The influence of habitat conditions on the abundance and selected traits of the rare medicinal plant species *Filipendula vulgaris* Moench

[1]Kinga Kostrakiewicz-Gierałt[*], [2]Alina Stachurska-Swakoń

Department of Plant Ecology, Institute of Botany, Jagiellonian University,
[1]Lubicz 46, 31-512 Kraków, Poland, [*]e-mail: kinga.kostrakiewicz@uj.edu.pl
[2] Kopernika 27, 31-512 Kraków, Poland.

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Abstract. The research on the influence of habitat conditions on the traits of *Filipendula vulgaris* were carried out in 2015 and 2016 in abandoned wet meadows (Patches I and II) and frequently disturbed, calcareous grasslands (Patches III and IV). The cover of vascular plants and cryptogams was much greater and soil pH was remarkably lower in the meadow patches than in the grassland ones, whereas the height of neighbouring plants and soil humidity gradually decreased from Patches I to IV. The meadow populations of *F. vulgaris* showed much lower abundance as well as lower total relative abundance of seedlings and vegetative rosettes compared to the grassland populations due to the scarcity of safe sites for offspring recruitment. Rosettes presenting solely spatial variability were characterised by a significantly greater number of short leaves in the meadow populations or not numerous, large leaves in the grassland populations. The similar (in consecutive years) height of generative shoots, the number of cauline leaves, inflorescences and flowers gradually decreased at subsequent study sites. The results may provide the basis for further studies on the impact of habitat conditions and the size of aboveground parts of *F. vulgaris* on the content of bioactive compounds in plant material.

Key words: calcareous grassland, disturbances, individual and population traits, land abandonment, *Molinia* meadow, soil conditions.

Introduction

The investigations focusing on abundance and structure of populations, as well as individual traits of medicinal plants, are very important ones. To date, the raw materials were harvested from wild growing plants, therefore the aforementioned studies enabled choosing of the source of the best quality plant material. Moving forward, the results of the observations might provide a basis for successful cultivation of this species for practical purposes. Currently, numerous authors have investigated the population and individual traits of species used in official and folk medicine. Such observations were devoted to numerous annuals (Zając et al., 2011), perennials (Kahmen & Poschlod, 2000; Morozowska, 2000; Hegland et al., 2001; Kostrakiewicz-Gierałt, 2015a), as well as shrubs and trees (Barna, 2004; Hampe, 2005).

One of these medicinal plants is *Filipendula vulgaris* Moench, which reveals antibacterial, anti-inflammatory, antipyretic, antihyperalgesic (Pavlovic et al., 2007; Katanic et al., 2015; Samardžić et al. 2016) and antioxidant properties (Maksimović et al. 2007, Katanic et al., 2015), as well as nootropic activity (Shilova & Suslov, 2015; Shilova et al., 2015). To date, studies focusing on the variability of selected traits of individuals of *Filipendula vulgaris* in cultivation (Lempiäinen, 1978; Bączek et al., 2010; Capecka et al., 2012), as well as in natural localities (Lempiäinen, 1982), are scarce. Regarding the widespread use of the aboveground parts of dropwort as medicinal material, the main goal of the investigations was to assess the effect of habitat conditions on population abundance and selected traits of *Filipendula vulgaris* Moench in abandoned meadows and in frequently disturbed calcareous grasslands.

2. Material and methods

2.1. The studied species

Filipendula vulgaris Moench (syn. *F. hexapetala* Gilib., *Rosaceae*), commonly known as dropwort, is a rosette-forming perennial, clonal herb with short rhizomes and roots bearing tubers (Klimešová & Klimeš, 2006). The flowering shoots, up to 80 cm high, bear inflorescences consisting of many cream-white flowers, pollinated mainly by insects (Clapham et al., 1987) or wind (Weidema et al., 2000). *Filipendula vulgaris* belongs to euro-siberian species (Zając & Zając, 2009), growing in the wild, from and north-western Africa, through Europe to middle Asia. *F. vulgaris* is a diagnostic species for *Festuco-Brometea* class, where calcareous grasslands are included (Medwecka-Kornaś et al., 1966; Towpasz & Stachurska-Swakoń, 2011, 2012). However, the species can also occur in wet meadows from the *Molinietalia* order (Dubiel et al., 1999) and *Caricetalia davalianae* order (Towpasz & Stachurska-Swakoń, 2009).

Dropwort is listed in the European Red List of Medicinal Plants (Allen et al., 2014), as well as in many national Red Books and Lists (Curtis & McGough, 1988; Moser et al., 2002; Cheffings & Farrell, 2005; Stroh et al., 2014).

2.2. The study area

The investigations were carried out in the south-western part of Kraków (southern Poland) from Pychowice (N 50º1'26''; E 19º52'25'') to Tyniec (N 50º1'26''; E 19º50'1''), at ca. 210 m a.s.l., on the low flood terrace of the Vistula river where the limestone hills (Jurassic-Cretaceous) and tectonic depressions of the Brama Krakowska gate occur (Kondracki, 2000). The observations were conducted in meadows and calcareous grasslands surrounded by arable fields and ruderal plant communities occurring in the vicinity of roads and housing estates. Patches I and II represented abandoned, overgrowing wet meadows from the *Molinion caeruleae* alliance, characterised by the presence of *Dianthus superbus, Galium boreale, G. verum, Gladiolus imbricatus, Inula salicina, Iris sibirica, Lotus corniculatus, Selinum carvifolia,* as well as *Succisa pratensis*. In Patch I, measuring 700 m^2, shrubs such as *Salix cinerea, S.repens* spp. *rosmarinifolia,* as well as tall-growing perennials such as *Betonica officinalis* and *Serratula tinctoria* dominated. Patch II, measuring 800 m^2, was overgrown by tall-growing perennials *Sanguisorba officinalis, Serratula tinctoria,* and *Solidago canadensis,* as well as *S. serotina*. Patches III and IV were located on south-exposed moderate slopes and represented frequently visited and trampled calcareous, grasslands from the *Festucetalia valesiacae* order. They were characterised by the presence of *Anthericum liliago, Dianthus carthusianorum*, *Festuca rupicola, Plantago media, Scabiosa ochroleuca, Salvia nemorosa, S. verticillata* and *Thymus* sp. Patch III, measuring 600 m^2, was dominated by *Anthericum liliago, Euphorbia cyparisias* and *Salvia verticillata.* Patch IV, measuring 800 m^2, was dominated by *Dianthus carthusianorum, Festuca rupicola, Inula ensifolia* and *Thymus* sp.

2.3 The investigation of the habitat conditions

In all of the Patches one representative, permanent study plot (15 m x 15 m) was established and fenced. Within each plot, 20 measuring points were chosen and marked with plastic pegs. Four points were placed systematically in the corners of the permanent plots, while the remaining points were chosen randomly. The marked points served as centres for setting iron rims, 30 cm in diameter, used for the evaluation of biotic (plant and cryptogam cover, height of vascular plants) and abiotic habitat conditions (moisture and pH of the soil). The plant and cryptogam cover was measured as a percentage of ground surface covered by vascular plants and cryptogams (moss and lichens). The average height of neighbouring plants was received on the basis of measurements of length (from soil level to the top) of the lowest and highest stems (excluding *Filipendula vulgaris*) growing within the rim, using a folding tape measure. Soil humidity and pH value was measured using a BIOWIN soil sensor (range 1-10) in the 5 cm deep upper soil layer. Soil humidity range: 1-3 – dry, 4-7 – moist, 8-10 – wet; pH range: 1-6 – acid, 7-10 – alkaline. The survey of the habitat conditions was performed on 8 July 2015 and 10 July 2016.

2.4. The investigation of rosette traits of *Filipendula vulgaris* Moench

In 2015, the abundance of populations of *Filipendula vulgaris*, understood as total number of adult vegetative leaf rosettes and leaf rosettes with at least one flowering shoot within the Patches, were studied. In the years 2015 and 2016, the number of seedlings, adult vegetative leaf rosettes, as well as leaf rosettes with flowering shoot (shoots) were inventoried and labelled with plastic pegs in the permanent plots. In all rosettes, the number of leaves and length of the longest leaf were noted. Also, the number of flowering shoots and their height (from ground level to basis of inflorescence) were examined in each rosette creating generative stems. Moreover, in all generative shoots, the following traits were counted or measured: (i) the number of cauline leaves (ii) the number of inflorescences; and (iii) the number of flowers per each inflorescence.

2.5. Statistical analyses

The normal distribution of each group of the untransformed data (from a particular Patch and year) was tested using the Kolmogorov-Smirnov test, while homogeneity of variance was tested using the Levene test at the significance level of P<0.05. As the values in some groups were not consistent with normal distribution, and the variance was not homogeneous, the Kruskal-Wallis H test was applied to check whether there are the significant differences among the Patches in: (i) plant and cryptogam cover, height of standing vegetation, soil humidity and soil pH; (ii) number and length of rosette leaves; and (iii) the number and traits of the flowering shoots. After a significant value of test (P≤0.05), the post-hoc multiple comparisons were performed. Simultaneously, the Mann-Whitney U test was applied to check if there were significant differences in the aforementioned traits between the years. These analyses were performed using the STATISTICA 12 software package. The interactive chi square test calculator (Preacher, 2001) was applied to check whether there were significant differences among the studied Patches and years regarding the share of seedlings, as well as adult vegetative rosettes, and rosettes with flowering shoot (shoots).

3. Results and discussion

3.1. Habitat conditions

Our results showed that plant and cryptogams cover, height of neighbouring plants, as well as soil pH and humidity, similar in consecutive years, varied remarkably among

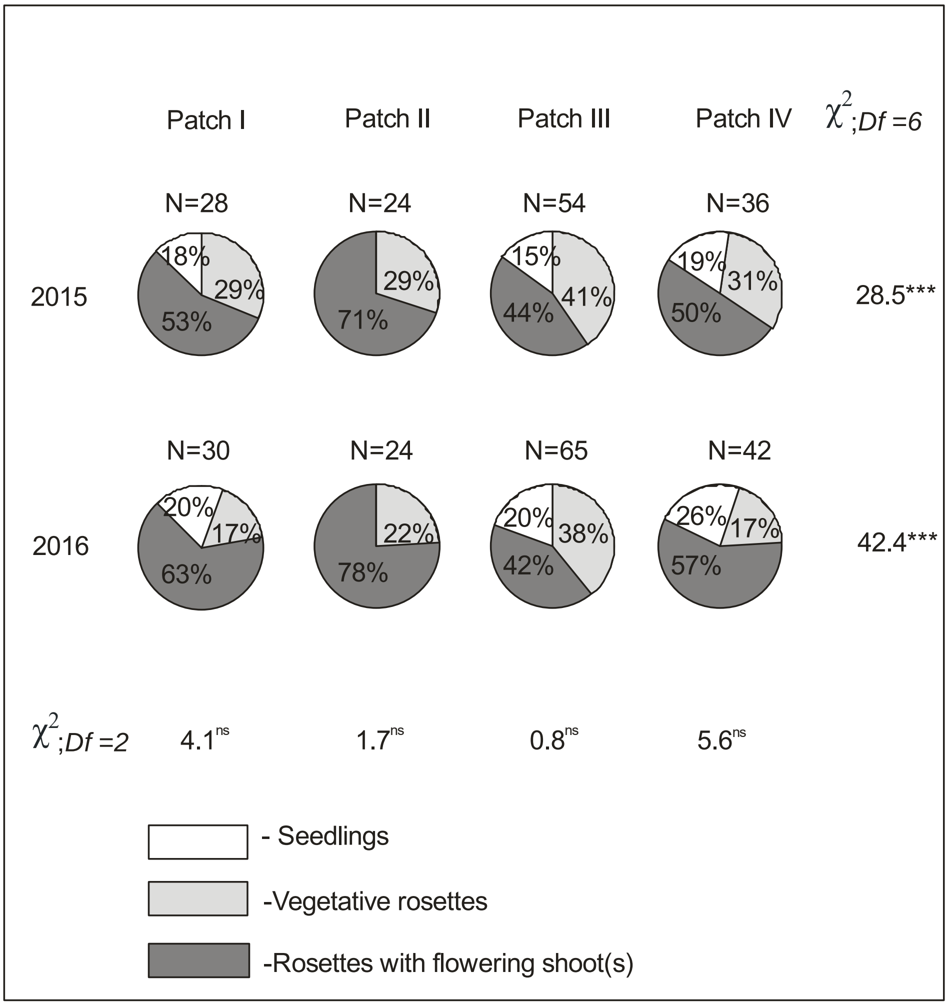

Figure 1. The share of seedlings, vegetative rosettes and rosettes with flowering shoot(s) of *Filipendula vulgaris* Moench in study plots established in meadows (Patch I and II) and calcareous grasslands (Patch III and IV) in the years 2015 and 2016. Explanations: ns- not significant, *- significant at the level ≤ 0.05; ***- significant at the level P <0.001

the Patches (the differences were repetitive in consecutive years).

The much lower plant and cryptogam cover observed in Patches III and IV (located in calcareous grasslands) than in Patches I and II (located in meadows) (Table 1) might be caused by loss of seeds deposited in the upper parts of soil as the result of water flowing down the steep slopes during seasonal precipitation. The susceptibility of the seeds to removal with running water was observed both by García-Fayos et al. (2010) and Jiao et al. (2013). On the other hand, many studies (García-Fayos et al., 1995; Cerdà & García-Fayos, 1997; García-Fayos et al., 2000) proved that seed losses are negligible and the scarcity of vegetation on the slopes might be the result of the limited germination of propagules, as well as difficulties in recruitment and survival of seedlings of numerous species in the shallow, dry and rocky ground. The germination and survival of seedlings could be also reduced by the allelopathic influence of plants growing in the neighbourhood (e.g. Skrzypek et al., 2015). Moreover, the observed gaps in continuous plant cover within the calcareous grassland Patches might be the effect of standing vegetation damage caused by trampling. Such a phenomenon was observed in a wide range of habitats from sand grasslands (Hesp et al.,

Table 1. The mean (range) height of neighboring plants, plant and cryptogam cover, soil humidity and pH in in study plots established in overgrowing meadows (Patch I and II) and grasslands (Patch III and IV) in consecutive the years 2015 and 2016 calculated on the basis of 20 measurements. Explanations: P*- value P calculated using the Kruskal-Wallis H test, P**- value P calculated using the Mann-Whitney U test. The significant P values are underlined. The different letters in superscript mean statistically significant difference among Patches

		Patch				P*
		I	II	III	IV	
Plant and cryptogam cover (%)	2015	98.7 (95–100)[a]	97.7 (90–100)[a]	77.8 (55–95)[b]	91.7 (80–100)[c]	<u>0.00001</u>
	2016	99.0 (98–100)[a]	98.6 (90–100)[a]	80.3 (60–100)[b]	92.6 (80–100)[b]	<u>0.00001</u>
	P**	0.22	0.24	0.15	0.53	
Height of neighboring plants (cm)	2015	44.8 (21–73)[a]	39.8 (17–69)[ab]	28.1 (7–64)[b]	26.5 (7–45)[c]	<u>0.004</u>
	2016	49.4 (17–87)[a]	40.8 (12–77)[ab]	32.7 (15–70)[ab]	23.9 (6–47)[b]	<u>0.004</u>
	P**	0.55	0.68	0.14	0.06	
Soil humidity (range 1–10)	2015	8.2 (7–10)[a]	6.8 (4–8)[ab]	3.2 (2–5)[b]	2.6 (2–4)[c]	<u>0.00003</u>
	2016	8.5 (7–10)[a]	7.2 (4–9)[a]	5.0 (3–4)[ab]	3.1 (2–4)[b]	<u>0.00002</u>
	P**	0.63	0.35	0.24	0.06	
Soil pH (range 1–10)	2015	6.4 (6–8)[a]	7.0 (6–8)[a]	7.7 (6–9)[b]	7.8 (7–9)[b]	<u>0.0001</u>
	2016	6.7 (6–8)[ab]	7.0 (6–8)[a]	7.6 (6–9)[ab]	7.9 (7–9)[b]	<u>0.001</u>
	P**	0.45	0.80	0.93	0.87	

Soil humidity range: 1–3-dry, 4–7-moist, 8–10 wet; pH range: 1–6-acid, 7–10 alkaline.

2010), through limestone lowland grasslands (Harrison, 1981), to alpine grasslands (Pickering & Growcock, 2009).

The soil pH values in the grassland Patches exceeded those noted in the meadow Patches (Table 1). The observed lower values of pH in the meadows corresponds with data found in *Molinia* meadows by Zelnik & Čarni (2008). It might be caused by the formation of carbonic acid and weak organic acids as an effect of decomposition of litter and soil organic matter. Nevertheless, the experiments of Van Duren et al. (1998) produced evidence that artificial sod cut in *Molinia* meadows contributes to the slight increase of soil pH. Moreover, the reduction of pH value in the observed meadow Patches might be caused by the runoff of acidifying fertilisers containing ammonium from adjacent arable fields. The mechanisms and effect of fertiliser application on soil acidification has already been widely discussed (Barak et al., 1997; Guo et al. 2010; Goulding, 2016).

The performed observations showed that the height of neighbours of *F. vulgaris* and soil humidity diminished gradually in subsequent Patches (Table 1). Also, other authors found that the augmentation of standing vegetation height causes an increase in soil humidity in wet meadows (Kulik, 2014) and calcareous grasslands (Gross et al., 2008). The aforementioned authors argued that the increased canopy height, accompanied by a growing accumulation of litter, can reduce incident radiation and might promote water retention.

3.2. The population abundance and traits of rosettes of *Filipendula vulgaris* Moench

The performed observations showed that the abundance of rosettes of *Filipendula vulgaris* varied in subsequent Patches and achieved 82, 94, 176 and 167, respectively. Also, the abundance of seedlings and adult rosettes in the

Table 2. The mean (range) number of leaves per rosette (A) and length (cm) of the longest rosette leaf (B) in vegetative rosettes and rosettes with flowering shoots of *Filipendula vulgaris* Moench in study plots established in meadows (Patch I and II) and calcareous grasslands (Patch III and IV) in the years 2015 and 2016. Explanations: N- number of data per group; P*- value P calculated using the Kruskal-Wallis H test, P**- value P calculated using the Mann-Whitney U test. The significant P values are underlined

			Patch				P *
			I	II	III	IV	
Vegetative rosettes	A	2015	5.0 (3–6) N=14	5.3 (4–6) N=14	4.0 (2–13) N=27	3.1 (2–4) N=17	0.06
		2016	5.3 (5–6)[a] N=13	5.7 (5–7)[ab] N=13	3.7 (2–10)[ab] N=30	2.8 (2–4)[b] N=15	0.03
		P **	0.93	0.85	0.51	0.56	
	B	2015	18.0 (15–21) N=14	24.3 (19–29) N=14	38.0 (28–47) N=27	42.4 (31–51) N=17	0.08
		2016	19.7 (17–24)[a] N=13	28.0 (23–32)[a] N=13	39.0 (23–50)[ab] N=30	50.4 (43–56)[b] N=15	0.0007
		P **	0.85	0.28	0.54	0.06	
Rosettes with flowering shoot(s)	A	2015	6.8 (3–9)[a] N=19	7.2 (3–13)[a] N=20	4.3 (2–8)[b] N=29	4.7 (±3.5)[b] N=22	0.005
		2016	6.6 (3–9)[a] N=21	8.6 (5–17)[ab] N=21	4.1 (±2.6)[ab] N=32	4.3 (±3.5)[b] N=26	0.0003
		P **	0.90	0.37	0.25	0.54	
	B	2015	24.4 (20–33)[a] N=19	26.5 (18–36)[a] N=20	32.3 (±4.5)[b] N=29	35.7 (±9.8)[b] N=22	0.004
		2016	25.5 (18–33) N=21	24.3 (20–32) N=21	34.4 (±4.6) N=32	36.5 (±9.3) N=26	0.06
		P **	0.93	0.41	0.24	0.87	

permanent plots increased similarly. Moreover, the observed much lower combined share of seedlings and vegetative rosettes of the species in meadow Patches (Fig. 1) might be due to a lack of gaps in the continuous plant cover performing the role of "safe sites for seedling recruitment" in *Molinion caeruleae* meadows (Kostrakiewicz, 2011; Kostrakiewicz-Gierałt, 2014). The recorded abundant appearance of offsprings in Patches III and IV might be the effect of the occurrence of openings in the plant cover. On the other hand, Franzén (2001) asserted that the established vegetation in dry–mesic seminatural grasslands does not limit recruitment of *F. vulgaris* seedlings.

The performed studies suggest that a dense canopy in abandoned meadows seems to favour individuals creating short, multi-leaved rosettes, while the considerable percentage of bare soil in frequently disturbed grasslands promotes the production of rosettes with scarce, long leaves (Table 2). This phenomenon might be an effect of the environmentally mediated size/number 'trade-off' of organs. This fundamental principle of strategy theory in evolutionary ecology assumes that individuals allocate their resources optimally between number and size of organs to maximise fitness (Roff, 1992). To date, the leaf size/number trade-off was observed in trees (e.g. Fonseca et al., 2000; McDonald et al., 2003; Kleiman & Aarssen, 2007; Yang et al., 2008). The aforementioned authors argued that many small leaves tend to be advantageous in dry, cold, windy, high-altitude and low-nutrient habitats, but that their photosynthetic capacity is usually limited by the stressful environments. In addition, the trade-offs between the size and number was studied in the production of flowers (Sargent et al., 2007; Kettle et al., 2011), fruits (Dombroskie et al., 2016) and seeds (Shipley & Dion, 1992; Jakobsson & Eriksson, 2000; Moles et al., 2004).

The performed investigations also showed lack of spatial and temporal variability of the number of flowering shoots (Table 3). Moreover, the recorded similar in consecutive years height of generative shoots, number of

Table 3. The mean (range) number of flowering shoots per rosette, height of flowering shoot, number of cauline leaves and inflorescences per flowering shoot, number of flowers per inflorescence of *Filipendula vulgaris* Moench in study plots established in meadows (Patch I and II) and calcareous grasslands (Patch III and IV) in the years 2015 and 2016. Explanations as in Table 2

		Patch				P*
		I	II	III	IV	
Number of flowering shoots	2015	1.0 (1–1) N=19	1.1 (1–2) N=20	(1–2) N=29	1.1 (1–2) N=22	0.25
	2016	1.0 (1–1) N=21	1.4 (1–2) N=21	(1–1) N=32	1.1 (1–2) N=26	0.23
	P**	1.00	0.75	1.00	0.88	
Number of cauline leaves	2015	2.6 (2–3)^{ab} N=19	3.5 (3–5)^{a} N=20	2.2 (1–4)^{b} N=29	1.2 (1–3)^{b} N=25	0.008
	2016	3.1 (2–5) N=21	2.9 (2–4) N=25	2.8 (2–4) N=32	2.9 (2–4) N=29	0.86
	P**	0.30	0.08	0.60	0.01	
Height of flowering shoots (cm)	2015	69.3 (59–82)^{a} N=19	62.9 (56–68)^{ab} N=20	55.0 (41–98)^{b} N=29	60.5 (42–74)^{ab} N=25	0.001
	2016	72.3 (58–95)^{a} N=21	65.8 (56–72)^{ab} N=25	58.2 (40–106)^{b} N=32	64.5 (40–79)^{ab} N=29	0.01
	P**	0.67	0.10	0.78	0.21	
Number of inflorescences	2015	1.4 (1–2) N=19	1.3 (1–2) N=20	1.1 (1–2) N=29	1.0 (1–1) N=25	0.22
	2016	1.6 (1–2)^{a} N=21	1.4 (1–3)^{ab} N=25	1.2 (1–2)^{ab} N=32	(1–1)^{b} N=29	0.0008
	P**	0.49	0.85	0.76	1.00	
Number of flowers per inflorescence	2015	62.8 (28–97)^{a} N=23	53.1 (15–92)^{ab} N=22	32.3 (6–77)^{b} N=36	40.4 (23–72)^{ab} N=25	0.001
	2016	59.0 (18–115)^{a} N=28	66.2 (12–86)^{ab} N=28	41.9 (6–83)^{b} N=32	37.8 (22–78)^{ab} N=29	0.001
	P**	0.76	0.43	0.78	0.43	

cauline leaves, inflorescences and flowers – decreasing in subsequent study sites – correspond with the observations of van Groenendael (1986), who found that individuals of *Plantago lanceolata* growing in meadows developed higher flowering shoots with longer inflorescences than those in open dune grasslands. The appearance of high flowering shoots with a considerable number of inflorescences and flowers in the vicinity of tall-growing plants might contribute to an improvement of pollination. This phenomenon was observed in other rosette-forming species inhabiting overgrowing meadows such as *Betonica officinalis* (Kostrakiewicz-Gierałt, 2015a, 2017a), *Serratula tinctoria* (Kostrakiewicz-Gierałt & Bąba, 2014), *Succisa pratensis* (van der Meer et al., 2014; Kostrakiewicz-Gierałt, 2015b, 2017b). Moreover, the aforementioned species, similarly to *F. vulgaris*, show an increase of number of cauline leaves improving light capture in the neighbourhood of plants of a substantial size (Table 3).

4. Conclusions

In summary, the present results clearly indicate that sparse and short-statured vegetation established on dry, alkaline ground provides the occurrence of safe sites for the recruitment of new individuals of *F. vulgaris*, leading to an increase in population abundance, as well as favouring the development of rosettes with large leaves. On the other hand, the occurrence of higher neighbouring plants contributes to an increase in the height of generative shoots, as well as a substantial number of cauline leaves, inflorescences and flowers of the species. Considering the relation between morphological traits and content of secondary metabolites observed in many species (Paul et al., 2011; Akhtar et al., 2014; Wahid et al., 2016), it could be concluded that the performed investigations provide a basis for further studies on the impact of habitat conditions and size of the aboveground parts of *F. vulgaris* on the content of bioactive compounds in plant material.

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