Phenology and germination in *Stellaria media* (L.) Cyrill.

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Judy G. Semprevivo (Rutgers University, New Brunswick, N.J.) Phenology and germination in *Stellaria media* (L.) Cyrill. Hutcheson Memorial Forest Bull. 3:14-23. 1973. Observations on the flowering of *Stellaria media* were made from the autumn of 1970 through March 1972. Flowering occurred in at least one of the sites observed throughout the study in all months except for September, November and December. Buds (or closed flowers) were observed in all months. Seeds were produced from April through November although peak production was in May and June. Seeds collected at various times and places were tested for germination. Seeds from all collections made during the course of the year showed good germination. No mature seeds were found to be produced from flowers appearing from October through February. Seeds collected germinated well under several different conditions of light and temperature and preconditioning including germination at 4 C in constant dark. *Stellaria media* seeds thus exhibit a high degree of physiological heterogeniety.

The survival of a plant species depends primarily upon its reproductive efficiency (flowering, pollination, and seed production) and successful establishment of its seedlings (Stebbins, 1970, 1971). A plant species which could flower and produce viable seeds throughout the whole year would have a considerable advantage over those which did not, especially if the seeds produced did not all have identical germination requirements. The seedlings of species exhibiting extended flowering would thus possess the opportunity of becoming established many times during the year, often with little competition from other species. Also, the total number of plants (and seeds) which could be produced in a given area would be greatly increased.

For at least 60 years various investigators have reported that certain species of plants do flower throughout the whole year, not just in one or two specific seasons. This extended-flowering phenomenon has been observed in what are considered taxonomically to be primitive as well as advanced families. For example, Poulter (1924) found that *Thlaspi arvense* L. (Cruciferae), *Capsella bursa-pastoris* (L.) Medik. (Cruciferae), *Taraxacum officinale* Weber (Compositae), and *Stellaria media* (L.) Cyrill. (Caryophyllaceae) bloomed quite late in Iowa and were able to withstand freezing and thawing several times. In Kansas, Agrelius (1929) noted *T. officinale* was likely to have flowers and fruits on it any month in the year, blooming whenever the weather was favorable. Hulbert (1963) published the results of Gates' phenological records of 132 plants at Manhattan, Kansas, noting that some *S. media* plants were in flower in protected places in January, although peak flowering occurred in March and April.

In New Jersey, Buell and his coworkers have approximately 20 years of phenological records of a large proportion of the species occurring in Hutcheson Memorial Forest (HMF), its borders, and associated old fields. They report *S. media* and *T. officinale* blooming during favorable weather throughout the year, particularly at the forest's north edge (Buell, personal communication).

All the above studies involved observing only flowering of the plants; no mention is made of measuring environmental influences such as air temperature, soil temperature, and soil moisture. Also, apparently no attempt was made to determine if flowers observed at various times during the year produced viable seeds, and if they were capable of germinating. In fact, many studies report only the date of first flowering (for example, Jacques and Hilleary, 1956; King, 1930, 1931), but not its length and cessation or whether flowering resumed later in the year.

The purpose of this study, therefore, was to make a more thorough study of the extended-flowering phenomenon by using only one species and recording exactly when it flowered, produced seeds, and determining whether seeds produced throughout the year were viable and/or capable of germinating. Also preliminary observations were to be made on whether flowering time, seed production and/or seed viability were significantly affected by forest-edge versus open-field locations. *Stellaria media* growing at HMF was chosen as the plant to study, and voucher herbarium specimens have been deposited in the Chrysler Herbarium at Rutgers University.

Stellaria media (L.) Cyrill.[1] (common chickweed) is described in Gray's Manual (Fernald, 1950) as a "weak annual or perennial" but in Gleason and Cronquist (1963) as an "annual" only. Fiske (1941) classified it as a winter annual; that is, seeds germinating in fall, plants growing but slightly during winter, blossoming in spring and dying about midsummer. It is a common weed in North America, having been naturalized from Eurasia. In describing the weeds of New Jersey, Fiske (1941) notes the following:

> *S. media* flourishes everywhere, in rich or poor soil, and is one of the first seen in the spring. It not only grows well in spring, but it continues to reproduce and spread throughout the summer [note this contradicts her definition above]. At any time ripened or partially ripened seeds can be found on the plants. These at maturity drop to the ground and the plant is rapidly scattered by the continuous seed production . . .

Stellaria media is extremely variable in size and number of flower parts such as stamens, apparently showing a high degree of phenotypic as well as genotypic plasticity. European authors tend to subdivide the spe-

[1] John W. Moore (1972) in a personal communication with M. F. Buell verified that Cyrillo's transfer of *Alsine media* to *Stellaria* occurred before that of Villars and therefore, Cyrill. is the correct authority.

1973. William L. Hutcheson Memorial Forest Bulletin 3(1):14-23.

cies while American authors do not. Several studies have been made to determine the chromosome number of the species and its purported ancestors, *S. neglecta* Weihe and *S. pallida* (Dumort.) Piré. In 1965, Sinha and Whitehead summarized all previous work and presented their own chromosome counts, accompanied by photographs and camera lucida drawings. They concluded the basic number for the group is probably 11, and *S. pallida* and *S. neglecta* appear to be diploids and ancestors of *S. media* (n = 22) which may be an allotetraploid.

Stellaria media is self pollinated (Sinha and Whitehead, 1965) and grows in a wide range of habitats including cultivated ground, damp woods and thickets, and around buildings. At HMF it is found principally on the north side of the upland forest section, between the forest and adjacent old fields. In specimens collected in May from HMF, the number of ovules ranged from 11 to 17 (average = 14). However, average number of mature seeds produced by one flower was only 8 (range = 4 to 14).

A few laboratory germination studies using *S. media* were reported in the literature. In Germany, Borriss (1940) reported that high temperatures (above 20 C) and light were inhibitory to germination and that secondary ripening was required. Kurth (1967) in Germany indicated a temperature regime of 5 C (dark)-12 C (light) gave optimum germination results. Steinbauer et al. (1955) published results of germination tests on several Michigan weeds. Sixteen combinations of temperature, light, darkness and moistening agents were used. (Temperatures used were constant 16 C, 20 C, 30 C, and alternations of 15-30 C and 20-30 C; moistening agents used were distilled water and 0.2% aqueous solution of potassium nitrate. Additional tests included a one-week prechill treatment at 5 C prior to germination tests.) They found that (using water as the moistening agent) *S. media* tested after one month of dry storage at room temperature gave highest germination percentages in the 20-30 C temperature regime (12%), while seeds stored as above for 10 months had highest germination percentages (94%) when given one week of prechill, and then placed in the 20-30 C temperature regime.

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Methods and materials

Field observations

On September 27, 1970, observations were begun and continued at 7- to 10-day intervals as to whether *S. media* was flowering at the north edge of the upland forest (hereafter designated forest edge) where it had been seen for several years. On March 17, 1971, a cloudy day, two identical 33 x 51 cm transplants of *S. media* were made from a garden in Middlebush, a town two miles northeast of HMF. One was placed 31 m directly north of the forest edge in the open field (hereafter designated the open field transplant), the other 21 m east at the forest edge (hereafter designated the forest edge transplant). Two inches of soil around the roots were moved with each transplant to minimize root disturbance, and each transplant was watered upon planting. At the time of transplanting both clumps of *S. media* were in flower and some plants had partially and fully mature capsules. These flowers and capsules died shortly due to transplanting stress. Within one week however, new flowers had appeared and were used in the study.

All partially to fully opened flowers were marked at each site by loosely tied cotton thread around their stems. Each date of first observation of flowering was identified by a different color of thread. After marking the flowers, care was taken to replace the stems in the same position as they had been found.

Capsules of *S. media* open readily only if the seeds are mature (reddish brown). Thus, when a capsule was observed to be turning brown, it was tested for maturity by gently squeezing. If it opened easily, the seeds were collected in small plastic bags.

Soil temperature readings were begun at all three sites on April 4, 1971, with a Weston thermometer, and air temperature on April 11, 1971, with max-min thermometers protected in aluminum shields. Soil temperature was measured 5 cm below and air temperature 5 cm above ground level. Tensiometers were installed on May 11, 1971. Thus, at 7- to 10-day intervals, readings of air and soil temperatures and soil moisture were taken at all three sites, flowers marked and recorded, and mature seeds collected with a notation of the date on which the flowers were first observed. Upon returning from the field, seeds were removed from their capsules and stored at room temperature (22 C) in glass vials for four to five weeks.

Precipitation data were provided by records kept at HMF and the U. S. Dept. Comm. publication, "Climatological Data, New Jersey."

Regular germination tests for each seed collection date

Germination tests were carried out in seed germinators in 10 x 10 x 2 cm closed plastic boxes on one piece of blue-black germination blotting paper moistened with 10 ml of distilled water. Additional distilled water was added during the 10-day tests as required. The germinators were set to electronically control photoperiod and temperature. Approximately 100 ft. c. of light were supplied in the germinators by eight 40-watt cool-white fluorescent tubes. Germinators used were a Pfieffer model X-C,D,L, Stults model 48 Senior Duplex, and model G-30 (Controlled Environments, Inc.). Three replications of 50 seeds per collection date were used when possible. For some collection dates, however, there were not enough seeds; for these as many replications as possible were used. Seeds were considered germinated when the radicle had penetrated the seed coat. Germination counts were made at approximately the same hour each day. Percentage germination was calculated for each test for each collection date. Rate of germination according to Timson (1965) was also calculated; that is, the percentage germination is recorded each day and these results are then summed at the end of the 10-day test.

After seeds had been collected from plants which were observed flowering on a particular day and stored dry at room temperature (22 C) for four to five weeks, they were placed in a coldroom in the dark at 4 C in the plastic boxes for one week. After this prechill treatment, seeds were placed in a germinator for the germination test. The germinator was programmed for 8 hours of light at 20 C and 16 hours of dark at 10 C. These temperatures were chosen on the basis of the research of Borriss (1940), Steinbauer et al. (1955), and on prior pilot studies. Initial germination tests with *S. media* were attempted within one week of harvest, resulting in no germination (this confirmed Borriss' conclusion that a period of after-ripening is required). Seeds used for subsequent pilot-study tests were dry-stored at room temperature (22 C) for 1 1/2 months and then dry-stored at 4 C for 3 months. One replication of 20 seeds was used for each test. Results were 100% germination in constant dark at 15 C, 95% in constant dark at 10 C, 90% in 8L:16D photoperiod at 15-25 C, 10% at 20-30 C, 0% at 20-35 C, and 75% in constant light at 20 C. (The lowest temperature of an alternating regime always occurred during the dark period.) Since the highest germination percentage obtained in alternating-temperature regimes was in the 15-25 C, it was thought that lowering these temperatures to 10-20 C would allow even greater germination percentages as suggested by Borriss (1940) and more closely correspond to fall temperatures in the field. At the time the 10-20 C temperature regime was decided upon, Kurth's publication (1967) suggesting 5-12 C had not been seen.

Germination tests at 4 C in constant dark and an 8L:16D photoperiod

After the above experiment, there were enough seeds left from three collection dates to test the ability of *S. media* seeds to germinate at a constant temperature of 4 C in constant dark and in an 8L:16D photoperiod. At the time of these tests, the seeds had been in dry storage for approximately seven months. As many replications as possible of 20 seeds each were made for each of the three collection dates. Half of the replications were placed in constant dark by inserting the germination boxes in two thicknesses of black polyethylene plastic bags. These were placed beside the other plastic boxes on a bench in a 4 C coldroom over which were suspended two 40-watt cool-white fluorescent tubes giving the same ft. c. as in the germinators. Seeds not inside the bags were given the usual 8L:16D photoperiod. The test was conducted for 30 days. Every ten days one replication for each collection date was removed from the bags, germinated seeds counted, and the boxes then left at 4 C in the 8L:16D photoperiod to see if further germination would occur.

Tetrazolium tests of viability

At the end of all germination tests, any seeds which had not germinated (and were not decayed or moldy) were tested for viability with 0.5% 2,3,5 triphenyl tetrazolium chloride. Seeds were cut in half such that one-half the embryo was left in each half, placed in plastic petri dishes on filter paper moistened with distilled water and then covered with two drops of 0.5% tetrazolium. The plates were placed in the dark for eight hours at 22 C and then observed for color change. Initially, several seeds which had just germinated were tested, and the color of these recently germinated seeds was used as the indicator for viability. Thus, only seeds with embryos turning bright red were considered viable.

Results

Field observations

In comparing soil and air temperatures between the three sites, it can be seen that the open field transplant had more harsh conditions (Figure 1). In summer, the soil temperature was higher than either forest edge site, whereas fall soil temperatures were about the same for all three sites. Minimum air temperature in the open field was almost always lower than at the forest edge. Maximum air temperature in the open field exceeded that of the other two sites during the study except December, 1971, and early January, 1972. In summer the open field maximum air temperature exceeded 100 F from early May to mid-September, 1971, while that of the forest edge rarely reached 90 F. The range seen at the open field site was from 0 F on 1/19/72 to 120 F on 7/16/71; for the forest edge transplant site from 5 F on 1/19/72 to 96 F on 4/19/71; and for the other forest edge site from 2 F on 1/19/72 to 90 F on 4/19/71. The greatest diurnal ranges at the forest edge occurred in spring and fall while the open field had considerable diurnal ranges throughout the year.

By mid-May trees at the forest were completely leafed out, shading the forest edge site completely but the forest edge transplant site only partially. Field observations were generally made between 11:00 and 14:00 hrs when it was not raining. At this time the forest edge transplant received some direct sunshine as well as sunflecks while the forest edge site consistently received only sunflecks.

Due to repeated disturbances by ants and moles, tensiometer readings of soil moisture were considered to be highly unreliable. Thus, these data have not been included. However, precipitation data do give a general idea about what one would expect (Figure 1). Slightly less than average precipitation occurred in September, October, and December, 1970, while November, 1970, had 2 1/4 inches above normal (U. S. Dept. Comm.,

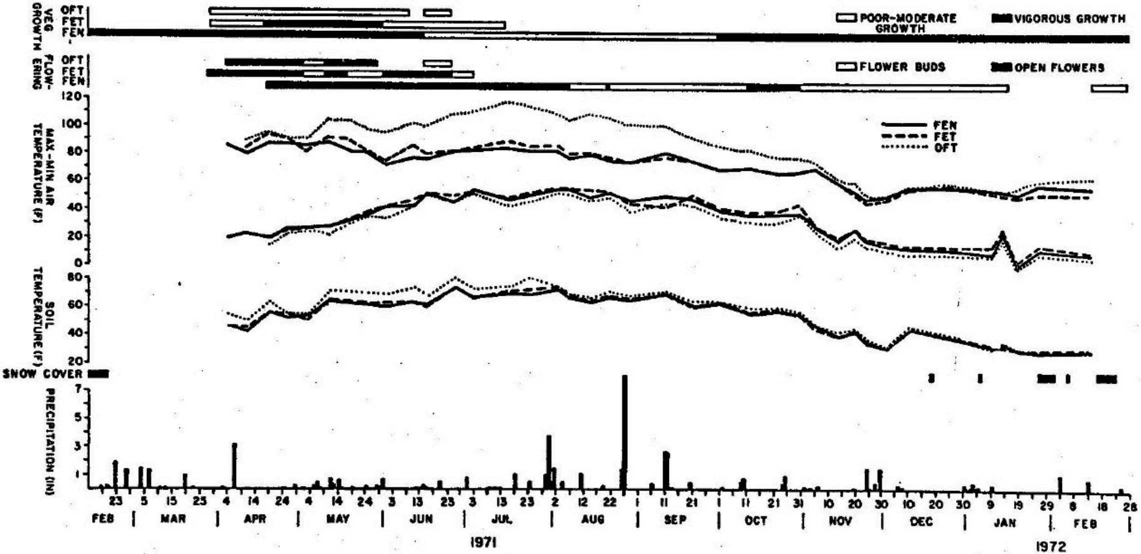

Figure 1. Composite diagram in which precipitation, snow cover, soil temperature, and max-min air temperatures are shown in relation to when vegetative growth and flowering occurred at three sites at HMF. FEN = *S. media* occurring naturally at HMF, FET = transplant made from a Middlebush garden on 3/17/71 to the edge of the forest, and OFT = transplant made from a Middlebush garden on 3/17/71 to the open field.

1970). In 1971, January had below-normal average precipitation and temperatures, and June received 4 inches less than normal rainfall. However, the yearly average for 1971 was 7.98 inches higher than normal (U. S. Dept. Comm., 1971), due mostly to 8.25 inches of rain which occurred on August 28 as a result of Tropical Storm Doria. August thus received 13.36 inches of rain, 8.66 inches above normal.

Stellaria media grew continuously at the forest edge during the study (9/27/70-3/2/72) (Figure 1). By June 16, those plants which had been flowering in April and May were beginning to wither, and "new" plants were appearing. The only period of poor-to-moderate growth occurred in August and September, 1971, when those plants which had flowered and produced seeds in June, July and early August disappeared. Vigorous growth resumed in mid-October 1971, with the appearance of small "new" plants. Neither transplant grew as well as these although the forest edge transplant's growth was somewhat more vigorous than that of old field plants. Some leaves and stems, notably those with partially and fully mature capsules, withered after the transplants were made on 3/17/71, but growth had resumed by 3/29/71 and both transplants appeared green and healthy. Vegetative growth of the forest edge transplant stopped in mid-July, while that of the open field transplant ceased in June. *Stellaria media* did not reappear at the open field site but a few plants were seen at the forest edge transplant site from 8/29/71 to 11/13/71.

Open flowers were observed at the forest edge from early April until late August and again in mid-October, but peak flowering occurred in May. Buds, or closed flowers, were seen at the forest edge from late October until mid-January, in mid-February, and early March, 1972. Flowers and/or buds were seen at the forest edge transplant from April to mid-June and at the open field transplant from April to mid-May (Figure 1).

Peak seed collections occurred in May and June at all sites (Table 1). These numbers must be viewed with caution however. It must be remembered that the transplants already had flowers and were producing seeds at the time of their transplanting. Based on this, and observations in springs 1971 and 1972 that *S. media* growing in cultivated fields or lawns near buildings (that is, in protected areas) flowered profusely in March and April, it is reasonable to suppose that the transplants' peak flowering in their former habitat (Middlebush garden) would have been March and April and thus peak seed production would have occurred in April and May. Therefore, numbers seen in Table 1 for April for the transplants reflect a lag caused by transplanting while the lack of seed collections at the forest edge site in April indicate that plants here did not begin to flower until mid-April.

The numbers in Table 1 do represent trends, but not necessarily total seed production. It was observed that rain and wind play a major role in disseminating *S. media* seeds. Thus, if seeds matured just before a storm, many or most of them were disseminated before they could be collected. An effort was made to collect seeds before such storms, but this was not always possible. For example, 35 flowers were observed and marked at the open field transplant site on 4/4 but only 126 seeds were recovered; on 4/11, 55 flowers were marked but only 105 seeds recovered. All other collection dates at this site gave about the number of seeds expected based on number of flowers marked. Thus, if seeds from flowers marked on 4/4 and 4/11 had all been recovered, this

Table 1. Number of seeds collected per month at the forest edge (FEN), forest edge transplant (FET), and open field transplant (OFT) at HMF. FET and OFT collections made in 33 x 51 cm transplants of solid *S. media* growth while FEN collections made in an approximately 61 x 511 cm area of fairly widely dispersed *S. media* plants.

	FEN	FET	OFT
April		11	74
May	969	114	847
June	5107	1328	311
July	244	68	
August	86		
September	9		
October	78		
November	47		

Table 2. Germination responses of seeds collected at the forest edge site at HMF. Rate of germination after Timson, 1965 ($\Sigma 10$ germ.).

Date flowers marked	Date seeds collected	Total seeds collected	No. seeds tested	No. seeds germ.	% germ.	$\Sigma 10$ germ.	% viab.
4/19	5/25	13	13	13	100.0	900.0	100.0
4/26	5/25	31	31	28	90.3	725.8	90.3
5/3	5/19	45	45	45	100.0	802.2	100.0
	5/25	476	150	149	99.3	780.5	99.3
	6/1	554	150	136	90.7	549.4	99.3
	6/11	79	79	72	91.1	726.7	91.1
	6/16	17	17	15	88.2	670.4	94.1
	6/26	26	26	26	100.0	734.7	100.0
5/11	5/25	404	150	149	99.3	782.5	99.3
	6/1	303	150	141	94.0	670.5	96.7
	6/11	44	44	44	100.0	870.5	100.0
5/19	6/1	941	150	149	99.3	517.9	100.0
	6/11	1833	150	144	96.0	870.7	96.7
	6/16	872	150	149	99.3	735.1	99.3
	6/26	32	32	31	96.9	968.7	96.9
6/1	6/26	265	150	148	98.7	984.9	98.7
	7/3	39	39	31	79.5	710.3	79.5
6/11	6/26	141	141	135	95.7	851.5	95.7
	7/3	111	111	103	92.8	771.2	92.8
6/26	7/16	59	59	55	93.2	798.1	93.2
7/3	7/16	7	7	7	100.0	785.7	100.0
	7/24	28	28	26	92.9	668.0	92.9
7/24	8/7	73	73	70	95.9	708.3	95.9
	8/22	9	9	9	100.0	766.7	100.0
	8/29	4	4	4	100.0	850.0	100.0
8/22	9/12	9	9	0	0	0	100.0
10/13	10/31	78	78	45	52.6	255.2	100.0
10/23	11/6	47	47	0	0	0	97.9

would have increased total April and May seed-collection figures, but indicated the same trend seen in Table 1. It is interesting to note June collections were extremely high (except for the open field transplant which had already begun to wither), remembering June had only 0.88 inches of rain.

Table 3. Germination responses of seeds collected at the forest edge transplant site at HMF. Rate of germination after Timson, 1965 (Σ10 germ.).

Date flowers marked	Date seeds collected	Total seeds collected	No. seeds tested	No. seeds germ.	% germ.	Σ10 germ.	% viab.
4/4	4/26	7	7[a]	0	0	0	85.7
	5/3	8	0				
4/11	4/26	4	4[a]	0	0	0	50.0
4/19	5/3	13	0				
	5/19	18	18	17	94.4	566.5	100.0
	5/25	25	25	25	100.0	764.0	100.0
4/26	5/19	45	45	45	100.0	668.9	100.0
	6/1	9	9	8	88.9	455.6	100.0
5/11	5/19	5	5	5	100.0	540.0	100.0
	6/1	56	56	29	51.8	237.5	100.0
	6/16	6	6	6	100.0	650.0	100.0
6/1	6/11	35	35	29	82.9	723.2	85.7
	6/16	8	8	5	62.5	512.5	62.5
	6/26	12	12	9	75.0	750.0	75.0
6/11	6/26	26	26	25	96.2	962.5	96.2
	7/3	9	9	0	0	0	0
6/16	6/26	26	26	19	73.1	950.0	100.0
Forest edge transplant misc.[b]	6/1	601	150	128	85.3	466.7	100.0
	6/11	242	150	105	70.0	534.6	70.0
	6/16	157	150	145	96.7	586.7	96.7
	6/26	150	150	117	78.0	778.6	78.0
	7/3	59	59	48	81.4	668.0	81.4

[a]No prechill treatment was given to these seeds.

[b]Seeds collected on the days indicated whose flowers had not been marked.

Regular germination tests

Germination percentages, Σ10 germination (after Timson, 1965), and viability percentages are given in Tables 2, 3 and 4. It can be seen that there was more than one seed-collection date for most dates that flowers were marked, indicating open flowers which were marked on a particular day were not all the same age, and possibly that not all seeds ripened at the same rate.

In Table 3 there is a separate category called "forest edge transplant miscellaneous." These are seeds from flowers which had not been marked. On June 1, 1971, several fully and partially mature capsules were observed. The flowers must have opened on days between observations, been overlooked, or possibly did not open at all. Collections were made of these "miscellaneous" seeds from 6/1 to 7/3.

In germination tests a greater number of seeds of forest edge plants were viable and germinated than transplants (Table 5). Although most tests of old field transplant seeds resulted in less than 90% germination, only 2 resulted in less than 90% viability, whereas 6 out of 20 tests of seeds of forest edge transplants resulted in less than 90% viability. This trend is also reflected in mean percentages for germination and viability.

Differences in viability and germination percentages among sites are due to moldy and/or decayed seeds, immature seeds and/or unsuitable germination conditions such as temperature, photoperiod and/or gas exchange, or possibly unsuitable storage and ripening conditions. Table 6 indicates how many seeds were moldy or decayed of the total seeds tested.

It is interesting that for all miscellaneous seed collections of forest edge transplants except 6/1, all seeds which did not germinate were either moldy or decayed. This was not the case with most seed collections from this site however; this can be seen by the higher percentage viability in relation to percentage germination in most tests.

Fall collection dates of seeds from forest edge plants (FEN, Table 2) resulted in the lowest germination percentages of the year at this site in the 10-20 C regime. However, in germination tests of seeds collected on the same dates at the Middlebush garden, percentages were higher (ranging from 7.3 to 98.0) than those in spring (0.0 to 37.5). Viability of seeds for both sites remained above 90%.

Germination tests at 4 C in constant dark and an 8L:16D photoperiod

Germination percentages were generally low in these tests, never approaching 90% (Table 7). Also percentage germination was lower for all dates for seeds tested in constant darkness than for those in the 8L:16D photoperiod. Three of the six tests resulted in more than 50% germination: 6/1 seeds in the 8L:16D photoperiod and both constant-dark and 8L:16D-photoperiod 6/11

Table 4. Germination responses of seeds collected at the open field transplant site at HMF. Rate of germination after Timson, 1965 (Σ10 germ.).

Date flowers marked	Date seeds collected	Total seeds collected	No. seeds tested	No. seeds germ.	% germ.	Σ10 germ.	% viab.
4/4	4/26	45	45[a]	8	17.8	97.9	91.1
	5/3	25	0				
	5/19	56	56	44	78.6	482.3	94.6
4/11	4/26	29	29[a]	0	0	0	75.9
	5/3	11	0				
	5/11	65	65	21	32.3	218.5	92.3
4/19	5/3	37	0				
	5/11	109	109	38	34.8	219.1	93.0
	5/19	118	118	71	60.2	248.4	96.6
	5/25	104	104	96	92.3	497.1	96.2
	6/1	50	50	5	10.0	54.0	88.0
4/26	5/11	39	39	21	53.8	348.6	94.9
	5/19	60	60	33	55.0	325.0	100.0
	5/25	33	33	33	100.0	751.5	100.0
	6/1	62	62	18	12.9	125.8	100.0
5/11	5/19	27	27	21	77.8	440.9	100.0
	5/25	163	150	132	88.0	569.2	94.7
	6/1	108	108	15	25.0	63.9	95.4
5/19	6/1	91	91	47	51.6	113.3	98.9

[a]No prechill treatment was given to these seeds.

seeds. No trend can be seen in terms of germination percentages increasing or decreasing with age of seeds.

Seeds collected from forest edge plants on 6/11 gave better percentage viability than the others, although it is interesting that the only decayed seeds in all groups were in these 6/11 seeds (7 of 180). Thus, all seeds not germinating in the 6/1 and 6/16 groups were able to be tested with tetrazolium since none were moldy or decayed. None of these seeds were viable according to the tetrazolium tests, and none had any outward signs of being immature or damaged.

For those replications in constant darkness for each date which were removed after 10 and 20 days and left in the 8L:16D photoperiod, 6/11 seeds had higher germination percentages than 6/1 and 6/16 seeds, as did the other 8L:16D-photoperiod replications. However, the germination percentages for 6/1 and 6/16 seeds were reversed. Further germination occurred in only 2 of the 6 replications removed from the dark, total percentages being 20 (6/1) and 60 (6/11). Those having further germination had been in the dark for 10 days. None of the seeds at 4 C in constant dark for 20 days germinated further after exposure to the 8L:16D photoperiod.

Table 5. Overall results of germination and viability tests. (FEN = forest edge, FET = forest edge transplant, and OFT = open field transplant)

018			Tests resulting in less than		Tests resulting in less than			
	No. of tests	No. of seeds tested	90% viab.	50% viab.	90% germ.	50% germ.	Mean % germ.	Mean % viab.
FEN	28	2092	1	0	5	2	87.3[a]	96.8
FET	15	291	6	1	9[b]	3[b]	68.3	83.7
FET misc.	5	659	3	0	4	0	71.8	84.1
OFT	16	1146	2	0	14[b]	7[b]	49.4	94.5

[a]When the August and September collections are deleted from this figure, percentage germination = 95.7.

[b]Two tests of both FET and OFT seeds were made without a prechill treatment, all 4 tests resulting in less than 50% germination.

Table 6. Seeds which were decayed or moldy at end of regular germination tests. (FEN = forest edge, FET = forest edge transplant, and OFT = open field transplant)

	Total seeds tested	No. of moldy seeds at end of test	% of total	No. of decayed seeds at end of test	% of total
FEN	2092	26	1.2	20	1.0
FET	291	69	23.7	6	2.1
FET misc.	659	12	1.8	22	3.3
OFT	1146	8	0.7	23	2.0

Table 7. Germination responses of approximately 7-month old seeds tested at 4 C in constant dark and an 8L:16D photoperiod.

Seed coll. date[b]	Total no. seeds for each test 8-16	D[c]	No. of seeds germ. 8-16	D	% germ. 8-16	D	Σ10 germ.[a] 8-16	Σ20 germ.[a] 8-16	Σ30 germ.[a] 8-16	% viab.[a] 8-16	D
6/1	160	120	102	11	63.8	9.2	0	304.9	942.2	94.4	89.1
6/11	180	140	134	90	74.4	64.3	0	219.4	1092.1	93.3	91.4
6/16	120	80	52	9	43.3	11.3	0	160.0	636.3	93.3	82.5

[a]Not applicable to seeds tested in constant darkness.

[b]All seeds are from flowers of forest edge plants marked on 5/19.

[c]Figures for constant dark (D) based on 40 seeds less than 8-16 since for each date, one replication was removed after 10 and 20 days to determine progress of germination and then placed in the 8L:16D photoperiod. These 6 replications were analyzed separately.

Discussion and conclusions

Field observations in this study indicate flowering of *S. media* is not controlled solely by photoperiod. Although *S. media* did not flower continuously during this study at HMF, it did flower in more than one season. It flowered at HMF about two months after snow melt at the forest edge, although in the Middlebush garden from which the transplants were obtained, *S. media* flowered within one month of snow melt. Both transplants had open flowers as well as fully and partially mature capsules at time of transplanting (3/17/71) which was a month after snow melt. The forest edge transplant stopped flowering in June and the open field transplant stopped in May. Forest edge plant flowering continued through most of the summer and into fall. Although only "buds" were seen thereafter, there is some indication that these "buds" may actually have been closed flowers. It was often observed in my own garden that *S. media* flowers, which were in full flower in sunshine, closed when the sky became cloudy and when temperatures lowered at dusk.

It is interesting to compare time of flowering and seed production of *S. media* growing in uncultivated soil at HMF with that in the Middlebush garden from which transplants were obtained. At the Middlebush garden, open flowers were observed from March to May, 1971, and from September, 1971, through March, 1972 (the end of this study). This garden, which is plowed in fall, is located fairly close to buildings, and is protected on all sides by trees. Soil and maximum-minimum air temperatures were also taken at the Middlebush garden throughout the study. Soil temperatures there closely followed those of the open field site (highest = 110 F, while the open field site = 120 F) until October when the garden's maximum air temperatures were about the same as those of the open field but minimum air temperatures were consistently higher than at all three HMF sites.

Buds and/or flowers seen at the forest edge from October, 1971, through February, 1972, had not produced seeds by the end of this study (3/2/72). However, on January 14 and 19, 1972, white, normal-appearing immature seeds were found in capsules sampled from the Middlebush garden. This garden had been plowed in early November; by 12/2 buds had appeared and on 1/10 open flowers were observed on small *S. media* plants. However, no other immature or mature seeds were seen by March, 1972, at Middlebush. Thus, in summary, viable seeds were produced from plants which flowered in spring, summer and fall at the forest edge, but no open flowers or seeds were observed in winter. At the Middlebush garden, viable seeds were produced from plants which flowered in spring and fall, but no flowers or seeds were observed from June through August. Flowers were observed throughout the winter at the garden and immature seeds were observed in January, but no mature seeds were found.

Where and when *S. media* occurred appeared to be affected by competition with other plants. For example, it was observed that *S. media* growing naturally at the forest was found in conjunction with *Rubus occidentalis* L. (black raspberry) bushes which grow at the forest's north edge. In spring and early summer, 1971, *S. media* was growing over a large area north of the bushes; that is, next to the bushes, in the east-west path between the *R. occidentalis* bushes and old field, and extending slightly into the adjacent old field. By July *Pilea pumila* (L.) Gray covered much of the area around the path and the number of *S. media* plants was reduced. Then as *Aster simplex* Willd. reached full growth (about 3' tall) in the old field near the path, all vegetative growth under it ceased and *S. media* was observed only near *R. occidentalis*, where there was no *A. simplex*.

Also, at the Middlebush garden, a small area was set aside to study *S. media* while the rest of the garden was plowed in spring and fall. Plowing temporarily removed *S. media* and *Glecoma hederacea* L. (ground ivy), while in the area set aside, *G. hederacea* rapidly outgrew *S. media*, and by early summer no *S. media* remained or was ever observed again during the study in that area. In the plowed area, *S. media* returned. Thus plowing appeared to help *S. media* seedling establishment and growth by eliminating competition from other plants.

Another effect of plowing may be to increase germination of buried seeds (Koch, 1963). In extensive studies of *S. media* and other plants, Wesson and Wareing (1967, 1969a and b) found freshly harvested seeds of *S. media* were indifferent to light, but prolonged exposure to cold treatment and burial of seeds after being shed from the parent plant induced light sensitivity. They hypothesized that this failure to germinate might have been due to the presence in the soil of an inhibitor which was a product of the seed's metabolism. Seeds buried in the soil which had imbibed water were kept from germinating by this inhibitor. Thus a disturbance of the soil (plowing) stimulated germination of previously buried seeds, possibly by allowing more oxygen to reach soil surrounding them or by a breakdown of the inhibitor upon exposure to light. It is possible that such an inhibition occurred in *S. media* seeds in this study kept 10, 20 and 30 days at 4 C in constant dark for which consistently low germination percentages were observed.

Müllverstedt (1963) found *S. media* seeds required 6-8% oxygen to begin germinating and 12-16% to reach 15% germination, and lack of oxygen induced secondary dormancy. However, gas tensions were not measured in these experiments inside germination dishes. Had this been done, one might have found variability in germination percentages were partially a result of varying amounts of oxygen in the dishes.

Although germination percentages did not reach 100% in all tests performed in this study and others, some seeds germinated in all regimes used, exhibiting what Koller (1964) called "physiological heterogeneity." Steinbauer et al. (1955) reported that a one-week prechill plus a 20-30 C (8L:16D) regime was optimal for germination of 10-month old *S. media* seeds, obtaining 94% germination in two replications of 100 seeds. In the present study, using a 10-20 C (8L:16D) regime plus one-week prechill at 4 C, 4 to 5 week old forest edge seeds had a mean germination percentage of 87.3 (1,958 seeds) (removing the last three tests for seeds collected in August and September [134 seeds], the mean percentage germination for forest edge seeds was 95.7). Six-month old seeds in the present study tested as above had a mean percentage germination of 97.5 and mean percentage viability of 97.5.

Seeds from transplants at both sites tested within 4 to 5 weeks of collection required a prechill treatment as can be seen from tables 3 and 4 where those tests conducted without a prechill treatment all resulted in less than 18% germination. However, 6-month old seeds did not need the prechill treatment in order to germinate (Semprevivo, 1972). This corroborates Borriss' report (1940) that after ripening is required for germination in *S. media* seeds. After ripening would have adaptive value for *S. media* seeds, preventing most seeds from germinating in the hot, dry summer when seedling survival would be jeopardized and allowing germination in the cooler, more moist fall and spring.

Even under conditions of constant darkness at 4 C some seeds did germinate, and after their removal from complete darkness after 10 days into an 8L:16D photoperiod, again some seeds germinated. Koller (1964) stated that physiological heterogeneity is typical of wild plants since they are faced with variable environmental complexes. Thus, plants which exhibit incomplete germination within one environmental complex will have some ungerminated seeds available at all times allowing for survival of the species should one set of seeds fail. Physiological heterogeneity has been reported by Popay and Roberts (1970) for *C. bursa-pastoris* and *Senecio vulgaris* L. which were observed to undergo flushes of germination throughout the year. Popay and Roberts were able to correlate at least some of these flushes with specific environmental factors such as soil and air temperatures, moisture, and soil nitrate levels.

It can be seen that specific correlations between flowering of *S. media* at HMF and environmental parameters measured in this study can only be hypothesized. For example, it does appear that continuously high air and soil temperatures from May to August may have caused the death of plants transplanted to the open field. Maximum air temperature exceeded 100 F from May to August and afternoon soil temperature was between 70 and 80 F most of that time. Low soil moisture as well as lack of protection from solar radiation, rainfall and winds undoubtedly also played a role. In any case, such plants did produce seeds in April and May, many of which were not collected and were therefore available for germination in the field. Why did these seeds not germinate in the cooler, more moist fall while seeds of plants at the forest edge apparently did? Remembering that observations made on transplants were done in the same season that they were transplanted, three hypotheses could be set forth:

(1) Perhaps seeds disseminated from transplants in the open field were killed by lack of moisture or high temperatures, eaten by predators, or disseminated elsewhere.

(2) If seeds produced did not germinate until the next spring, "new" plants seen at the forest edge must have been from shoots off stems of parent plants whose above-ground vegetative growth had withered. There is some evidence for this idea. For example, a voucher herbarium specimen collected from the forest edge contained a minute green shoot starting from the stem of the parent plant. Also, after the Middlebush garden had been plowed in November, *S. media* plants, which had been chopped up and vegetative parts left above ground, continued to grow; that is, roots developed from shoot pieces and soon thereafter buds and open flowers appeared on these "new" plants. Perhaps then, *S. media*, which is generally classified as an annual, can also function as a perennial as Fernald said (1950). Maybe *S. media* plants at the open field site were dead above and below ground by June and so could not generate new shoots.

(3) Perhaps seeds produced in April and May became relatively dormant as a result of the high temperatures. This might help to explain the generally low germination percentages in tests of seeds from the open field site in the laboratory. For example, Stearns (1960) reported that the temperature at which *Plantago aristata* Michx. matured affected subsequent growth of seedlings. Thus, seeds matured at 80 F produced larger and more vigorous seedlings than those matured at 60 F; and 80 F seeds germinated at a faster rate than 70 and 60 F seeds. At HMF, even in spring when there were cooler temperatures and adequate moisture, it was observed that *S. media* plants growing in the shade of trees and *R. occidentalis* were taller with larger leaves and produced larger seeds than plants growing in full sunlight. Thus environmental conditions during maturation of plants *and* seed development may affect subsequent seed production, germination and seedling growth.

Further research must be conducted to characterize growth of *S. media* at HMF. Soil and max-min air temperatures and soil moisture should be measured over a longer period of time. Also, since temperatures at and just below ground level vary more than at greater depths and germination and root growth occur primarily in the upper 5 cm, perhaps continuous maximum and minimum surface soil temperature measurements would be more ecologically significant. It would be interesting in addition to measure the amount of solar radiation actually reaching *S. media* plants as well as the direction and duration of wind 5 cm above ground level. All observations and measurements should be made constantly or at least every other day rather than weekly to better monitor rapid environmental changes. This would also help determine whether flowers marked on a particular day were of the same age and produced seeds that ripened at the same time.

It is impossible to make conclusive correlations between flowering and environmental parameters observed. However, it appears the very basis of this plant's success as a weed is its ability to adapt physiologically and morphologically to changing environmental conditions.

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