages (Fig. 3). The constant, over the whole study period, share of generative ramet clusters diminished, while the contribution of senile and fragmentized ramet clusters increased substantially from Patch I, via Patches II, III and IV, to Patch V ($\chi2= 29.22$; df=8; $P<0.001$). The size structure of ramet clusters showed the spatial and temporal variability (Fig. 4). The number of generative stems did not differ in consecutive years but varied substantially among the sites. In the patches dominated by small meadow species it was considerably lower than in the patches dominated by large-tussock grasses, shrubs or overgrown shrubs and trees (Table 2). The height of flowering stems (Table 2) and the production of flowers (Table 3) and fruits (Table 4) did not show the temporal variability but they differed significantly among the patches. All aforementioned traits increased gradually from Patch I, via Patches II, III and IV, to Patch V.

5. Discussion

The observed spatial and temporal variability of total number of ramets, as well as the spatial variability of the number of *I. sibirica* ramet clusters and their distribution are in concordance with investigations conducted in populations of several clonal species, such as: *Adonis vernalis* (Jankowska-Błaszczuk 1991, 1995), *Carex cespitosa* (Brzosko 1992, 1999a, 2001),

Table 3. The flower production in the subpopulations of *Iris sibirica* established in the patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V)

	The number of flower per ramet cluster		The number of flower per generative stems	
	Year 2011	Year 2012	Year 2011	Year 2012
	The mean (range)	The mean (range)	The mean (range)	The mean (range)
Patch I	6.31 (2-16)	5.81 (1-16)	3.15 (2-5)	2.90 (1-4)
Patch II	10.84 (2-30)	8.76 (2-21)	3.35 (2-5)	3.25 (2-6)
Patch III	19.66 (9-55)	18.03 (5-65)	4.50 (3-8)	4.62 (4-8)
Patch IV	19.61 (4-42)	18.42 (5-38)	4.61 (2-8)	4.46 (2-7)
Patch V	20.60 (9-45)	19.90 (5-51)	4.68 (3-6)	4.73 (2-7)
The statistical significance level	B**; C***; D***	B**; C***; D***; F*; G*	B***; C***; D***; E***; F***; G***	B***; C***; D***; E***; F***; G***

Explanations: asterisks denote significant statistical differences (H Kruskal-Wallis test) in the flower production among subpopulations established in the Patches, I and II (A), I and III (B), I and IV (C), I and V (D), II and III (E), II and IV (F), II and V (G), III and IV (H), III and V (I), IV and V (J) at the level < 0.05 (*), < 0.01 (**), < 0.001 (***)

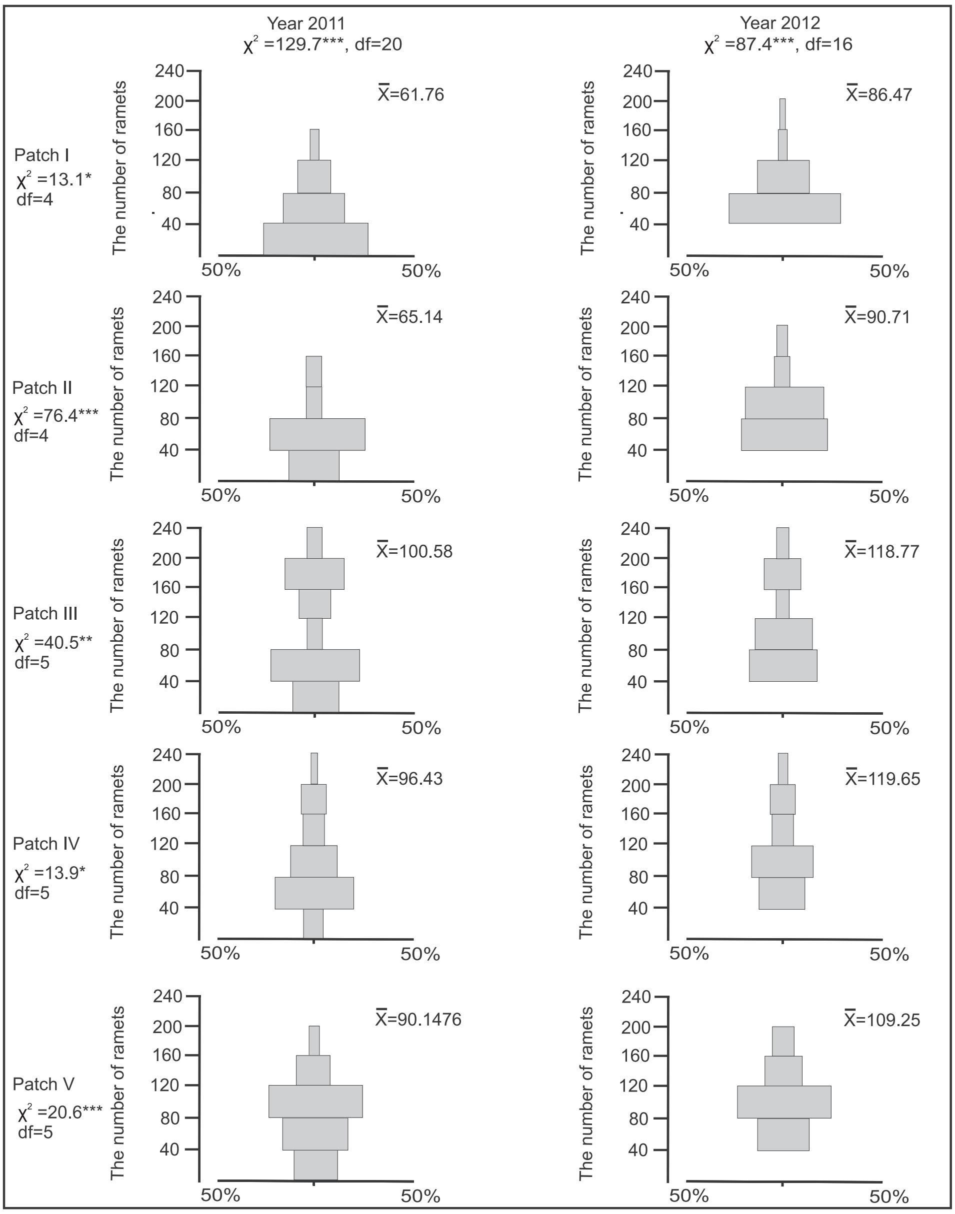

Fig. 4. The size structure based on the total number of ramets in the clusters of *Iris sibirica* in subpopulations established in the abandoned *Molinietum caeruleae* patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V) in the years 2011-2012

Table 4. The fruit production in the subpopulations of *Iris sibirica* established in the patches dominated by: small meadow species (Patch I), macroforbs (Patch II), large-tussock grasses (Patch III), bushes (Patch IV), bushes and trees (Patch V)

	The number of fruits per ramet cluster		The number of fruits per generative stems	
	Year 2011	Year 2012	Year 2011	Year 2012
	The mean (range)	The mean (range)	The mean (range)	The mean (range)
Patch I	4.31 (1-11)	4.25 (1-12)	2.15 (1-4)	2.12 (1-5)
Patch II	7.61 (1-22)	6.00 (1-16)	2.35 (1-4)	2.22 (1-3)
Patch III	12.23 (4-41)	12.06 (4-51)	2.48 (2-7)	2.35 (1-7)
Patch IV	12.13 (3-24)	11.13 (5-29)	2.85 (1-6)	2.84 (1-5)
Patch V	13.00 (6-28)	12.80 (4-21)	2.95 (1-4)	3.04 (2-5)
The statistical significance level	B***; C***; D***	B**; C***; D***; G*	B***; C**; D**; E***; G*; H**; I**	B***; C**; D***; E***; F*; G**; H**

Explanations: asterisks denote significant statistical differences (H Kruskal-Wallis test) in the fruit production among subpopulations established in the Patches, I and II (A), I and III (B), I and IV (C), I and V (D), II and III (E), II and IV (F), II and V (G), III and IV (H), III and V (I), IV and V (J) at the level < 0.05 (*), < 0.01 (**), < 0.001 (***)

Filipendula ulmaria (Falińska 1995; Falińska *et al.* 2010), *Iris pseudacorus* (Falińska 1986), *Ligularia sibirica* (Kukk 2003), *Lythrum salicaria* (Franczak & Czarnecka 2009) and *Senecio rivularis* (Czarnecka 2008, 2011). The above mentioned authors noted the augmentation of population abundance, the substantial clonal multiplication of aboveground units, as well as the increasing trend toward creation of aggregations of individuals during early successional stages and the opposite tendency in the terminal phase of succession.

The performed studies, showing an absence of individuals in pre-reproductive ontogenic stages in subpopulations of *I. sibirica* regardless of habitat conditions, are consistent with previous observations (Kostrakiewicz 2007, 2008). This phenomenon might be caused by lack of safe sites for seedling recruitment, such as gaps in continuous plant cover and litter (Kostrakiewicz-Gierałt 2012) or tussocks of disintegrating grasses (Kostrakiewicz 2011). The obtained results support previous observations that documented the progressive ageing of *Iris pseudacorus* and *Carex cespitosa* populations during successional transformations of vegetation (Falińska 1986; Brzosko 1999b). Moreover, it should be pointed out, that the structure of developmental stages in *Iris sibirica* subpopulations is positively correlated with the size structure of ramet clusters. Similar phenomenon was recorded in populations of *Filipendula ulmaria* (Falińska 1995).

The gradual increase in the number of generative stems observed in subpopulations of *I. sibirica* growing in successive patches might be caused by an increased allocation in sexual propagation in crowded stands. Also, the considerable increase in the number of generative shoots in dense places was observed in *Pistia stratiotes* (Coelho *et al.* 2005) and *Scirpus olneyi* (Ikegami *et al.* 2004). On the other hand, *Doronicum austriacum* showed much greater production of generative stems in open habitats, than in overgrown sites (Stachurska-Swakoń & Kuz 2011).

The successive augmentation of height of generative stems, as well as flower and fruit production recorded in subpopulations of *I. sibirica* occurring in the vicinity of tall-growing plants are consistent with observations conducted in populations of other long-lived taxa inhabiting *Molinietum caeruleae* meadows such as *Dianthus superbus* (Kostrakiewicz-Gierałt 2013a), *Gentiana pneumonanthe* (Kostrakiewicz-Gierałt 2013b), *Gladiolus imbricatus* (Kubikova & Zeidler 2011) and *Trollius europaeus* (Antkowiak 2002; Kostrakiewicz 2009). Similar phenomenon was also noted in populations of other perennials, i.e. *Polygonum hydropiperoides* (Collins & Wein 2000), as well as annuals, such as *Polygonum sagittatum* (Collins & Wein 2000) and *Impatiens capensis* (Dudley & Schmitt 1996). An increase in the stem height in effect of artificially induced shading was found in cultivars such as *Chrysanthemum morifolium* (Cermeno *et al.* 2001) and *Dianthus caryophyllus* (Hlatshwayo & Wahome 2010). The low height of generative stems in place dominated by small meadow species might be caused by the decomposition of growth hormones by strong light (Kopcewicz & Lewak 2005).

The augmentation of flower number in the subpopulations of *I. sibirica* occurring in shaded habitats might contribute to better visibility of inflorescences for pollinators, whereas an increase in the production of fruits may increase the chances for successful seed dispersal to new sites. Such phenomenon is consistent with predictive models (Loechle 1987; Gardner & Mangel 1999) stating that investment in generative propagation in clonal plants increases in sites with fluctuating environmental conditions and in the surroundings of strong competitors.

In light of the performed investigations, it can be concluded that subpopulations occurring in the places dominated by small meadow species and macroforbs exhibit an unsatisfactory condition. The low abundance, small number and height of generative stems, as well as scarce production of flowers and fruits are not offset by the most advantageous structure of developmental stages. Surprisingly, subpopulations inhabiting sites prevailed by large-tussock grasses and shrubs are in a quite good condition due to the great abundance of ramet clusters, considerable number and height of generative stems, as well as the substantial flower and fruit production. The slight abundance, considerable percentage of ramet clusters showing advanced signs of senility, as well as the low number of generative stems indicate that the subpopulation established in the plot overgrown by bushes and trees is in the worst conditon.

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