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POPULATION SIZE OF THE MONOCARPIC PERENNIAL *PEUCEDANUM ARENARIUM* WALDST. ET KIT. WITH REGARD TO EXPERIMENTALLY TESTED MANAGEMENT STRATEGIES

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Abstract

The monocarpic perennial *Peucedanum arenarium* is a critically endangered plant species in Slovakia, growing only in several micro-localities on the Sandberg hill near Bratislava (NNR Devínska Kobyla). Disturbances such as grazing and fire were excluded from possible management measures on the dry, sandy slopes of the Sandberg hill. Three types of treatments (selective clipping, full clipping, and raking) were tested as possible management methods for the preservation of *P. arenarium* during a 10 year period. Two types of clipping treatments showed a positive effect on the population size. The most useful treatment for the management of *P. arenarium* was the spring clipping of all non-*P. arenarium* individuals and the removal of biomass from the plot (selective clipping). This treatment was correlated with a more than 100% increase in the total number of *P. arenarium* between 2000 and 2009. In contrast, the raking of dry biomass had a negative effect when compared to the abandoned plots. Evaluation of the population size of *P. arenarium* showed a five year temporal fluctuation. This fluctuation was connected with a high or low number of small vegetative individuals. The presented management and realities may be effective for in situ conservation of monocarpic perennial species growing on sand or dry habitats with sparse vegetation (*Ferula sadleriana*).

Introduction

Peucedanum arenarium Waldst. et Kit. is a monocarpic perennial plant belonging to the Apiaceae family (Fig. 1). This species is native to southwest Europe. Three described subspecies are distributed in Europe and Turkey. The main regions in which the nominate subspecies *P. arenarium* ssp. *arenarium* occurs are in Slovakia, Hungary, Bulgaria, Romania, and Serbia. The distribution area of *P. arenarium* ssp. *neumayeri* (Vis.) Stoj. et Stefanov is in Albania, Bulgaria, and the south and west part of the former Yugoslavia. The parallel occurrence of both subspecies has been recorded only in Bulgaria. The endemic subspecies *P. arenarium* ssp. *urbanii* (Freyn et Sint. ex Wolff) DF Chamb. grows in Turkey; further information about its distribution is described in Šerá *et al*., (2005).

Peucedanum arenarium ssp. *arenarium* is a critically endangered species of the Slovak Republic (Čeřovský *et al.*, 1999; Feráková *et al.*, 2001). Few micropopulations grow on the Sandberg hill in the National Nature Reserve (NNR) Devínska Kobyla. Grassland management is necessary for the preservation of many shrub or herbaceous plant species and to increase the species diversity in grasslands, rangelands and nature reserves (Critchley *et al.*, 2004; Hooper *et al.*, 2005; Ahmad *et al*., 2012). Fire and grazing are common events in many grassland ecosystems (Fidelis *et al.*, 2008; Farris *et al.,* 2010; Daur, 2012), and intensive grazing may have caused a decrease in the native biodiversity and led to eroded soils (Kimball & Schiffman, 2003; Baur *et al.,* 2007).

Fig. 1. *Peucedanum arenarium* in a reproductive stage of the life cycle in a permanent plot on the slope of the Sandberg hill (photo: Z. Podešva).

The Sandberg hill, with sandy soil and short, sparse vegetation (ground cover about 80%, Šerá *et al.*, 2005) is unsuitable for grazing. Analogically, fire may present a harmful management method in very hot and dry localities. *Peucedanum arenarium*, the examined species, is well adapted to semiarid sand communities (also other species of the Apiaceae family, c.f. Yu *et al.*, 2008). Its population has been influenced by competitive grassland communities in the NNR Devínska Kobyla. The species, with a narrow ecological plasticity, needs some maintenance to stabilise and increase the population. For this reason, a rescue programme has been necessary.

In this study, we analysed the effect of clipping (cutting) and raking on experimentally managed plots in comparison with non-treated controls for the species *P. arenarium*. Analyses of the population size and stage classes were carried out over a period of ten years to establish the optimal management strategy. We hypothesised that the population of *P. arenarium* was favoured by a type of long-term management that would support the survival of mainly vegetative individuals. The results of this study will be used for the Recovery Programme of *P. arenarium* in the NNR Devínska Kobyla, supervised by the Regional Administration of the Protected Landscape Area Malé Karpaty. In addition many presented results may be useful for conservation rules of monocarpic perennial species growing on semiarid sand grasslands.

Materials and Methods

Study site: The study site forms a part of a permanent plot (20 x 20 m^2) that had been marked in 1994. It was selected to represent a characteristic population of *P. arenarium* growing in the NNR Devínska Kobyla on the slopes of the Sandberg hill located near the municipal parts of Bratislava Devínska Nová Ves (48°10´55´´N, 16°59´10´´E) (Fig. 2). The study site is located at 200 m a.s.l. and has a southern exposition of about 20 degrees. The underlying geological substrate is limestone of the Jurassic and Lower Cretaceous period and the soil is of the carbonate sand type (Middle Miocene deposits in the marginal parts of the Vienna Basin) that is most common in this area. The average annual temperature and level of precipitation are 9.6^{o}C (1931-1960) and 640mm (Feráková & Kocianová, 1997). Recent information about the temperature and precipitation are given in Figs. 3 & 4.

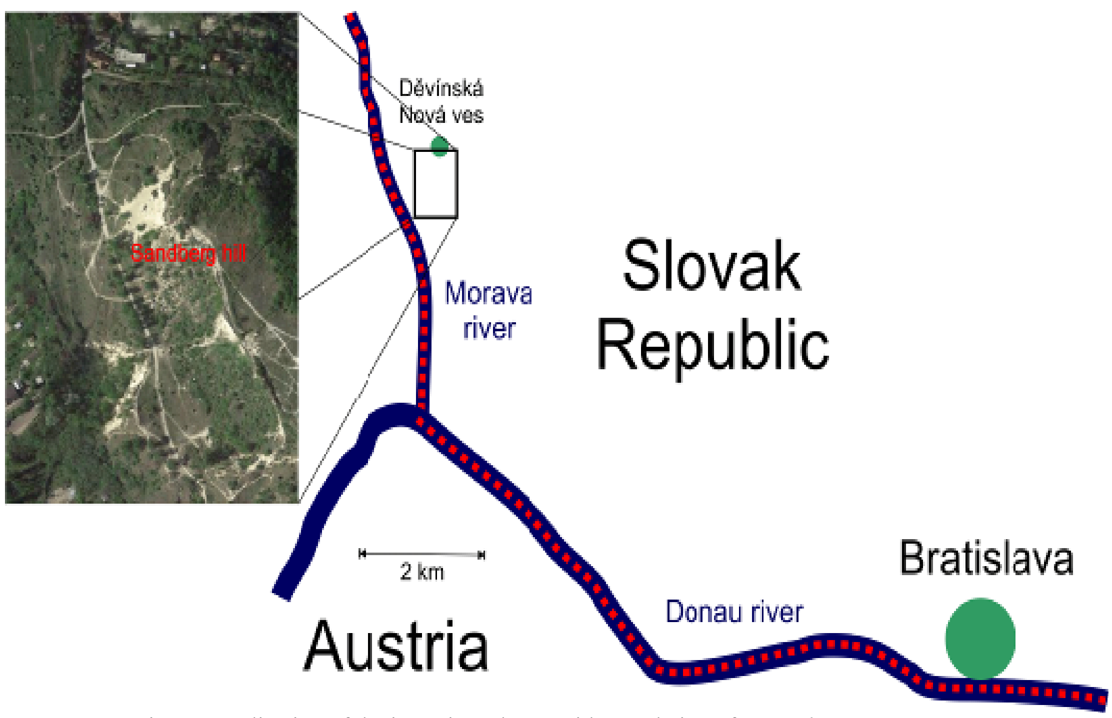

Fig. 2. Localization of the investigated area with population of *Peucedanum arenarium*.

The study area is primarily composed of short and sparse dry grassland dominated by 2 grasses, *Festuca pallens* and *Poa bulbosa*. Its associated species are *Achillea collina, Artemisia campestris., Asparagus officinalis., Astragalus onobrychis, Dichanthium ischaemum, Eryngium campestre, Euphorbia cyparissias, E. seguieriana, Petrorhagia saxifraga, Sanguisorba minor, Senecio jacobaea, Silene otites, Teucrium chamaedrys* and *Thymus praecox* (Marhold & Hindák, 1998). More detailed information on the classification and structure of the vegetation can be found in Feráková & Kocianová (1997) and Šerá *et al*., (2005).

Experimental design: Sixteen random plots (each 1 x 1 m^2) were established in 2000. These plots are within the one larger square with representative vegetation including native growth of *P. arenarium* (20x20 m; Šerá *et al*., 2005). Four plots were non-treated controls, and three types of disturbance pressures were simulated in the other 12 plots (each with four repetitions). These treatments were made one time per year in the early spring (April) during the period of 2000-2009. The plots were visited 2 times per year: once to carry out treatments in the early spring (before the vegetation season) and once to collect data in the summer (when the *P. arenarium* started to fruit).

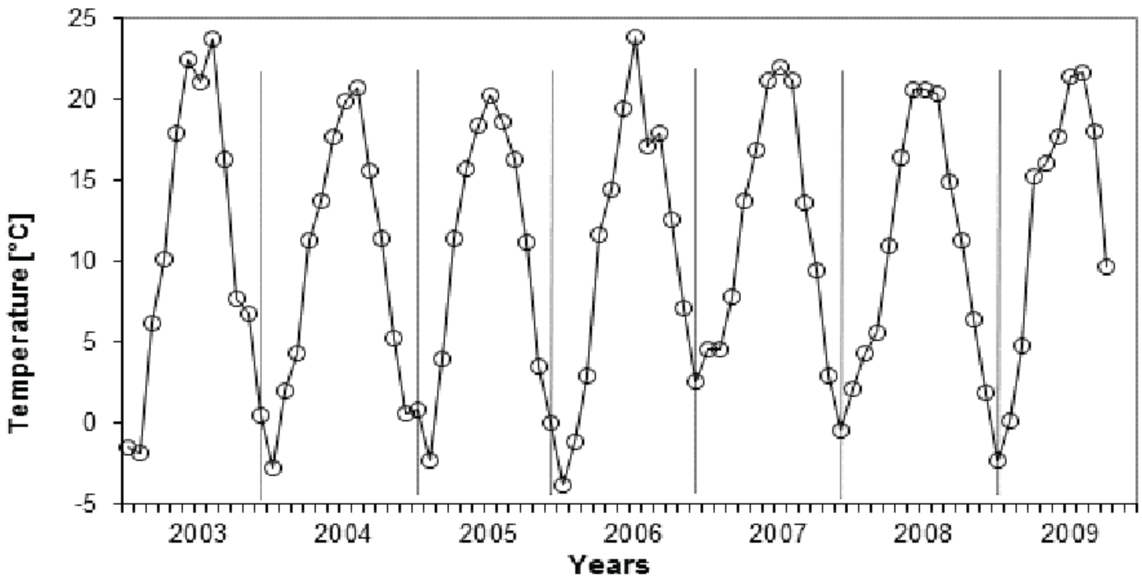

Fig. 3. Monthly average temperature per month for the Bratislava Koliba Meteorological Station during period of 2003-2009 years.

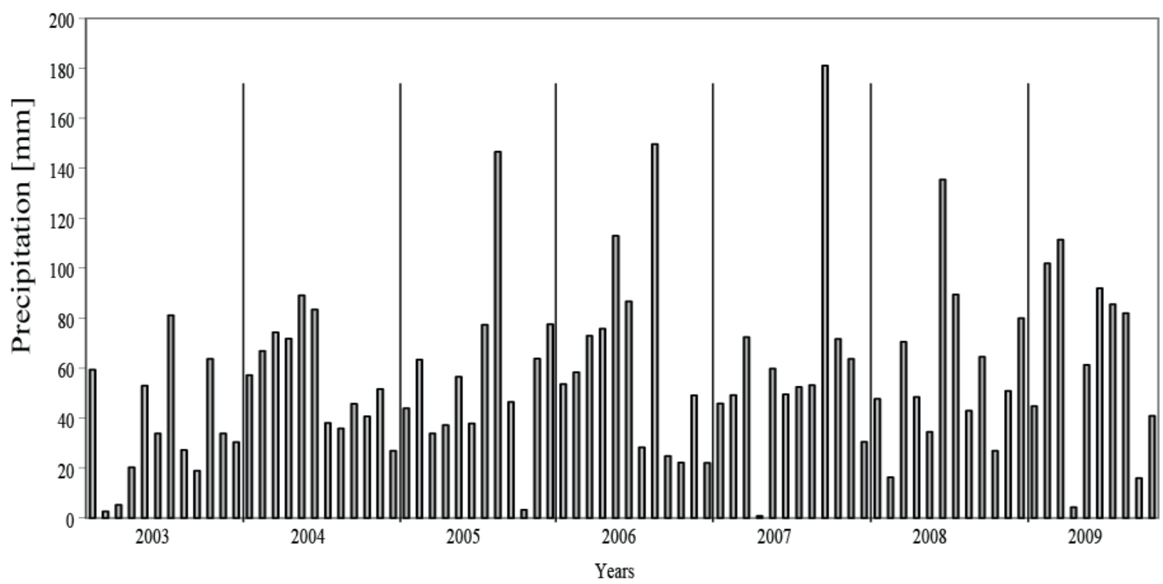

Fig. 4. Precipitation totals per month for the Bratislava Koliba Meteorological Station during period of 2003-2009 years.

Individuals of all stage classes of *P. arenarium* were not damaged by clipping or raking because the plants were very small in the early spring. The treatments used were discussed and prearranged with the Regional Administration of the Protected Landscape Area Malé Karpaty. The treatments agreed with the potential rescue management techniques that could be practiced in the NNR Devínska Kobyla.

The types of treatment used were:

Selective clipping: Clipping of all the vegetation except the rosettes of *P. arenarium;* clipping to the height of 2 cm above the soil surface*;* biomass removed from the plots; and all stage classes of *P. arenarium* were not disturbed.

Full clipping: Clipping of all the vegetation to the height of 2cm above soil surface; biomass removed from the plots; and individuals of *P. arenarium* received a soft disturbance.

Raking: Raking of dry biomass; biomass was then removed from the plot.

Control: Without treatment; this was an abandoned control plot.

All individuals of *P. arenarium* in the plots were permanently marked once a year in late summer (August) during the period between 2000 and 2009, except for in 2005. In the year 2005, data were not collected. The individual spatial position, number of leaves, size of the rosette, and height of flowering individuals were recorded to determine four stage classes. These stage classes were relatively easily recognisable at the study site (Šerá *et al.*, 2005). The monitoring of this critically endangered species was based on a non-destructive method, and the suggested design of the experiment was minimized.

The recognized stage classes of *P. arenarium* in the permanent plots were:

Small vegetative: Small-sized individuals; sterile stage; and a minimum leaf number of 1-2.

Medium vegetative: Medium-sized vegetative individuals; sterile stage; establishment of a loose leaf rosette; and a minimum leaf number of 2-3.

Large vegetative*:* Large-sized vegetative individuals; sterile stage; establishment of a rich leaf rosette; and a minimum leaf number of 3-4.

Reproductive: Large-sized flowering individuals found at the fertile stage.

The data were evaluated with the common statistical programme STATISTICA. The relationship between the temperature and precipitation (various months were selected) and the number of small vegetative individuals of *P. arenarium* was calculated using a Pearson correlation test (x(X,Y) = Pearson's correlation coefficient). The correlation between the time and the number of the *P. arenarium* individuals that were growing in various treated plots was tested using a Spearman correlation test (R = Spearman's correlation coefficient). The differences among the types of treatment, as related to the number of individuals in the recognised stage classes, were calculated using an analysis of variance analysis (one-way ANOVA). The Duncan test was used. All of the statistical tests were run at the significant level $\alpha = 0.05$.

Results

Effect of temperature and precipitation on the number of seedlings: Information about the temperature and precipitation were obtained from the Bratislava Koliba Meteorological Station for the period from 2003-2009 (Figs. 3 & 4). The monthly average temperature (or the precipitation totals per month) for February, May and April from 2003, 2004, and 2006-2009 were correlated with the number of small vegetative individuals of *P. arenarium* observed during those years. Similarly, the temperature and precipitation of September, October, and November from 2003 and 2005-2008 were correlated with the number of *P. arenarium* obtained from 2004 and 2006-2009. No significant relationships between the temperature or precipitation and the number of small vegetative individuals of *P. arenarium* were found.

Effect of treatment on the population size: In 2006 and 2007, we observed significant differences among the number of *P. arenarium* individuals after the various treatments (Duncan test, $p<0.05$). The major differences were found between the treatments of selective clipping and full clipping and between the treatments of selective clipping and raking. These results, though significant, were not very important for this monocarpic perennial plant because population size fluctuation plays a key role in the life history (see discussion).

Positive trends for both clipping treatments on the number of growing individuals of *P. arenarium* were observed. We found a significant correlation between the treatment duration and the number of all individuals of *P. arenarium* that were treated by selective clipping ($R=+0.450$, $p<0.04$). Above all, significant differences were found for a number of both small vegetative individuals and reproductive individuals ($R=+0.430$, $p<0.01$ and $R=+0.374$, $p<0.03$, respectively) after the selective clipping. This treatment increased the number of *P. arenarium* by much more 100% when 2009 was compared to 2000 or to the control in 2009 (Fig. 5). In contrast, raking showed a negative trend in the total number of individuals (not a significant correlation; $R=-0.218$, $p>0.21$) (Fig. 3).

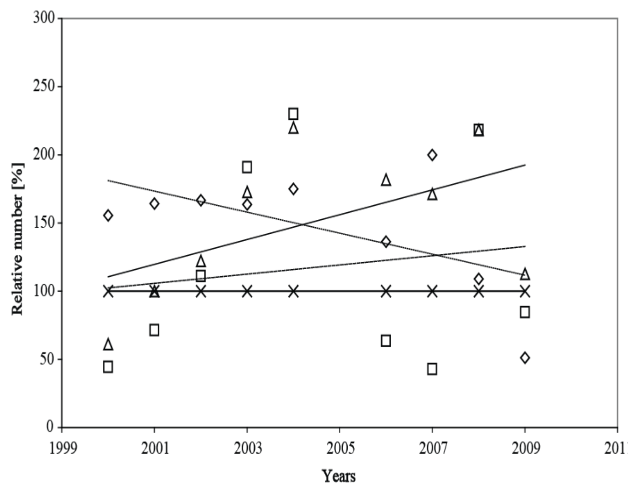

Fig. 5. Trends of *Peucedanum arenarium* individuals after treatments in comparison to abandonet (control) plots. Number of all stage classes was calculated. More detail in text.
△ Selective clipping; □ Full clipping; ◇ Raking; ✕ control
—— Trend of selective clipping; ---- Trend of full clipping; ········ Trend of raking

Temporal population size fluctuation: The number of all individuals of *P. arenarium* was extremely large in 2004 and 2009. However, a significant decline in the population size was obvious in 2002 and 2007 (Fig. 6). Therefore, it seems that the total number of growing plants of *P. arenarium* fluctuated with a five year period.

Stage class structure: The population structures of all investigated stage classes of *P. arenarium* are shown in Table 1. The number of flowering individuals (reproductive stage) did not correspond with the five year period of fluctuation. The large populations found in 2004 and 2007 were connected with a large proportion of the small vegetative individuals (about 50% of the total number; Table 1). The small number of individuals observed in 2002 and 2007 was related to a large proportion of both medium-sized and large vegetative individuals (about 85% of the total number; Table 1).

Discussion

The treatments used showed both positive and negative effects on the population size of *P. arenarium* (Fig. 3). The biggest increase was caused by the treatment of clipping/cutting of all vegetation except the individuals of *P. arenarium,* with removal of the biomass from the treated area. This treatment did not disturb the *P.*

arenarium individuals. We suggest the use of this management technique in micro-localities of this species in the NNR Devínska Kobyla. We recommend that this management be practised in the early spring because disturbance at that time is not destructive for any of the stage classes of the *P. arenarium* plants. In addition, at that time it is likely advantageous for the seedlings of *P. arenarium* to have the biomass removed. The previous year's rosettes are dead in the early spring, and the present year's rosettes are not established until May. For this reason, the clipping or cutting of the vegetation cover must not be performed to a height that is below 2cm.

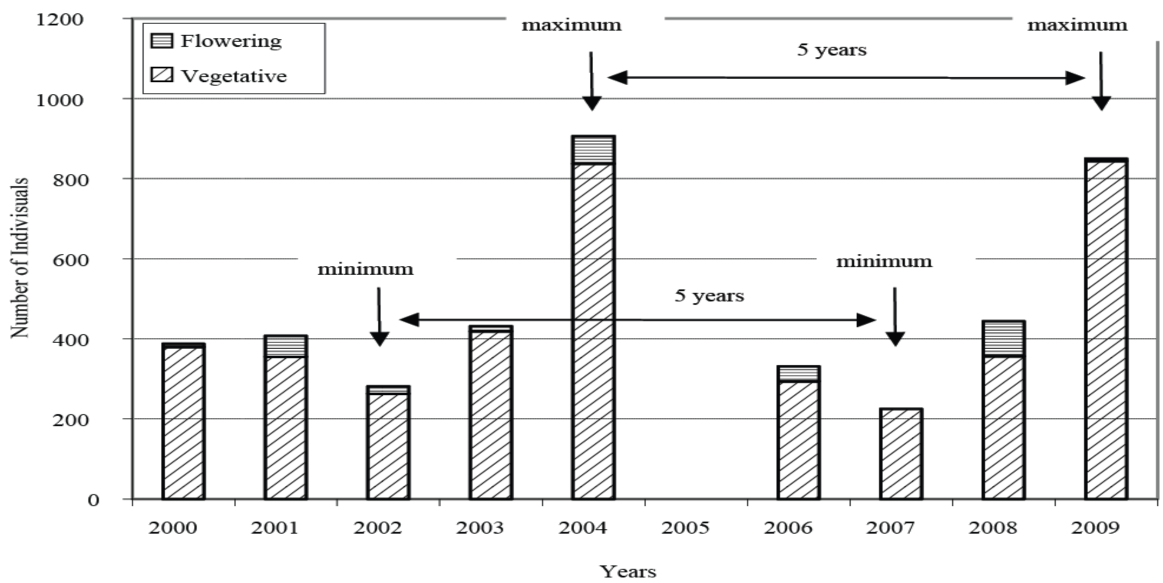

Fig. 6. Fluctuation of *Peucedanum arenarium* population growing on abandoned plots in a ten year period. Number of individuals is given per 100 m x m area.

Table 1. Number of individuals of stage classes in *Peucedanum arenarium* population in time.

Number/Year	2000	2001	2002	2003	2004	2006	2007	2008	2009
Flowering individuals	2	10	3	2	11	6	0	14	1
Large vegetative	38	26	30	32	32	18	16	15	28
Medium vegetative	20	22	8	26	30	13	15	21	34
Small vegetative	5	3	4	9	72	16	5	21	73
Sum	65	61	45	69	145	53	36	71	136

The occurrence of a high number of plants in the investigated population structure was correlated with a high proportion of small vegetative individuals (2004 and 2009 in Fig. 6 and Table 1). In contrast, a low number of individuals in the population was correlated with a relatively low number of reproductive individuals (2002 and 2007 in Figs. 5 & 6). If the development and growth of flowering individuals are disturbed (by disease, animal biting, disturbance), a lack of small vegetative plants will occur in the following years. A disturbed season may have a large effect on the number of fruits produced and the number of new potential individuals. The following years will be crucial in terms of *P. arenarium* survival. Only a healthy, flowering plant is able to produce the necessary quantity of fruits and therefore saturate the life cycle of the population.

The monocarpic perennials, like *P. arenarium* plants, remain in the vegetative stage for a few years. A rosette of leaves persists for several years until the plant either flower, produces fruit and dies, or dies without flowering. Such a pattern is common for monocarpic rosette species (Baskin & Baskin, 1979; Fidelis *et al.*, 2008). The plants start to flower only after establishing a sufficiently large leaf rosette and gathering sufficient supplies, e.g., of carbohydrates (Fenner, 1985; Silvertown & Doust, 1993). The reproductive period during the previous year of a plant´s life must also cover the previous vegetative period, which lasts many years. Monocarpic perennial plants, similarly to biennials, become exhausted by flowering to such an extent that they usually subsequently die (Thompson, 1984). A new generation is guaranteed because of the large number of fruits produced in the previous year of the plant´s life. It has been experimentally shown that the investment in fruit production in the biennial Apiaceae is eight times larger than in perennial Apiaceae plants, which flower every year (Lovett Doust, 1980). The potential number of fruits produced by one plant of *P. arenarium* during its lifetime is about 8400 (Šerá *et al.*, 2005). This overproduction is necessary from the viewpoint of fruit ontogenesis, fruit loss caused by predators, competition in the habitat, mortality of the seedlings, and plant mortality in the subsequent stages of their growth. The seeds, fruits, seedlings and young individuals of both plants and animals are overproduced and typically endangered by a relatively high mortality.

Even the mortality of particular age stages may be crucial for the life cycle of the *P. arenarium* population (Werner, 1975). High mortality was obvious in the small and medium vegetative stage classes. During the data collection, we found that individuals of *P. arenarium* may fluctuate from one stage class to the next in various time periods. Usually the period was one year, but sometimes was two or three seasons. The change of an individual plant from the current stage class into the previous one was even recorded. Similar transitions between stage classes were observed in the life cycle of *Heracleum mantegazzianum* (Hüls *et al.*, 2007). This fact indicates that individuals of various ages may be added to the same stage class. We know how to describe and process the data from such a plant population using a matrix model. Research on the life cycle of *P. arenarium* will be discussed in a separate paper.

Population size of species with same kinds of life and reproductive strategies can be stabilized due to a similar management measures. For example, *Ferula sadleriana* Ledeb. (syn.: *Peucedanum sibiricum* Waldst. et Kit. non Wild., Apiaceae) occurs on dry and warm calcareous cliffs or steep rocky slopes. It is a monocarpic perennial plant without possibilities to a vegetative reproduction (Čeřovský *et al.,* 1999; Elibol *et al*., 2012). Both species of *P. arenarium* and *F. sadleriana* have small number of adults on locality and the same reproductive trait. Above all both are bad competitive species who obligate short sparse vegetation cover. So, they will need the same management for the stabilisation and increasing of the population size. *F. sadleriana* also requires a change of protectionist measures. This species is a Pannonian endemic plant which is in Europe categorised as endangered species in evidency of EIONET (European Environment Information and Observation Network, http://forum.eionet.europa.eu). It is known only from a few localities in Hungary, Slovakia and Romania.

The 5 years fluctuation in the size of the population of *P. arenarium* may be coincidental (Fig. 6), as a ten-year research period is not sufficient for a correct prediction. The fluctuation was connected with a high or low number of small vegetative individuals. Mortality of the young vegetative individuals was also of great importance. It is necessary to continue the work at the permanent plot in the coming seasons to confirm these theories.

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