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Reproductive biology of the critically endangered endemic plant *Erodium somanum* in Turkey

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Abstract: The reproductive characteristics of *Erodium somanum* (Geraniaceae), a critically endangered endemic species, were investigated in order to evaluate the main factors that affect its reproductive success and to evaluate their importance on its conservation. The estimated pollen/ovule ratio was calculated as 1187. Pollen viability and stigma receptivity experiments showed that stigma receptivity and pollen viability were high and synchronous throughout the anthesis. *E. somanum* is a strictly dioecious species and pollinated by insects. Flower visitors in the studied populations were mostly beetles and ants. The average percentage of fruit formation for each plant was determined as 46%. Capacity of seed production for each plant was 36%. Seed viability and germination success were determined as 81% and 80%, respectively. When combined, the capacity of viable and germinative seed production for each plant was determined as 29%. The factor that most affects the reproductive success is thought to be the low density of pollinators. With the direct and indirect effects, population viability seems considerable.

Key words: *Erodium somanum*, reproductive biology, endangered endemic species, dioecious plant, conservation needs

1. Introduction

Turkey is located within the Mediterranean basin, which is one of the Mediterranean climate regions. All Mediterranean climate regions have a high number of rare and locally endemic taxa (Cowling et al., 1996). In terms of the number of plants, Turkey is one of the important regions in the Mediterranean basin. A great number of new species is being described every passing day. Most of the rare and locally endemic taxa are threatened by transformation and degradation of natural habitats in all Mediterranean climate regions (Cowling et al., 1996). Likewise, many endemic plant species have been evaluated as threatened in Turkey (Ekim et al., 2000). The rich plant diversity offers many opportunities to researchers. There have been many systematic studies on plants in Turkey, whereas there are limited studies on the reproductive biology of species. In the world, numerous researchers have studied single or multiple constituents of the reproductive biology and ecology of rare plants because any information on the reproductive biology of a threatened plant is important in terms of understanding the formation process of flowers, fruits, and seeds. Any factors influencing the life history traits are crucial in order to understand the vulnerability of the species to extinction. It is necessary to gather information belonging to rare species for planning their conservation strategies (Godt and Hamrick, 1995).

Erodium L'Herit is one of the six genera belonging to the family Geraniaceae (Takhtajan, 1997; Aldasoro et al., 2002; Fiz et al., 2006) and is represented by 74 species on all continents except Antarctica (Fiz et al., 2006). North America has 1, South America 1, Australia 5, and Asia 4 species, while the Mediterranean region, as the largest center of diversity, has 63 species (Fiz et al., 2006). Considering the number of *Erodium* species registered in Turkey, there are a total of 30 taxa with 25 species and subspecies, and 16 units of these taxa are endemic (Davis, 1967; Davis et al., 1988; Güner et al., 2000; Yıldırımlı and Doğru-Koca, 2004). In the study conducted with 74 species by Fiz et al. (2006), it was seen that 17 species exist in Turkey. Of those not involved in the study, 11 of the 13 taxa are endemic to Turkey. In this case the Mediterranean basin may contain more species than known. There are 12 annual taxa and 18 perennial taxa belonging to the genus *Erodium* in Turkey. According to the current research results, 15 of these perennial taxa are endemic and 10 of these taxa are dioecious (Davis, 1967; Davis et al., 1988; Güner et al., 2000; Yıldırımlı and Doğru-Koca, 2004).

E. somanum Peşmen, a dioecious perennial endemic species, was first collected and defined by H Peşmen in 1966. It is distributed in the Güllük Mountains in Soma-Manisa, in the western part of Turkey (Davis et al., 1988).

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This species was first classified as Endangered (Ekim et al., 2000) and was later classified as Critically Endangered, due to a distribution area of less than 100 km^2, a small number of individuals, and the determination of a reduction in the size of the area and quality (unpublished data, Oskay).

The objectives of this study were to provide knowledge about the reproductive properties of *E. somanum*, a critically endangered endemic plant in Turkey. The primary goals of this study were: 1) to determine any obstacle to reproductive potential, such as low pollen number, pollen viability, or stigma receptivity; 2) to identify the main pollinators; 3) to represent its seed viability and germination ability; 4) to consider its reproductive efficiency and performance at the population level; and 5) to investigate the requirements for the preservation of this species.

2. Materials and methods

2.1. Study species and study sites

E. somanum is a dioecious perennial plant. Plants form very wide, hard cushions of up to 60 cm in diameter. Stems are erect, simple, or scarcely branched, bearing 2–4 peduncles. The umbel inflorescence has 3–5 flowers in female plants while the umbel inflorescence has 6–11 flowers in male plants. There are two types of flowers in *E. somanum*. Female plants have only female flowers while male plants have only male flowers. *E. somanum* has pentamerous flowers comprising five sepals, five antipetalous nectaries, five petals, and five staminodes. Petals are pale sulfur yellow, sepals are transparent, and sepal veins are usually green and darker than the rest of the sepal. Fruit type is schizocarp and divided into five mericarps. Fruit is long-beaked, 4.8–8 cm (unpublished data, Oskay).

E. somanum grows naturally in rocky habitats, between 830 and 960 m in altitude, above the tree line. It is distributed in the Güllük Mountains in the western part of Turkey, in Soma/Manisa (Figure 1).

The investigations were conducted in the Güllük Mountains on Kocasivri Hill. The reproductive properties of plants were observed from late March to early June in 2007–2009.

2.2. Pollen/ovule ratio

Mature buds just before flower opening were used to determine the pollen grain number and ovule number. The collected buds were stored in 70% ethyl alcohol. Male flowers have five fertile stamens and five staminodes enclosing the vestigial gynoecium, while female flowers have five vestigial stamen and five staminodes enclosing a gynoecium with five carpels (unpublished data, Oskay). Vestigial organs were not included in the calculations. Ovules and anthers were counted in ten female and ten male plants from the population. The number of pollen grains was counted for each male plant. In order to count the pollen grains, the anther was placed on a slide, a drop of water was placed on top, and then it was dissected and squashed with a cover slide. Pollen counts were made in at least 30 different fields of view on each slide. An 18 × 18 coverslip was used for the pollen counts and observations were carried out at 4× objective lens magnification and 16× ocular lens magnification with a Nikon SE model microscope. The average number of pollen produced by anthers was calculated as a result of the microscopic view factor multiplied by the average number of pollen in the field of view. The ovule was counted in several flowers due to having a single pistil on each female plant manually without a microscope. The pollen/ovule (P/O) ratio was calculated as the product of the number of pollen grains per anther by the number of anthers per flower, divided by the number of ovules per flower according to Cruden (1977). However, the P/O ratio is not an individual plant trait in dioecious species; therefore, it should be adjusted to describe a population or species (Alarcón et al., 2011). Related population information (unpublished data, Oskay) was added to these values of the P/O ratio as *E. somanum* is a dioecious species. This was carried out by dividing the product of the number of male plants × the number of flowers per male plant × the number of grains of pollen per male flower by the product of the number of female plants × the number of flowers per female plant × the number of grains of pollen per female flower according to Alarcón et al. (2011).

2.3. Pollination type

E. somanum is an obligate outcrossing species because it is dioecious. It may use the wind or animals to pollinate. In order to understand the pollination type of this species, the inflorescences of 6 female bud plants were sealed with wire cages so as to not allow the entry of small animals during the whole flowering period for 2 consecutive years.

2.4. Pollinators

Observations of the pollinators were based on field studies conducted over 3 years, which consisted of 28 field days. During the field studies, all insects were observed while visiting *E. somanum* individuals and noted, and representative specimens were collected for identification. In this study, records excluded the number of insects visiting flowers and visit times. Assessments are based on the observations of the land on the days of the study.

2.5. Pollen viability

Lactophenol blue stain was used to determine pollen viability, which differentially stains pollen as viable and nonviable. If the pollen grain turned blue for 10 min, it was considered viable. On each of the 10 plants, anthers of marked flowers from some inflorescences were collected in a test tube on day 1 of anthesis. Some parts of the pollen were removed from the test tube and a droplet of

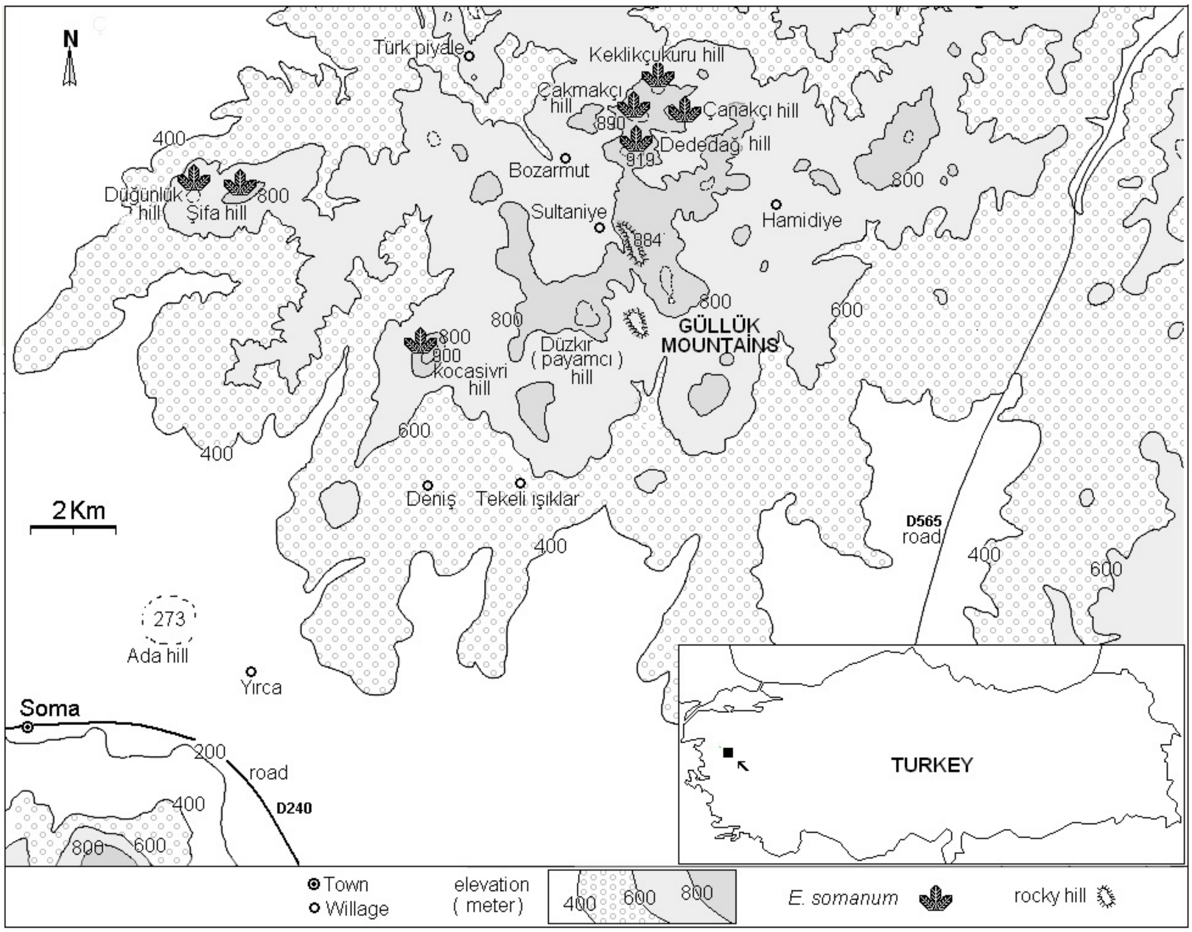

Figure 1. Distribution of *Erodium somanum*.

lactophenol blue stain solution was placed directly on the pollen on a slide and inspected after 5–10 min for blue coloration. A different sample from the test tube was prepared every day of anthesis from day 1 to day 4 or 5. To examine the slides, a light microscope was used. Each day of the flowering, the numbers of viable and nonviable pollen grains were counted from three different slides and three randomly chosen fields of view at 10×.

2.6. Stigma receptivity

In order to determine the stigma receptivity, 10 female plants were marked and mapped randomly from the population. Some inflorescences and buds on these plants were tagged with colorful yarn connecting slightly. Observations on the inflorescence were recorded daily for 5 days (15–19 April 2008). The tagged inflorescences were harvested at the end of 5 days because most flowers wilted within 4–5 days. Flowers marked with colored yarn (n = 63) were then divided according to the length of their existence (such as on day 1, day 2, day 3, day 4, and day 5). The pistils of harvested flowers were cut and Perex solution was dropped onto the stigma of the pistils. A few minutes were spent to see whether there was a color change. Perex solution (Merck chemical 16206) was used to test for the presence and concentration of hydrogen peroxide in the range of 10–500 ppm (Dafni and Maues, 1998). If peroxide is present the tissue turns a deep orange within 1–4 min. The kit has a color chart indicating the concentration of hydrogen peroxide.

2.7. Seed viability

Seed viability is an indication of the capability of seeds to germinate and generate a healthy plant under suitable germination conditions (AOSA, 2000). In order to determine the viability of *E. somanum* seeds, 0.1% solution of 2,3,5-triphenyl tetrazolium chloride was used. One fruit per plant was harvested from the population randomly and 156 seeds obtained from these fruits were scored for viability. Seeds that were obtained by peeling the mericarps were submerged in distilled water (dH_2O) for 24 h. The seed coat was then peeled and seeds were left for 24 h at room temperature in a 0.1% solution of 2,3,5-triphenyl tetrazolium chloride. The seeds that were not bisected through the embryo were then examined under a stereomicroscope and counted for viability (viable = majority of the embryo stained red).

2.8. Germination

For germination tests, one fruit (composed of 5 mericarps) per plant was harvested from the population randomly. Mericarps were selected randomly from the harvested fruits and were allowed to dry after being collected, and then were preserved at room temperature. Seeds that were obtained by peeling the mericarps were used in germination tests. Seeds were disinfected with 2.5% NaOCl for 5 min and then seeds were washed with sterile pure water twice. These seeds were submerged in sterile water at room temperature for 2 h. Seeds were then situated in sterile petri dishes on sterile filter paper moistened with autoclaved dH_2O. The seeds (n = 75) were allowed to germinate at 16 °C for 7 days. A temperature close to natural conditions was selected to measure the germination power of seeds. Their germination was recorded over the course of a week and the percentage of germination was calculated.

2.9. Reproductive success

In order to determine the reproductive success, a permanent plot (3 × 3 m) was established in the population of Kocasivri Hill in 2007. All individuals within the plot (12 female plants and 5 male plants) were marked and mapped. The monitoring of these plants' traits and related measurements were carried out on every census day between 2007 and 2009. Plant size was measured according to the areas they occupied on the ground for each plant. Stem number of individuals within the plot was recorded on each census day. Likewise, the number of opened flowers and the number of growing fruits were counted for each plant on every census day in the permanent plot. The percentage of fruit-producing flowers was calculated for each plant in order to see the annual fruit yield. The ovule number per plant was calculated by multiplying total flower numbers per plant by ovule number in a flower (5). In order to calculate the mean number of seeds per fruit, 100 fruits (1 fruit per plant) were used by taking a random sample from the population before opening every census year. The reason for selecting the calculation of different methods for the number of seeds per fruit is the separation of the mature fruits of the seeds immediately; this made it difficult to make measurements on all individuals within the permanent plot. Total seed production per plant was calculated by multiplying the mean number of fruits per plant by the mean number of seeds per fruit to estimate female reproductive success (Dafni, 1992). The maximum and minimum values and calculated mean and standard deviation of variables were then determined.

3. Results

3.1. Pollen/ovule ratio

According to the census conducted per field of view, the pollen count average of 14.66 pieces is between 10.95 and 20.26. An average number of pollen produced by anthers was calculated as a result of the microscopic view factor (calculated: 51) multiplied by the average number of pollen in the field of view. The number of ovules in a flower was 5. The number of anthers in a flower was 5, the average number of pollen in the anther was calculated as 748, and the average number of pollen in the flower was calculated as 3740. The umbel inflorescences have 3–5 flowers in female plants while the umbel inflorescence has 6–11 flowers in male plants. The sex ratio (number of male plants/number of female plants) was 0.79 in the population (unpublished data, Oskay). The estimated P/O ratio of 1187 was calculated based on Alarcón et al. (2011).

3.2. Pollination type

As a result of the trials, 6 female plants did not create fruits; therefore, they could not connect seeds at the end of the flowering period every 2 years. These results show that wind pollination is not a way for this species. This result was already supported through the observations of pollinators.

3.3. Pollinators

Pollinators were identified at the family level (Figures 2A–2X). It was observed that the species belonged to the families of Malachiidae (Figures 2A, 2B, 2C, 2D, 2M), Melyridae (Figure 2N), Alleculidae (Figures 2I, 2J, 2K, 2L), Bruchidae (Figure 2Q), and Dermestidae (Figures 2E, 2F, 2G, 2H) of the order Coleoptera and Halictidae (Figures 2O, 2P), Tenthredinidae (Figures 2R, 2S, 2T), and Formicidae (Figures 2U, 2V, 2W, 2X) of the order Hymenoptera.

3.4. Pollen viability

Anthers were opened the first day of blossoming. Pollen viability percentage was high at 93% on the first day of flowering. According to the results of mean pollen viability staining with lactophenol blue, it was 93% when flowers opened, 81% at 1 day after the opening of the flowers, 75% at 2 days after the opening of the flowers, and 71% at 3 days after the opening of the flowers. Pollen viability decreased on the following days.

3.5. Stigma receptivity

Stigma receptivity results showed that stigma receptivity begins with the opening of the flowers and reaches its peak on the second and third days of anthesis. The stigma receptivity decreases on the following days.

3.6. Seed viability and germination

As a result of the seed viability test with tetrazolium staining, 81% of the seeds were alive and 19% were dead. As for the germination test, a portion of seeds (n = 32) were germinated at 16 °C for about 2 days. Fifteen of a total of 75 seeds did not germinate, while 7 seeds showed very poor germination and did not develop because of mold. The germination rate was determined to be 80% of seeds.

Figure 2. Pollinators of *Erodium somanum* at family level. A, B, C, D, M: Malachiidae; E, F, G, H: Dermestidae; I, J, K, L: Alleculidae; N: Melyridae; O, P: Halictidae; Q: Bruchidae; R, S, T: Tenthredinidae; U, V, W, X: Formicidae.

3.7. Reproductive success

The average number of produced flowers, produced fruits, and produced seeds per plant in the population are shown in the Table for each year. Looking at the average of three years, the mean number of flowers produced per plant was 39. This means that if a plant generates 39 flowers, it is potentially capable of producing 39 fruits. Therefore, this means this plant must have 195 seeds. However, it was understood that 20 of these flowers were fertilized, because it was seen that 20 fruits were formed. If all ovules are fertilized it means that it must have 100 seeds. However, 71 seeds were produced by these flowers. In light of the data, one plant is potentially capable of producing 195 seeds, while actually it produces 71 seeds. These results were combined with the seed viability test (81%) and seed germination test (80%). It shows that the rate of seeds that can be germinated per plant reaches 29%.

4. Discussion

4.1. Pollen/ovule ratio

Cruden (2000) created a model to examine and describe the interrelation of floral traits of animal-pollinated plants, including pollen number, pollen size, P/O ratio, stigma area and depth, stigma receptivity, and the pollen-bearing area of the pollinator. Cruden (2000) stated that the P/Os of wind-pollinated plants are higher than those of animal-pollinated plants, and there is little difference in the pollination efficiency of the various animal vectors. Cruden (2000) also found that the P/Os of plants that provide only pollen as a reward to animal pollinators were higher than those that provide nectar as a reward to animal pollinators. As understood from the study, there are many parameters that affect the efficiency of a species. In a study concerned with the evolution of P/O ratios and breeding systems in *Erodium* (Geraniaceae) by Alarcón et al. (2011),

Table. Average values of some characters of the female plants.

Character	Years			
	2007[b]	2008	2009	Total
Size (cm^2)[a]	116.83 ± 65.97[c] (20.0–234.0)[d]	164.50 ± 82.03 (42.0–294.0)	162.50 ± 107.37 (40.0–368.0)	147.9 ± 27.0
Stem number	9.83 ± 5.92 (2.00–20.00)	10.50 ± 8.73 (1.00–31.00)	9.08 ± 10.27 (0.00–38.00)	9.803 ± 0.710
Total flower number	42.92 ± 29.92 (3.00–96.00)	38.25 ± 33.07 (1.00–104.00)	36.67± 39.31 (0.0–128.0)	39.28 ± 3.25
Fruit number	21.83 ± 21.04 (0.00–79.00)	19.67± 16.70 (0.00–48.00)	18.08 ± 17.71 (0.00–55.00)	19.86 ± 1.88
Ovule number per plant	214.58 ± 149.60 (15.0–480.0)	191.25 ± 165.33 (5.0–520.0)	183.33 ± 196.54 (0.0–640.0)	196.39 ± 16.25
Seed number per plant	80.35 ± 77.41 (0.0–290.7)	71.78 ± 60.94 (0.0–175.2)	60.58 ± 59.32 (0.0–184.3)	70.90 ± 9.91
Fruit formation %	45.08 ± 21.09 (0.00–82.00)	46.42 ± 23.88 (0.00–79.00)	47.17± 20.14 (0.00–67.00)	46.223 ± 1.059

[a] The area covered by the plant on the soil.
[b] The numbers of plants followed in a fixed quadrate for each year (N = 12), the calculation for total (N = 36).
[c] Standard deviation.
[d] The numbers in parentheses indicate the minimum and maximum measured values.

it was indicated that most of the perennial species had higher P/O ratios than the annual species. In dioecious perennial species where the population information was available, the P/O ratio was seen to range between 903 and 3624. Looking at the data of *E. somanum*, this species is an animal-pollinated plant and provides pollen and nectar as a reward to pollinators. The P/O ratio of *E. somanum* where the population information was available was determined as 1187. Compared with the results for perennial dioecious species, *E. somanum* appears to be compatible with other species. Eckhart (1991) stated that high male flower numbers probably evolved after the evolution of dioecism in response to sexual selection for a large male inflorescence. This statement seems to be illustrative for *E. somanum* because the male flower production per umbel inflorescence in male plants ranged from 2 to 2.2 times according to per umbel inflorescence in female plants or regarding selection for increased pollen output, as stated in the studies by Charlesworth et al. (1987) and Stanton et al. (1987).

4.2. Pollination type and pollinators

As shown previously, *E. somanum* is a dioecious species and shows all of the floral traits especially related to insect pollination. Nectar is presented in different ways and is the main gift for insects in Geraniaceae (Link, 1994; Aldasoro et al., 2000). Female plants are a nectar source and male plants are both pollen and nectar sources in *E. somanum*. The nectar is reachable for short-tongued pollinators because of the presence of the nectar in droplets on the nectaries (Link, 1994). The type of nectar presentation is in droplets on the nectaries in *E. somanum*. In a study of pollination ecology in Geraniaceae by Fiz et al. (2008), it was stated that syrphids and some other Diptera (e.g., Bombylidae) are better pollinators for *Erodium* because they hover and land on the lower petals and do not make random movements inside the flower. It was also seen that a wide spectrum of pollinators was observed for *Erodium* species, such as Hymenoptera, Coleoptera, Lepidoptera, Neuroptera, and Diptera. However, low-efficiency visitors were also seen in most species growing in disturbed habitats of the genus *Erodium*. The main pollinators of *E. somanum* are in the orders of Coleoptera and Hymenoptera. The presence of colored flower guides on petals frequently indicates the location of nectar (Kevan, 1978; Kaye, 1999). Darker petal veins seem to be guides for insects in *Erodium* (Sprengel, 1793; Aldasoro et al., 2000). *E. somanum* has floral clues for insects, having long hairs on the margins of the petal base and having darker petal veins. In order to produce fruits, *E. somanum* needs pollinators to bring pollen to the stigmas. It was observed that the activity of pollinators was negatively affected by the cool day time temperatures, precipitation, and strong winds.

4.3. Pollen viability and stigma receptivity

The low reproductive success is not based on the obtained results of pollen viability and stigma receptivity because both stigma receptivity and pollen viability were high and synchronous throughout the anthesis.

4.4. Seed viability and germination

Harper (1977) stated that germination conditions and germination ratios are crucial features of seeds related to plant health. According to Rossello and Mayol (2002), these features are key constituents in the ecology and evolution of plant life histories. It was indicated that information on these steps may help explain why there is a decrease in populations of endangered plant species by Rossello and Mayol (2002). In this study, both seed viability and germination ratio in *E. somanum* were found to be high, but as in all other species, it was necessary to hold on to the appropriate substrate. We also have some information about the germination time of the species in its natural habitat. As a result of demographic studies conducted in permanent plots and field observations, the time of the germination of seeds in the life cycle of *E. somanum* has been found to be autumn. This explained to us why high germination occurs at 16 °C. In the framework of preconservation studies in the spring and fall in their natural habitats with planting, the germination rate of the seeds was determined in a similar manner. However, seedlings growing from seeds that germinate in the spring could not survive during the summer drought (unpublished data, Oskay). In a study by Gonzales-Benito et al. (1995) related to *Erodium paulerense* Fdez. Glez. & Izco, it was stated that seeds of *E. paulerense* germinated well at 15 °C and hardly germinated at 25 °C. The authors made the inference that seeds might germinate in the natural habitat in the autumn, when the average temperature falls and water is available.

4.5. Reproductive success

For new individuals to establish themselves in a population, the development of flower, fruit, and seed must be seamless. Seeds must also escape predation and they must spread to proper places for germination and growth (Kaye, 1999). Moreover, if any problems in this series of events continue for a long time, it can cause the disruption of the plant's reproductive ability and may contribute to the rarity of species and prevent the conservation of the species, as stated by Kaye (1999). The average percentage of fruit formation was determined as 46% (Table). These values were very low for the population. As shown previously, *E. somanum* is an outcrossing of entomophilous plants and seed production depends on this. It is thought that the reproductive success of *E. somanum* limits the activity of pollinators because the mean number of flowers produced per plant was found to be 39. However, only 20 flowers were fecundated. A number of cloudy or rainy days throughout the flowering period may also limit pollination because many Coleoptera are not active under these climatic conditions. Sih and Baltus (1987) indicated that small populations may be less attractive to pollinators than large populations. This approach seems to support the lack of pollinators because of the restricted distribution and small population size of *E. somanum*. Twenty fecundated flowers potentially means 100 seeds, but 71 seeds were produced by these flowers. It was seen that the flowers have high seed binding capacity (71%) if there is fecundation. Gonzales-Benito et al. (1995) determined that 10% of 1450 mericarps contained fully formed seeds in *E. paulerense* and they thought that the outcome of the schizocarp development stimulated by one fertilization caused the low seed/fruit ratio. This is a reasonable explanation for the scope of this study, as well. The results of the number of produced seeds were combined with the seed viability test (81%) and seed germination test (80%). This showed that the rate of seeds that can be germinated per plant reaches 29%. One plant may produce 71 seeds but the number of viable and germinable seeds is 57. As a result, one plant can potentially produce 195 seeds but actually produces 57 viable and germinable seeds. It is not certain how many of these seeds can escape predation, can find a suitable substrate, or can be germinated. The decrease in seed production is one of the greatest dangers to plant life history and may stimulate the end of populations and species (Rathcke and Jules, 1993; Olesen and Jain, 1994; Ohara et al., 2006). However, restrictions in seed production in any single year are not expected to cause difficult situations in the populations, because individuals are perennial.

As a result, for *E. somanum*, reproductive success is quite low for the population. The low reproductive success is not based on the obtained results of pollen viability, stigma receptivity, seed viability, or capacity of germination, because all these parameters were determined to be high. In this study, the factor that most affected the reproductive success is thought to be the low density of pollinators, because the average percentage of fruit formation was determined as 46% and the capacity of seed production of these fruits was determined as 71%. Another factor might be related to the produced pollen numbers, but more evidence is needed for this inference. Observations of the pollinators should be extended, especially considering the number of insects visiting flowers and visit times.

4.6. Conservation needs and significance

E. somanum is at critical risk of extinction mainly due to its narrow distribution and small populations. This makes the species more vulnerable to any event because of natural causes or human activity.

This species is a dioecious species that needs accessibility for pollinators to bring pollen to their stigmas to produce fruits. This must be taken into consideration in conservation programs and executive plans for the species. Moreover, in this context, pollinators of the species should be protected from human impact. Flowering periods, or, in other words, phenological factors, significantly affect the reproductive success. In this respect, long-term changes in climatic conditions may indirectly influence the reproduction of this species.

It should be considered that the acquiring of information on the steps of plant life history is essential for the purpose of planning and implementing an effective conservation program.

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References

Alarcón ML, Roquet C, Aldasoro JJ (2011). Evolution of pollen/ovule ratios and breeding system in *Erodium* (Geraniaceae). Syst Bot 36: 1-16.

Aldasoro JJ, Aedo C, Navarro C (2000). Insect attracting structures on *Erodium* petals (Geraniaceae). Plant Biol 2: 471-481.

Aldasoro JJ, Navarro C, Vargas P, Sa'Ez LL, Aedo C (2002). *California*, a new genus of Geraniaceae endemic to the Southwest of North America. Anales del Jardín Botánico de Madrid 59: 209-216.

AOSA (2000). Tetrazolium Testing Handbook. Contribution No. 29. Washington, DC, USA: Association of Official Seed Analysts.

Charlesworth D, Schemske DW, Sork VL (1987). The evolution of plant reproductive characters; sexual versus natural selection. In: Stearns SC, editor. The Evolution of Sex and Its Consequences. Basel, Switzerland: Birkhäuser, pp. 317-336.

Cowling RM, Rundel PW, Lamont BB, Arroyo MK, Arianoutsou M (1996). Plant diversity in Mediterranean regions. Trends Ecol Evol 11: 362-366.

Cruden RW (1977). Pollen ovule ratios: a conservative indicator of breeding systems in flowering plants. Evolution 31: 32-46.

Cruden RW (2000). Pollen grains: why so many? Plant Syst Evol 222: 143-165.

Dafni A (1992). Pollination Ecology. A Practical Approach. New York, NY, USA: Oxford University Press.

Dafni A, Maues MM (1998). A rapid and simple procedure to determine stigma receptivity. Sex Plant Reprod 11: 177-180.

Davis PH (1967). *Erodium* L'Hérit. In: Davis PH, editor. Flora of Turkey and the East Aegean Islands, Vol. 2. Edinburgh, UK: Edinburgh University Press, pp. 475-487.

Davis PH, Mill RR, Tan K (1988). *Erodium* L'Hérit. In: Davis PH, Mill RR, Tan K, editors. Flora of Turkey and the East Aegean Islands, Vol. 10 (Suppl. I). Edinburgh, UK: Edinburgh University Press, pp. 105-106.

Eckhart VM (1991). The effects of floral display on pollinator visitation vary among populations of *Phacelia linearis* (Hydrophyllaceae). Evol Ecol 5: 370-384.

Ekim T, Koyuncu M, Vural M, Duman H, Aytaç Z, Adıgüzel N (2000). Türkiye Bitkileri Kırmızı Kitabı. Ankara, Turkey: Türkiye Tabiatını Koruma Derneği Yayınları (in Turkish).

Fiz O, Vargas P, Alarcón ML, Aedo C, Garcia JL, Aldasoro JJ (2008). Phylogeny and historical biogeography of Geraniaceae in relation to climate changes and pollination ecology. Syst Bot 33: 326-342.

Fiz O, Vargas P, Alarcón ML, Aldasoro JJ (2006). Phylogenetic relationships and evolution in *Erodium* (Geraniaceae) based on trnL-trnF sequences. Syst Bot 31: 739-763.

Godt MJW, Hamrick JL (1995). The mating system of *Liatris helleri* (Asteraceae), a threatened plant species. Heredity 75: 398-404.

Gonzales-Benito E, Martin C, Iriondo JM (1995). Autecology and conservation of *Erodium paularense*. Biol Conserv 72: 55-60.

Güner A, Özhatay N, Ekim T, Başer KHC (2000). *Erodium* L'Hérit. In: Güner A, Özhatay N, Ekim T, Başer K. H. C, editors. Flora of Turkey and East Aegean Islands, Vol. 11 (Suppl. II). Edinburgh, UK: Edinburgh University Press, pp. 74-75.

Harper JL (1977). Population Biology of Plants. London, UK: Academic Press.

Kaye TN (1999). From flowering to dispersal: reproductive ecology of an endemic plant, *Astragalus australis* var. *olympicus* (Fabaceae). Am J Bot 86: 1248-1256.

Kevan PG (1978). Floral coloration, its colorimetric analysis and significance in anthecology. In: Richards A.J, editor. The Pollination of Flowers by Insects. London, UK: Academic Press, pp. 51-78.

Link DA (1994). The nectaries of Geraniaceae. In: Vorster P, editor. Proceedings of the International Geraniaceae Symposium. Stellenbosch, South Africa: University of Stellenbosch, pp. 215-225.

Ohara M, Tomimatsu H, Takada T, Kawano S (2006). Importance of life history studies for conservation of fragmented populations: a case study of the understory herb, *Trillium camschatcense*. Plant Spec Biol 21: 1-12.

Olesen JM, Jain SK (1994). Fragmented plant populations and their lost interactions. In: Loeschcke J, Tmiuk J, Jain SK, editors. Conservation Genetics. Basel, Switzerland: Birkhäuser, pp. 417-426.

Rathcke BJ, Jules ES (1993). Habitat fragmentation and plant-pollinator interactions. Curr Sci India 65: 273-277.

Rossello JA, Mayol M (2002). Seed germination and reproductive features of *Lysimachia minoricensis* (Primulaceae), a wild-extinct plant. Ann Bot-London 89: 559-562.

Sih A, Baltus MS (1987). Patch size, pollinator behavior and pollinator limitation in catnip. Ecology 68: 1679-1690.

Sprengel CK (1793). Das entdeckte Geheimnis der Natur, im Bau und in der Befruchtung der Blumen. Berlin, Germany: Friedrich Vieweg dem aeltern (in German).

Stanton ML, Berecsky JK, Hasbrouck HD (1987). Pollination thoroughness and maternal yield regulation in wild radish, *Raphanus raphanistrum* (Brassicaceae). Oecologia 74: 68-76.

Takhtajan A (1997). Diversity and Classification of Flowering Plants. New York, NY, USA: Columbia University Press.

Yıldırımlı Ş, Doğru-Koca A (2004). A new species from Turkey, *Erodium aytacii* Yıldırımlı & A. Doğru-Koca (Geraniaceae). Ot Sistematik Botanik Dergisi 11: 1-6.