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The effect of life history and weather on onset of flowering and length of flowering period of agricultural weeds

Amanda Karpaty Wickbom

Examiner, Victor Johansson
Tutor, Per Milberg

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1 Abstract **1**
2 Introduction **2**
3 Methods **2**
3.1 Species classification 3
3.2 Data collection 3
3.2.1 Artportalen 3
3.2.2 SMHI 5
3.3 Statistical tests 5
4 Results **6**
4.1 First flowering and flowering period 6
4.2 Meta-analyses flowering data 9
4.3 Temperature data 10
4.4 Dependence of weather on first flowering and flowering period 11
5 Discussion **11**
5.1 Life history classification 11
5.2 Weather 11
6 Conclusion **12**
7 Societal and ethical considerations **12**
8 Acknowledgements **12**
9 References **12**

1 Abstract

With a warming climate and the usage of monocultures in food production it is possible we may face more issues concerning food insecurity in the future as pollinators struggle to find food in agricultural landscapes. Therefore, it is of value to know whether common agricultural weeds are important sources of food for pollinators. Pollinators are vital in the growing of food-crops and may depend on different agricultural weeds during their flying season. This study is based on observational citizen science data on the flowering of 24 agricultural weeds classified as useful to pollinators in the years 2008-2022. Data on first flowering and length of flowering was compared between life history classifications based on life span and time of germination. The results showed that while there is variation both between groups and within groups among the selected species, summer annuals are among the last to start flowering. Species classed as "summer and winter annuals", i.e that can germinate either in spring or autumn, had a longer flowering period than the other classes. Winter annuals were first to flower while the perennials and "summer and winter annuals" differed more among each other. Weather dependency was also addressed by comparison over years. Overall, the selected species were not significantly affected by mean winter temperature, mean summer temperature or mean summer precipitation.
Keywords: global warming, agricultural weeds, first flowering, flowering phenology.

2 Introduction

Climate change like raised temperatures, variations in precipitation and extreme weather events can lead to a change in the phenology in different groups of organisms (IPCC, 2022; Inouye, 2022). Phenology is the study of season-based events in nature such as when flowers bloom, when migratory birds move or the timing of mating events in many species (Lechowicz, 2001). Many species are dependent on each other and changes in the phenology in one species may affect many others (Srikanth & Schmid (2011), Morellato et al. (2016)), and it is therefore important to study the relationship between phenology and climate change (Renner & Zohner, 2018).

Plants constitute important food sources for many species, and changes in plant phenology may lead to a mismatch in animal activity and available food resources (e.g. McKinney et al., 2012). It is for example important that reproductive events happen at a favourable timing in order for the reproduction to be successful and for there to be enough food available to raise offspring successfully (Moe et al., 2009). This may be birds that feed on fruits or seeds of different plants, grazing animals or pollinators that depend on nectar and/or pollen for sustenance. Several studies have already shown changes in plant phenology. For example, in the Rocky Mountains (Colorado, USA) a study showed that changes in the timing of snow-melting affected the frost damage, phenology and floral abundance of montane wildflowers because as the first melting of snow occurs earlier in the spring, the buds of the wildflowers are exposed to a higher risk of frost-damage (Inouye, 2008). Amano et al. (2010) and Crimmins et al. (2013) investigated phenology changes in spring flowers in Great Britain and patterns in flowering onset depending on temperature changes and water gradients respectively and found that as the winter temperatures got warmer, onset of flowering happened earlier and that both onset of flowering in the spring as well as onset and duration of flowering in the summer was dependent on timing and amount of precipitation. Species dependent on plants also experience changes in phenology, for example Bonoan et al. (2021) showed that the population of the butterfly *Icaricia icarioides fenderi* consistently peaked earlier for each year as the mean temperatures continued to rise.

The flowering phenology of weeds have bearing on their usefulness for pollinators in the agricultural landscape which in turn is vital for food production for humans as well as our cattle and pets. The human population is heavily dependent on the fruits of flowering plants for food which makes plant phenology an important area of research (Srikanth & Schmid, 2011). Nectar production is among the lowest in arable land among terrestrial habitats (Baude et al. 2016) so the presence of agricultural weeds has great importance to pollinators as a food source. If the phenology of these agricultural weeds were to change and the phenology of the pollinators would not follow fast enough it would lead to a mismatch which would limit the food-supply for the pollinators during their flight period.

There are different types of agricultural weeds with different traits, they vary in time of sprouting, if they live for just 1, 2 or multiple years as well as how they reproduce (mainly through seeds or vegetative reproduction). However, we know little of their flowering times and if they vary depending on changes in climate. Summer annuals and winter annuals are plants that only live for one year before setting seed and then dying (Ogräsrådgivaren, SLU). Summer annuals germinate in the spring and flower in late summer while winter annuals germinate in the autumn and flower in the late-spring or summer. Perennials are plants that live for several years and flower multiple times during their lifecycle, often every year (Ogräsrådgivaren, SLU). In this study, a fourth classification of “summer and winter annuals”, germination generalists, is also presented which consists of species that may germinate either in the autumn or in the spring. Potential differences in first flowering, length of flowering and frequency of flowering individuals are important to evaluate how important weeds in crops are for pollinators and to identify which agricultural weeds are most important to sustain a pollinator assemblage over the year.

Some plants such as most food crops and fruit trees are well studied and their phenology known while others are not and collection of more data would be needed. For these types of studies, a lot of data over long periods of time are needed but such data is difficult and expensive to collect. In these cases, open-source databases with citizen science data such as Artportalen may be used. While there are studies such as Håkansson (1983) that have investigated Swedish annual weeds, the dependence of their sprouting on different temperature regimes and tilling at different times of the year. Rydberg & Milberg (2000) and Lundkvist & Verwijst (2011) that studied the presence of different agricultural weeds in Swedish organic farming depending on a multitude of variables such as crop, preceding crop, animal husbandry, plowing and harrowing, among others. Various studies on weed control and effect of herbicides (Håkansson, 2003; Boström & Fogelfors, 2002) and Milberg & Westerberg (MS) who studied the increase of pollinator-friendly weeds in arable land by Abstaining weed Control in a Single Year (ACSY). There seems to be a gap in the knowledge regarding the composite flowering time of common Swedish agricultural weeds and whether first flowering or length of flowering period vary depending on life history classification and/or weather.

The aim of this thesis was to investigate two research questions. The first research question was whether onset of flowering and/or length of flowering period of agricultural weeds was dependent on life history classification. My hypothesis was that the selected perennials would flower earlier in the year and for a longer time period compared to summer or winter annuals as perennials already have an established root system and stored nutrients while the annuals must grow from seed, develop a root system and collect energy before they may flower (Albani & Coupland, 2010). My second research question was whether first flowering or length of flowering period for agricultural weeds are dependent on summer temperature, winter temperature and/or precipitation during the growth period. Studies such as that of Amano et al. (2010) and Fox & Jönsson (2019) have indicated that first flowering in some plant species may be influenced by winter temperature. After summers with extreme temperatures and drought such as in 2018, I am also interested in how summer temperature and access to water may affect the first flowering and flowering period. To shed some light on these questions I selected 24 common agricultural weeds which may be important food-sources for pollinators in arable land.

3 Methods

To investigate if the first flowering and flowering period vary depending on life history and weather, citizen science data from Artportalen.se as well as temperature and precipitation data from SMHI were used. The data were collected for the period 2008 to 2022 in Götaland which is located on the approximate latitudes 55.40 to 59.20 and longitudes 11.30 to 18.50.

3.1 Species selection and classification

Twenty-four weed species were selected for the current study based on three criteria (Table 1). First, the species should score high on a recent classification of Swedish plant species (Tyler et al. 2021), this classification is a pollinator index that summarizes factors important for pollinators such as pollen and nectar production. To classify for this study they must have an index of 4-6. Second, the species should be widespread and relatively common on arable fields in southern Sweden (Milberg & Westerberg, MS), and third, both the species and its flowering state must be easily identifiable as observations are made by experts and the general public alike.

Classification of species into life history groups was based on Fogelfors (2006), Fogelfors (2022) and OECD (2006).

3.2 Data collection

3.2.1 Artportalen

Flowering data comes from Artportalen.se, a website where citizens, amateurs and experts alike, can record observations of Swedish plants, animals and fungi. Artportalen was developed by and is run by SLU Artdatabanken, Swedish University of agricultural sciences and is mainly funded by the Swedish Environmental Protection Agency. All of the data are available to the public (SLU Artdatabanken, 2023).
Data from artportalen.se consists of location, life stage and species name of each observation among other things. Data extraction from artportalen.se was done by selecting flowering observations of each species for the full years 2008 to 2022 in Götaland. The species that were investigated in this study are important agricultural weeds that have a great importance for pollinators (Tyler et al. 2021). The requirement for chosen species, apart from the criteria listed in 3.1, is that they have at least 9 observations per year for at least 11 out of the 15 years that were studied.

Table 1: selected species based on criteria, their respective life history classifications, total number of observations, number of observational years and pollinator indexes. Sorted by life history classification.

Life history classification	**Family**	**Species**	**Total number of observations**	**Number of observational years**	**Pollinator index**
Summer annual	*Asteraceae*	*Sonchus oleraceus*	515	15	4
Summer annual	*Brassicaceae*	*Erysimum cheiranthoides*	331	11	5
Summer annual	*Brassicaceae*	*Sinapis arvensis*	485	15	4
Summer annual	*Lamiaceae*	*Galeopsis bifida*	430	14	5

Summer annual	*Lamiaceae*	*Galeopsis speciosa*	461	13	5
Summer annual	*Lamiaceae*	*Galeopsis tetrahit*	693	15	5
Summer annual	*Polygonaceae*	*Fallopia convolvulus*	202	12	5
"Summer and winter annual"	*Asteraceae*	*Centaurea cyanus*	1037	15	5
"Summer and winter annual"	*Asteraceae*	*Matricaria chamomilla*	573	15	4
"Summer and winter annual"	*Asteraceae*	*Tripleurosper-mum inodorum*	1327	15	4
"Summer and winter annual"	*Boraginaceae*	*Anchusa arvensis*	745	15	5
"Summer and winter annual"	*Lamiaceae*	*Lamium amplexicaule*	389	15	4
"Summer and winter annual"	*Lamiaceae*	*Lamium hybridum*	445	15	4
"Summer and winter annual"	*Lamiaceae*	*Lamium purpureum*	1445	15	4
Crop	*Brassicaceae*	*Brassica napus*	199	13	5
Winter annual	*Asteraceae*	*Anthemis arvensis*	684	15	5

Winter annual	*Boraginaceae*	*Buglossoides arvensis*	514	15	4
Winter annual	*Boraginaceae*	*Myosotis arvensis*	941	15	4
Perennial	*Asteraceae*	*Cirsium arvense*	897	15	5
Perennial	*Asteraceae*	*Sonchus arvensis*	850	15	4
Perennial	*Brassicaceae*	*Barbarea vulgaris*	892	15	4
Perennial	*Convolvulaceae*	*Convolvulus arvensis*	666	15	4
Perennial	*Fabaceae*	*Trifolium pratense*	1590	15	6
Perennial	*Ranunculaceae*	*Ranunculus repens*	582	15	4

3.2.2 SMHI

Data collection from SMHI (Swedish Meteorological and Hydrological Institute) was done by summarizing temperature data from 35 weather stations in Götaland for each month from October 2007 to September 2022, as well as monthly precipitation for the months April to September from 2008 to 2022 from the same weather stations. Precipitation data was limited to what was judged as most relevant for flowering plants (April to September) to assess whether water access during the growth period affected first flowering or length of flowering. The temperature data was divided into the periods April to September for "summer" and October of one year to Mars the following year for "winter" to see whether winter or summer temperature, or both, had an effect on first flowering or flowering period.

3.3 Statistical tests

RStudio (R Core Team 2022) was used to process and analyze the data collected from Artportalen.se and SMHI. For the plant data, the first and last 5% of the observations were truncated which left 90% of observations for analysis. This was done as both onset of flowering and length of flowering period are variables sensitive to number of observations. The numbers of observations were then summarized over the 15-year period and visualized in Figures 1 and 2. For the weather data, monthly mean temperatures (℃) or precipitation (mm) were summarized and used in the analysis.

First flowering (mean first observation day of a flowering individual) was analyzed in relation to mean winter temperature using a linear model with a normal distribution. Flowering period (mean number of days between first and last observation of a flowering individual) was analyzed in relation to both mean summer temperature and mean summer precipitation using the same model as above.

The regression coefficients, and partial regression coefficients, were then subjected to metaanalyses using the software Comprehensive Meta Analysis 2.2.064 (www.meta-analysis.com). A weighted mean for the different life histories were calculated using species as "random effects".

4 Results

4.1 Weather data

Mean winter temperatures spanned between 0-4℃ while mean summer temperatures varied between 12-16℃. The summer of 2018 is clearly warmer than the other years while the winter of 2011 was the coldest.

The mean precipitation April-Sept varied from ~37 mm in 2018 to ~75 mm in 2011.

4.2 First flowering and flowering period

Date of first flowering and the length of flowering period varied greatly among species (Figure 1 and 2). When grouping species according to life histories, there were also some clear differences (Figure 3a, b). Summer annuals, winter annuals and perennials appear to have shorter flowering periods but have great variations between species within the groups while the "summer and winter annuals" seem to have a greater spread even though most species have a longer flowering season generally (Figure 1).

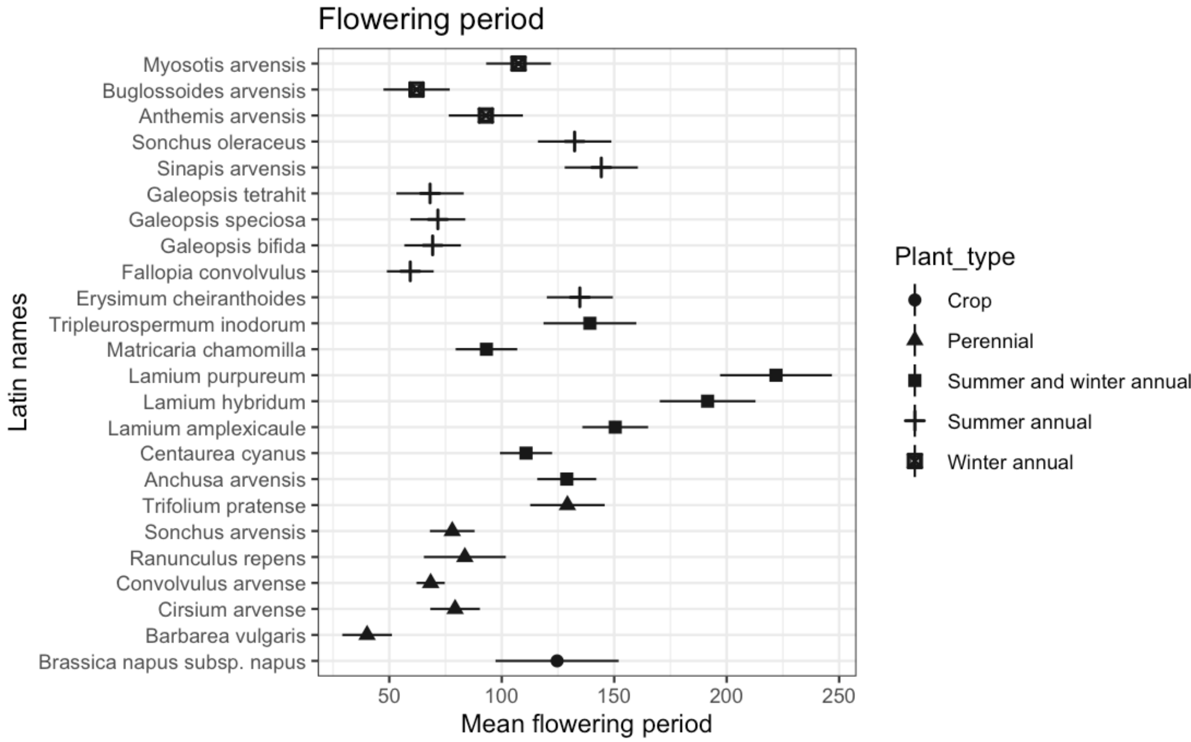

Figure 1: Mean flowering period for 24 weed species calculated over the years 2008 to 2022. The dots indicate the mean while the lines show the 95% confidence interval.

When it comes to the start of flowering, winter annuals, “summer and winter annuals” as well as some perennials are first to flower among the selected species (Figure 2). However, there is great spread both between and within species. For example, the perennial *Barbarea vulgaris* flowered relatively early compared to the other perennials (day 125 compared to day 180) and the *Lamium* species varied a lot within species with first flowerings between day 112 and day 182 (Figure 2).

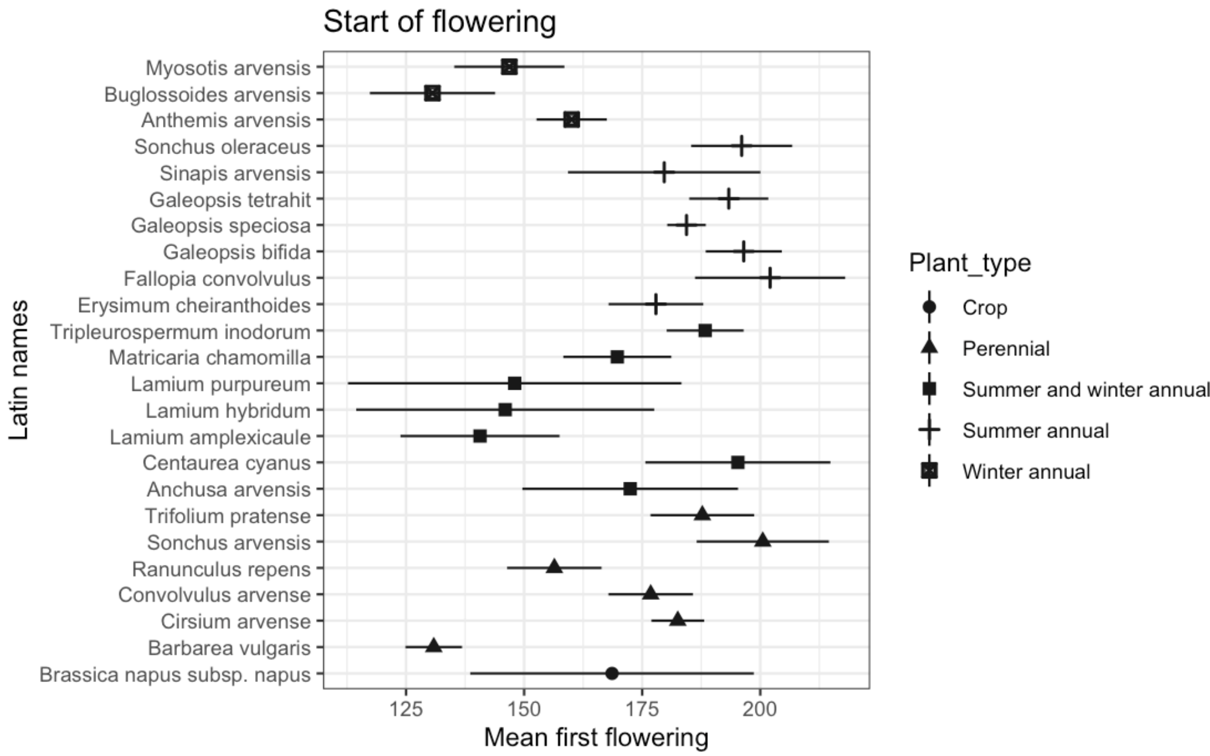

Figure 2: Mean first flowering for 24 weed species over the years 2008 to 2022. The dots indicate the mean while the lines show the 95% confidence interval.

4.3 Meta-analyses of flowering data

The results from the meta analyses showed that there are some differences between the life history classifications when it comes to date of first flowering and length of the flowering period (Figure 3a, b). The “summer and winter annuals” had a significantly longer flowering season (~112 to ~187 days) compared to the other life history classifications (~60 to ~125 days) (Figure 3a). Perennials seemed to have the shortest flowering season (80 days) while the summer annuals and winter annuals had slightly longer flowering seasons (87 days and 100 days respectively).

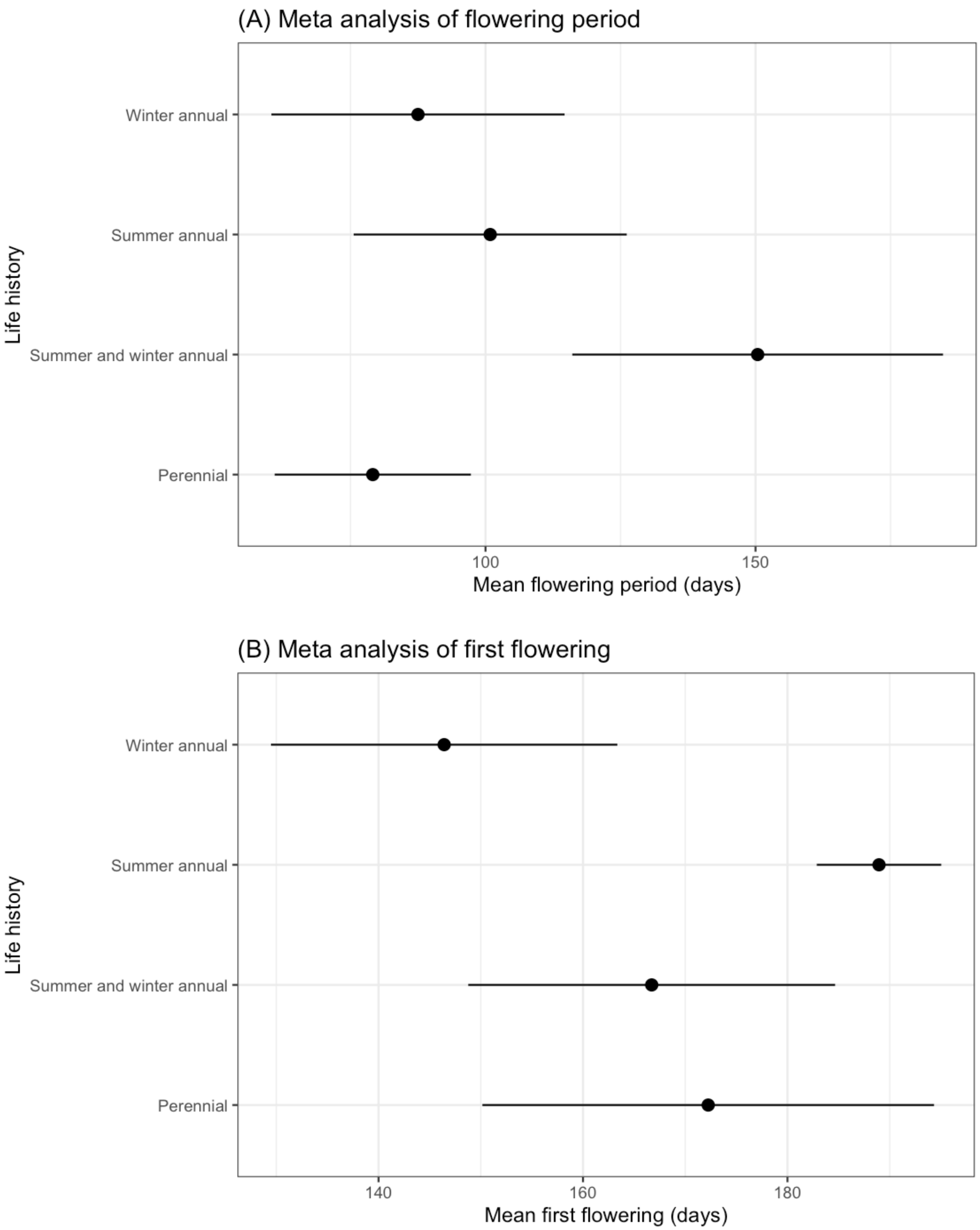

Figure 3. Visualization of the result from above-mentioned meta-analysis of a) flowering period and b) first flowering in relation to life-history. The dots represent the means and lines 95% CI.

Figure 3a, b. Figure 3a: Visualization of the result from above-mentioned meta-analysis of flowering period and its dependency on phenology; effect size with 95% CI. The dots represent the means. Figure 3b: Visualization of the result from above-mentioned meta-analysis of the first flowering and its dependence on phenology. The dots represent the means.

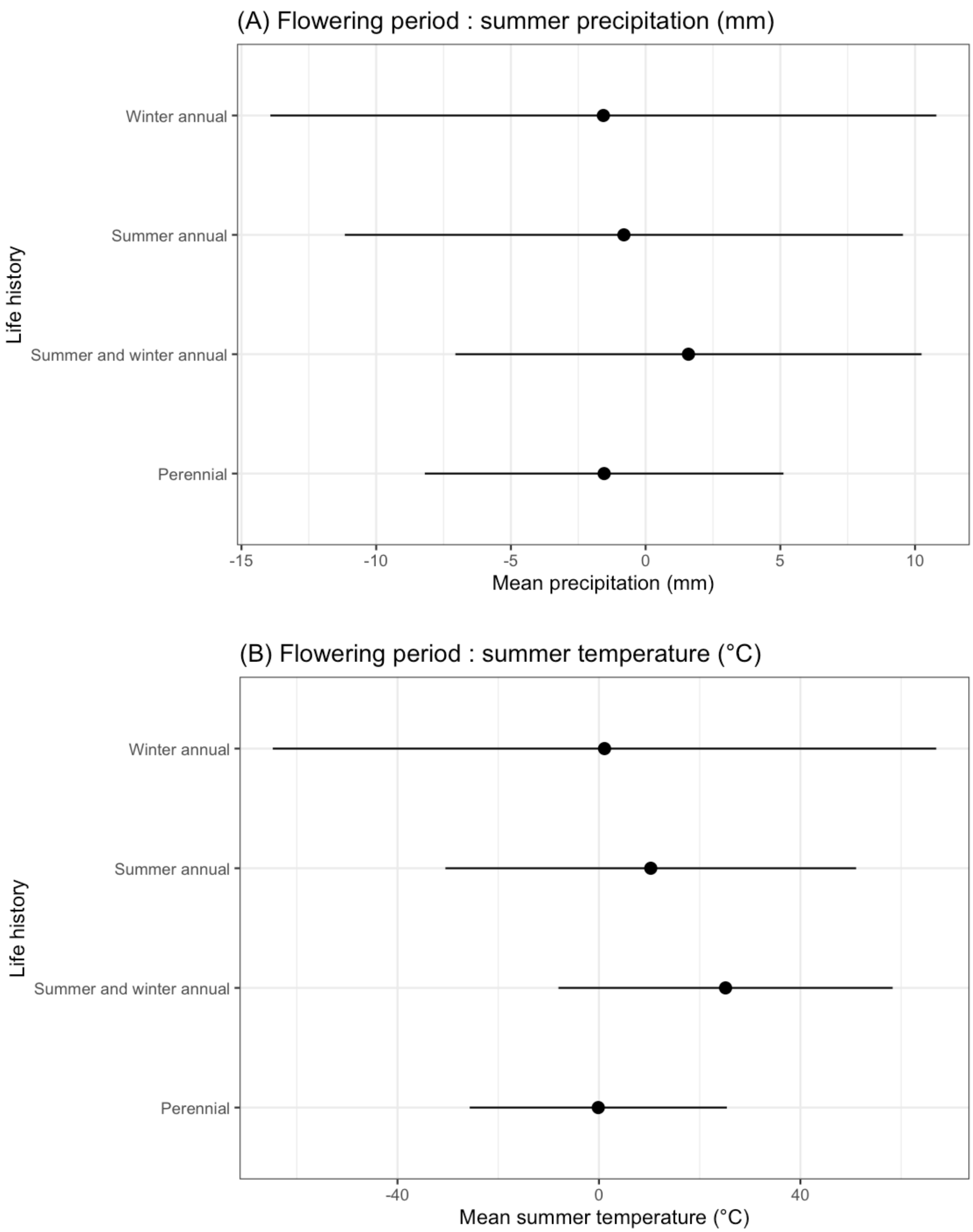

Figure 4. Visualization of the result of the meta-analysis of partial regression coefficients describing the relationship between length of the flowering period (days) and a) summer precipitaion (mm) and b) summer temperature (℃). The dots represent the means and lines 95% CI.

The first flowering varied greatly between and within groups but the summer annuals had a significantly later first flowering date compared to the other groups (Figure 3b). The perennials seem to have the greatest spread between species (~day 150 to ~day 195) when it comes to date of first flowering, the "summer and winter annuals" seem to have similar first flowering times as the perennials although the spread is slightly smaller (~day 48 to ~day 185). The winter annuals are the first to flower at ~day 130 to ~day 165 (Figure 3b). 4.4 Dependence of weather on first flowering and flowering period

The results of the regression analysis showed that in some species, first flowering or flowering period (or both) may be dependent on weather. When considering groups of species, however, neither precipitation nor summer temperatures could explain variation in partial regression coefficients (Figure 4a, b; all CI clearly overlap zero). In the analysis of individual species it appeared that the first flowering of *Lamium purpureum* was dependent on winter temperature. Similarly, summer temperature seemed to have an effect on the flowering periods of *Centaurea cyanus*, *Galeopsis speciosa*, *Galeopsis tetrahit* and *Myosotis arvensis*.

5 Discussion

5.1 Life history classification

Mean first flowering in the selected species was centered around day 130 to day 200 which corresponds to the period May 10th to July 19th where *Barbarea vulgaris* (perennial) and *Buglossoides arvensis* (winter annual) were the first to start flowering while *Fallopia convolvulus* (summer annual) and *Sonchus arvensis* (perennial) were the last to start flowering (Figure 2). The mean flowering periods varied a lot between species but also between groups, while *Barbarea vulgaris* (perennial) only flowered for ~30 days other species such as *Lamium purpureum* ("summer and winter annual") could flower continuously for over 200 days (Figure 1). On average, summer annuals, perennials and winter annuals had a flowering period of ~75 days to 100 days while "summer and winter annuals" had a flowering period of ~150 days (Figure 3a).

From the analyses performed it could be deduced that life history classification affected both the onset of flowering as well as the length of the flowering period differed for different life history classifications. The summer annuals generally started to flower in the later part of the growth season (Figure 2, 3b). This aligns with studies performed by Hirose et al. (2005) and Fogelfors (2006) who reached similar conclusions. Perennials, summer annuals and winter annuals appeared to have a shorter flowering period of about 30-125 days while the plants that are classed as “summer and winter annuals" had a longer flowering period of about 110-200 days (Figures 1 & 3a). From this it could be concluded that the selected agricultural weeds flower during the entire growth season and also throughout the flight season for most pollinators (Duchenne et al. 2019). This is important as pollinators need a continuous food supply during their flight period. However, further studies are needed to estimate the amounts of pollen and nectar at different times during the growth season as variations in number of species in each life history classification group varies, this may lead to high production of nectar and pollen available at some times while production may be much lower at other times. In this study it may also be relevant to investigate how the biomass of agricultural weeds vary between different types of crops and methods of farming such as organic farming vs use of pesticides and/or herbicides/weed killers. From this, it would also be of interest to investigate how variations in nectar and pollen abundance fluctuate in relation to fluctuations in pollinator populations both overall and depending on crop and/or method of farming.

5.2 Weather

The species-wise statistical tests investigating the relationships between first flowering, flowering period and weather of the 24 species were not clear. As mentioned in 4.4, one regression indicated that the first flowering of *Lamium purpureum* may be affected by winter temperature. In addition, the flowering period of *Centaurea cyanus*, *Galeopsis speciosa*, *Galeopsis tetrahit* and *Myosotis arvensis* may vary depending on summer temperature. Overall, neither summer temperature nor precipitation affected the flowering period when the selected species were grouped in their life history classifications, which contradicts studies by Amano et al. (2010) and Fox & Jönsson (2019) who found an earlier onset of flowering as a result of warmer temperatures. Furthermore, Crimmins et al. (2013) found that access to water greatly lengthened the flowering period and Fitter et al. (1995) concluded that both onset of flowering in different botanical groups as well as the length of their flowering periods was dependent on temperatures of the autumn before, extreme winter temperatures (especially in February) and the temperature of the 1-4 months preceding onset of flowering.

It is possible that more temporal resolution of weather data, smaller geographic area, or a longer time frame could have confirmed some of the published observations. But based on the current data, there was no apparent relationship between winter temperature, summer temperature or summer precipitation regarding the onset of flowering or length of the flowering period among the groups. Looking at the individual species that appeared to be affected by temperature or precipitation, *Centaurea cyanus, Galeopsis speciosa* and *Galeopsis tetrahit* score relatively high on the pollinator index. It is possible that their seasonal variations may still have an impact on available food-sources for pollinators. Potential effects of this variability are not included in this study.

6 Conclusion

From this study it is clear that the onset of flowering and the length of the flowering period depend on life history classification. Winter annuals have an earlier onset of flowering while the "summer and winter annuals" have a longer flowering period. This study also shows that agricultural weeds in Sweden contributes with a continuous supply of nectar and pollen throughout the growth season as well as the flight season for most pollinators. It was also shown that neither first flowering nor flowering period in the selected species were clearly affected by weather.

7 Societal and ethical considerations

The data used in this study are citizen science data obtained from Artportalen.se. The observations may come from experts in the field, interested amateurs or anyone with identifying skills between these levels. The data is valuable because it would cost large amounts of money to collect this kind of data through a research institute. All observations are made for free by citizens.

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