Can ambient temperature patterns predict fireweed phenology?

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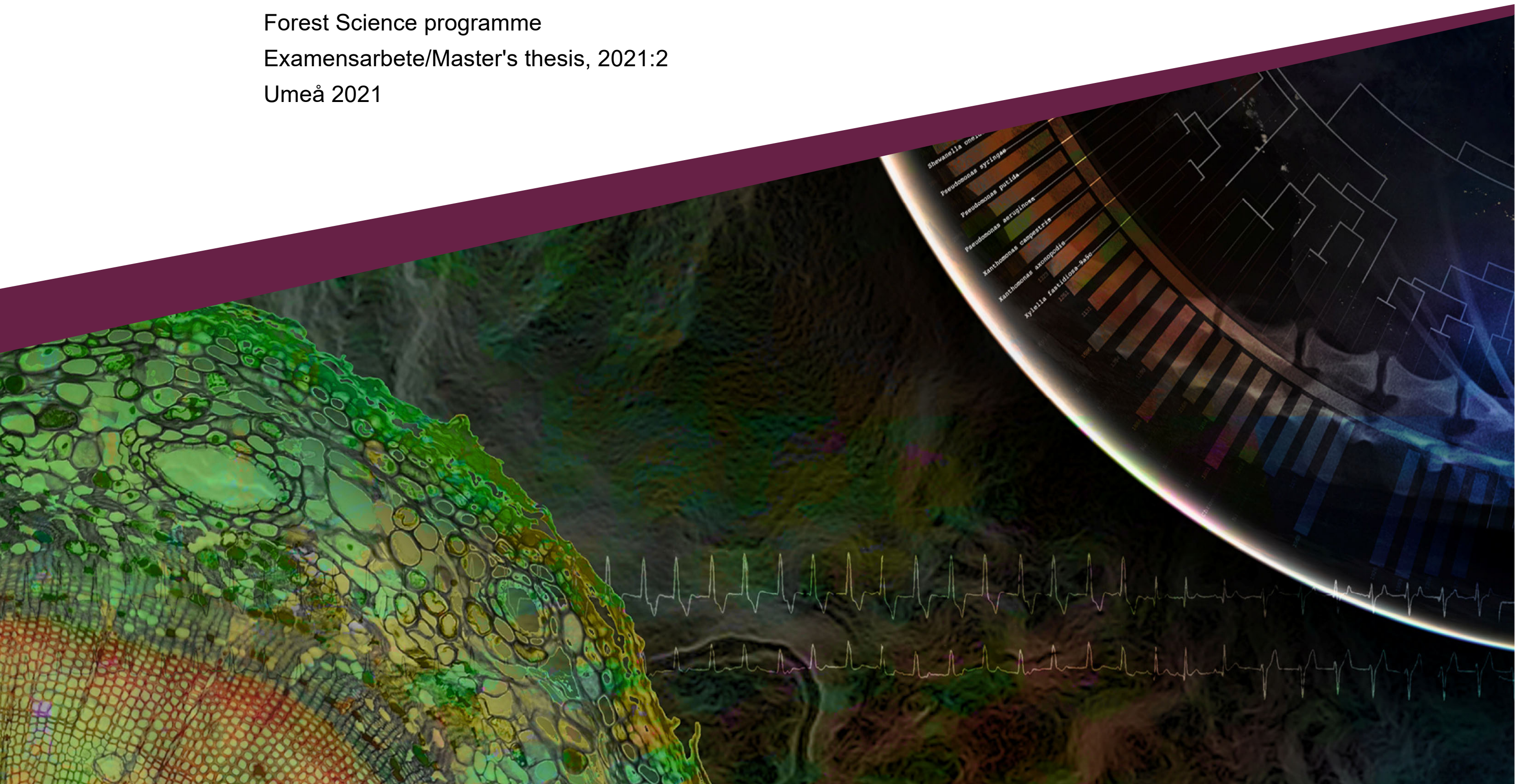

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Abstract

The Earth's climate has been changing with greater intensity and frequency in recent years. These changes, especially the warmer climate, have advanced plant phenology, thus increasing the risk of interspecific temporal mismatches, for example pollinators and pollinated flower species. This study's aim is to find out if temperature accumulations can be used to predict *Chamaenerion angustifolium* flowering phenology. A novel short-term camera trap dataset and a 13-year old long-term dataset of *C. angustifolium* flowering were used in conjunction with air temperature from an ensemble dataset to calculate accumulated growing degree-days. A comparison between the short- and long-term dataset was required in case the two datasets wouldn't provide similar result. A Mann-Whitney U-test suggested that there was no significant difference between the two methods of collecting flowering phenology data. A significant difference was provided by the Welch's t-test in accumulated growing degree-days between flowering and non-flowering sites, which suggests that temperature accumulation could be used to predict flowering phenology of *C. angustifolium*.

Keywords: Fireweed, *Chamaenerion angustifolium*, growing degree-days, camera trap, phenology

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Abbreviations

AGDD	Accumulated Growing Degree-Days
GDD	Growing Degree-Days
REGKVAL	Regional Kvalitet
SMHI	Swedish Meteorological and Hydrological Institute

1. Introduction

The Earth's natural climate varies on both a long- and short-term scale (Wong and Pape 2015). In more recent years, however, these disturbances have increased in frequency and intensity due to human activities, for example burning of fossil fuels (Wong 2015), that have also led to a gradual increase in the Earth's atmospheric temperature. The gradual increase in temperature is caused by radiations not being able to leave our planet due to greenhouse gases, atmospheric particles, cloud cover, and earth's albedo (Jozefat 2015). The warmer temperature will likely cause an earlier and prolonged growing season (Sparks and Menzel 2002; Koca et al. 2006) along with an increased frequency and intensity of extreme weather conditions (e.g. drought and increased precipitation) (Pachauri et al. 2015).

The effects of global climate change may impact biotic systems as well (Aerts et al. 2004). Climate change has contributed to a decrease in wildlife populations as well as the extinction of species by rapidly changing the environment or interrupting natural schedules; many species cannot adapt fast enough with these changes (Jozefat 2015). Some warm-adapted species in the Northern Hemisphere are expanding north- and westward (Parmesan et al. 1999; Thomas et al. 2001; Parmesan 2006; Walther 2010). On the other hand, range-restricted species that are not able to change location, especially mountaintop and polar species, have an increased risk of extinction (Parmesan 2006). Asynchrony in predator-prey, insect-plant, and parasite-host relationships has been more notable than previously due to variation in phenological responses (e.g. temperature and light availability) leading to temporal mismatches in interspecific interactions (Parmesan 2006; Kronfeld-Schor et al. 2017; Renner and Zohner 2018). Kudo et al. (2004) reported that some bee-pollinated flower species had a decreased seed production caused by warmer temperatures in spring, which prematurely advanced flower phenology when no bees were present. Several spring events (e.g. bud burst, flowering, and breaking hibernation) have advanced with rising temperatures (Reeves and Coupland 2000; Menzel 2002; Root et al. 2003; van Vliet et al. 2003; Edwards and Richardson 2004; Parmesan 2006). For example, rising air temperatures may accelerate plant phenology and prolong the growing season (Reeves and Coupland 2000; Menzel 2002; van Vliet et al. 2003; Parmesan and Yohe 2003; Menzel et al. 2006). The increased soil temperature can also prolong the growing season as well as altering biogeochemical processes affecting plants (Jungqvist et al. 2014). Changes to plant growth could also be caused by phenotypic plasticity of traits responsible for plant growth in response to temperature (Atkin et al. 2006).

The effects of climate change on living organisms have been studied (e.g. shifts in interactions and species abundance) by observing correlations between climate and biological differences, experimental manipulations in laboratories as well as in the field, physiological research (Parmesan 2006), and fossil- and geological records (Blois et al. 2013). The frequency and intensity of climatic changes themselves have been estimated through shifts in the leaf and flower phenology of plants, which are known to be temperature sensitive (Menzel 2003; Pohlman et al. 2005; Franks and Weis 2008; Chen and Xu 2012). The relationship between plant phenology and climate or time of year is well-established through herbarium specimens (Willis et al 2017; Jones and Daehler 2018; Daru et al. 2019; Pearson 2019). Such specimens have therefore been used to estimate climate seasonality (Sahagun-Godinez 1996), disturbances (Gómez-Garcia et al. 2009), and plant traits (Bolmgren and Lönnberg 2005). Other studies rely on field observations or experimental temperature manipulations in controlled laboratory settings to examine this relationship (Laskin et al. 2019). The use of software to predict plant phenology is also an option (Richardson et al. 2018; Park et al. 2019) such as PhenoCam (https://phenocam.sr.unh.edu/webcam/) to characterize phenology and PhenoForecaster (https://github.com/isaacWpark/PhenoForecaster) to predict flowering. Another recent way of collecting phenology data is the use of cameras, either camera traps or phenocams, which have the benefit of being easy to setup, small size, and relatively low cost (Alberton et al. 2017; Hofmeester et al. 2020).

Fireweed, *Chamaenerion angustifolium*, is a circumpolar pioneer species that is distributed throughout Sweden and is particularly common in the boreal forest (Myerscough 1980; Mossberg and Stenberg 2018). It survives in varied habitat and substrates, from moist areas along streams, to forest, to dry roadsides (Myerscough 1980; Fleenor 2016). The species is often one of the first to establish and thrive after a disturbance (e.g. wind-throw of forest trees, forest fires, and after human activities such as forest felling) (Dyrness 1973; Frey et al. 2003; Betz 2019). However, *C. angustifolium* does not tend to survive at sites with constant disturbances such as continuous grazing and/or reoccurring fires (Myerscough 1980). The name, fireweed, derives from the plant's tendency to emerge after a fire (Fleenor 2016). The adaptation to occur after a fire comes from its quick regrowth through surviving rhizomes after a fire, or other disturbance, and wind-dispersed seeds that have the ability to travel hundreds of kilometers (Solbreck and Anderson 1987; Fleenor 2016). Seeds and roots can stay buried and still be vital for many years underneath mature forest (Myerscough 1980; Fleenor 2016). However, *C. angustifolium* needs the soil disturbance and direct sunlight to fully emerge and flower (Myerscough 1980). Flowering usually occurs within the first year, and then every consecutive year (Myerscough 1980). However, shade may delay flowering, sometimes to the point that the flower buds are shed before opening (Myerscough 1980; Lieffers and Stadt 1994).

C. angustifolium is an important component of the ecological community as it is used by many species of insects and ungulates, but also fungi (Wilms et al. 1980; Myerscough 1980; Hodkinson and Bird 1998). Insects lay eggs on the leaves, where larval feeding can cause blotches or defoliation (Myerscough 1980). Various insects also pollinate the plant though bumblebees seem to be the most abundant (Myerscough 1980; Lack 1982; Husband and Schemske 2000; Kennedy et al. 2006). Various ungulates, such as deer and moose, consume the plant mainly during the summers since it is easily digestible due to its low fiber content and high energy content (Bunnell 1990; Strong and Gates 2006; Martin et al. 2010). Plant energy and nitrogen content usually peaks while growing and decreases as phenology progresses (Shively et al. 2019). Another use of *C. angustifolium* is in reclamation of forest soil due to its capacity to germinate and grow on less fertile soil (Pinno et al. 2014). It also has the ability to suppress the growth of undesirable grass or weed and promote the growth of shade tolerant species (e.g. *Picea glauca*) (Pinno et al. 2014).

Previous studies have predicted plant phenology in different locations and species (Daru et al. 2019; Laskin et al. 2019; Park et al. 2019; Pearson 2019), however, it has not previously been done using *C. angustifolium* as the study species. The interest of having *C. angustifolium* as the study species is that it used by many other species and therefore an important component in ecological communities. Consequently, in this project, my aim is to establish the relationship between flowering *C. angustifolium* and temperature accumulation using a novel camera trap method (Hofmeester et al. 2019). I compare the relationship between temperature and phenology across two datasets: a short-term camera trap dataset, and a 13-year *C. angustifolium* dataset covering the northern third of Sweden. I further conduct a preliminary analysis to determine if ensemble temperature data could be used to predict the advancement of phenology across time and space. The results also give insight to potential mismatches in interspecific interactions with *C. angustifolium*, for example pollinators and foraging ungulates.

2. Material and Method

2.1. Camera trap data collection

The short-term data derives from camera trap photos situated in the county of Norbotten in north of Sweden at three separate sites, Bodträskfors, Muddus National Park, and Lainio. The sites contain subarctic boreal forest, and each had a large area naturally burned in 2006, between 300 to 1 800 hectares across each site with different fire intensities (Engelmark 2013). Camera traps were present in both unburned (36 cameras, 3 sites) and burned areas (36 cameras, 3 sites), but *C. angustifolium* was only identified in the burned areas. The cameras were installed at each site at the beginning of June 2018 and later retrieved in September the same year, with a total of 72 cameras installed. All six sites used infra-red-triggered cameras of the model Hyperfire HCO 500. Each site had the cameras facing north and placed selectively to catch photos of elusive animals. The cameras were attached to nearby trees at a ~40-centimetre height, in order to catch photos of smaller mammals, and with a 10 metre open view in front of the camera to prevent any obstruction of animals by natural features, such as fallen trees or boulders. When a camera triggered it took a series of 3 to 10 images in rapid fire mode. However, cameras also captured two control images each day at midday and midnight to confirm that the cameras were working. The setup and method are used by both Pfeffer et al. (2018) and Hofmeester et al. (2019).

I used camera trap images to determine the date that the first flower blossomed, as well as the date when all flowers were shed at each camera trap location. Since the camera traps can capture several images per day, I chose to mainly look at the midday control images to ensure equal time intervals and because the camera traps were not triggered by any animal that could obstruct *C. angustifolium*.

2.2. Long-term phenology data collection

Annual *C. angustifolium* phenology field collection data took place at sites throughout the Swedish counties of Västerbotten and Norrbotten between July 17 and 25 in 1988-1997 and 2017-present. The number of sites varied by year, ranging between 13 and 37 sites, and sites were only visited once each year. The data provide a snapshot of *C. angustifolium* flowering in each 1-ha site. The phenology was measured by estimating the overall percentage of ramets flowering per site. For the purpose of this study, I am comparing the sites and years where no plants were flowering with sites that had flowering plants. The described data is from the long-term project REGKVAL.

2.3. Ensemble temperature data collection

The ensemble weather data was obtained through E-OBS (https://surfobs.climate.copernicus.eu/surfobs.php) that provides climate monitoring products for Europe. The data is collected by ground-based observation networks via National Meteorological Services and other who owns and operate the data collection. Both historical (from 1950) and current data can be obtained of basic weather variables such as temperature and precipitation. I obtained the daily maximum and minimum temperatures from the start of the growing season to the end of the flowering period as denoted by my short-term dataset, and to the start of the annual data collection period for the long-term dataset. The start of the growing season is defined by the Swedish Meteorological and Hydrological Institute (SMHI) (https://www.smhi.se/en/climate/climate-indicators/climate-indicators-length-of-vegetation-period-1.91482) as, the first four consecutive days with a daily mean temperature of at least 5.0 °C (Appendix 1).

I then used the maximum and minimum temperatures to calculate the growing degree-days (GDD) from the start of the growing season until the last day of interest, start of flowering or collection date, for each respective dataset. GDD is a heat unit that allows for more precision in calculating phenological events compared with other time-based approaches such as time of year or number of days (McMaster and Wilhelm 1997). I used equation 1 to calculate GDD for each day of the growing season each year:

$$GDD = \left[\frac{(T_{MAX} + T_{MIN})}{2}\right] - T_{BASE} \qquad (1)$$

where T_{MAX} is the maximum daily temperature, T_{MIN} the minimum daily temperature and T_{BASE} is the temperature threshold at which growth starts to occur. I followed McMaster and Wilhelm (1997) in their modified approach, where GDD values less than zero are replaced with zero. This is the most commonly used method to calculate GDD, particularly in simulations (McMaster and Wilhelm 1997). The T_{BASE} were set to 5 °C, which is a commonly used base temperature for vegetation growth in Sweden (SMHI 2020). I then calculated the Accumulated

Growing Degree-Days (AGDD) for each site and year, summed from the start of the growing season until the last day of flowering (short-term data) or the start of the annual data collection period (long-term data).

2.4. Analyses

I extracted the ensemble temperature data using the *ncdf4* package (Pierce 2019). I then ran a summary statistic on AGDD associated with the first day of flowering of the camera trap data (n=15 sample size) and with the flowering (n=223) and nonflowering (n=146) sites of the long-term dataset project's data. The function I used for the summary statistics (mean and standard error) was *describeBy* from the R package *psych* (Revelle 2020).

To get a visual overview of the spatiotemporal patterns in the relationship between *C. angustifolium* flowering and temperature accumulation, I created heat maps with the AGDD at each site. I first created a map of the AGDD associated with the camera trap data on the first day of flowering (n=15), I then created two separate maps of the long-term dataset – one with the AGDD of sites with flowering *C. angustifolium* at the time of annual data collection (n=223) and the other of the AGDD at sites with no flowers (n=146). The maps were created with help of the *ggmap* (Kahle et al 2019), *ggplot2* (Wickham et al. 2020), and *sf* (Pebesma et al. 2020) packages.

I used a Welch's t-test to test if there was any difference between the AGDD of the long-term dataset's sites with flowering *C. angustifolium* and the sites with no flowers across years. I used a Mann-Whitney U-test to test if there were any significant differences between the long-term dataset and camera trap data by comparing the AGDD on the same date of sites with visible flowers. In this case, I used 20th of July 2018, since that is the year when the camera traps were installed and the majority of the REGKVAL observations with flowering site were conducted on the 20th of July.

The t-test was conducted using the *t.test* function in R with a significance level of $p < 0.05$. The U-test was also conducted in R but with the *wilcox.test* function available already available in R using the same significance level as the t-test.
All my analyses were done in R under the version R-4.0.3.

3. Results

Fifteen of the 72 camera traps examined in this study had images of *C. angustifolium*; all of these were in burned areas. The majority of the images were from Lainio (n=10 cameras), with a few from Bodträskfors (n=3), and Muddus National Park (n=2). The flowering duration differed somewhat between sites and camera locations, with the longest duration in Bodträskfors (37 days) and the shortest duration in Muddus NP (13 days). In most of the camera trap locations, *C. angustifolium* started flowering in early to mid-July, and finished flowering at the beginning of August, though some shed their flowers earlier (Appendix 3).

Table 1. Summary Statistics of Camera trap data.

	Mean	**SE**
AGDD (°C) at start of flowering	412	12.48
AGDD (°C) at end of flowering	711	22.72

The site with the lowest AGDD was Muddus NP at 322°C at the start of flowering, and the camera trap location with the highest AGDD at the start of flowering, 492°C, was in Bodträskfors (Figure 1). Muddus NP had a lower AGDD than the other two sites, which had AGDDs' closer to the mean (Table 1).

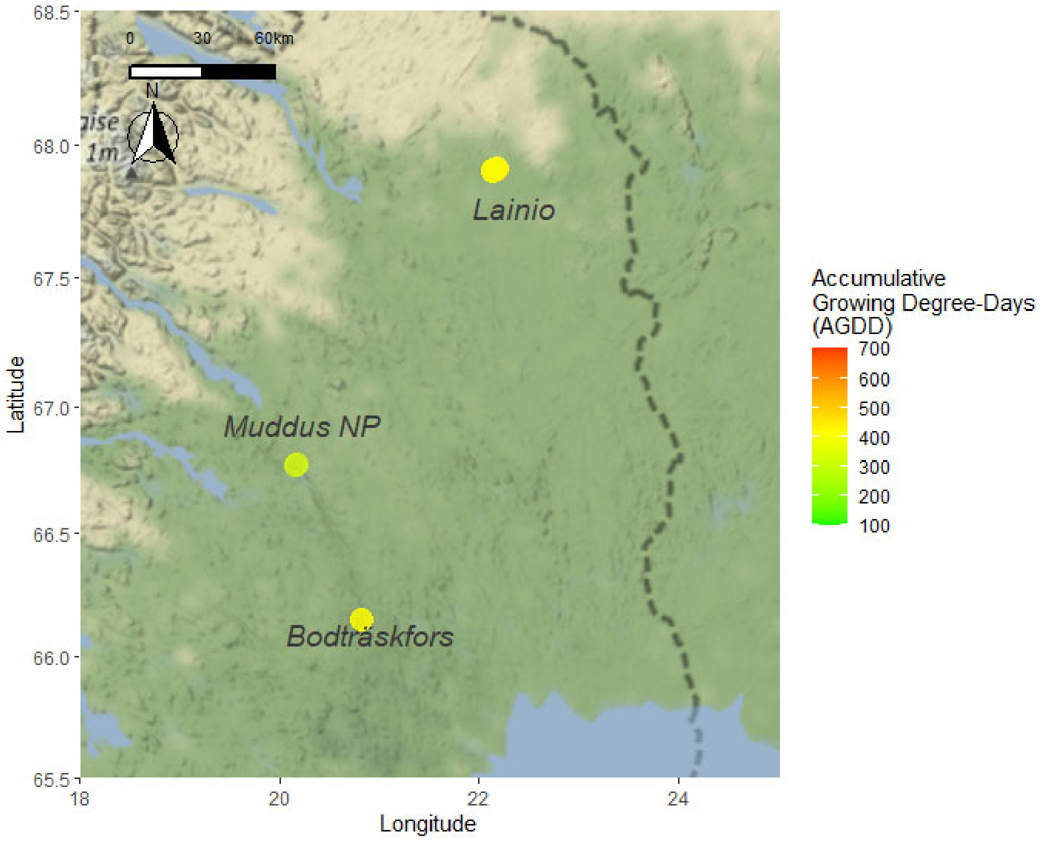

Figure 1. Camera trap locations and AGDD at the day of first flower.

A total of 333 phenology measurements were used from the long-term data. All 37 sites were visited in 2019 while the minimum of 13 sites were visited in 2018 (Figure 2). The proportion of sites with *C. angustifolium* flowering differed among years as well. In 1988, all of the visited sites had flowers, while in 1991 only three sites had flowering *C. angustifolium* (Figure 2; Appendix 2). The calculated AGDD also varied between years and locations (Figure 2); the highest calculated AGDD for any site happened in Älvsbyn 2018 (705°C) and the lowest value in Vouggatjålme 1989 (92°C) (Figure 2; Figure 3).

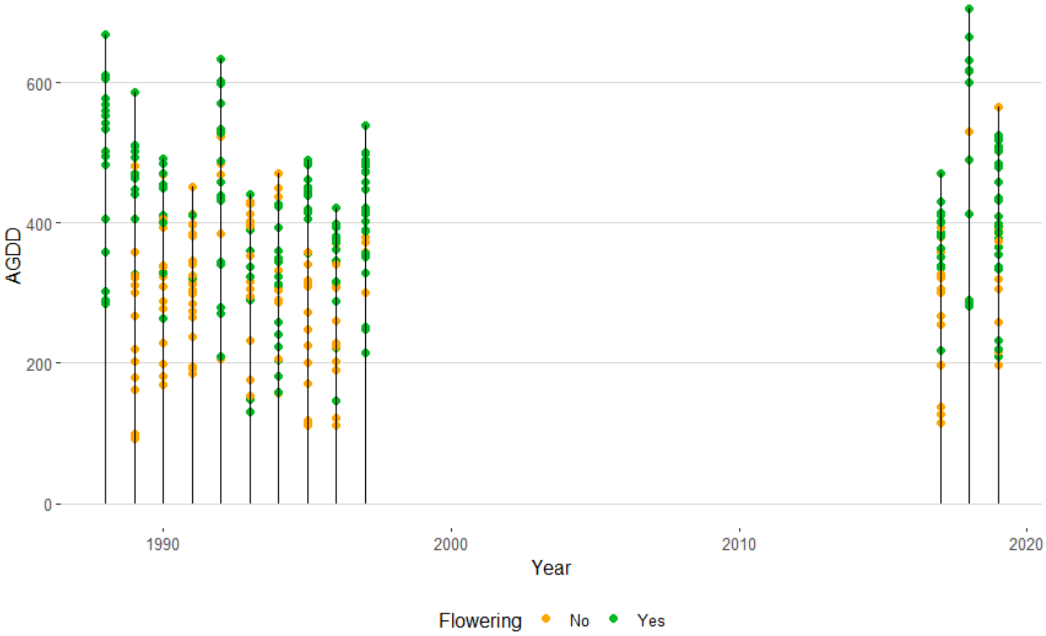

Figure 2. The REGKVAL projects AGDD of flowering (Yes, green) and non-flowering (No, orange) C. angustifolium per year.

Differences between sites were also apparent. Some locations always had flowering *C. angustifolium* when visited, and some locations never had any flowers (Figure 3). Most of the flowering locations had a higher AGDD than the nonflowering sites and most of the flowering sites were situated near the coast (Figure 3). For example, Nordmaling, south of Umeå always had flowering specimens when visited while Lainio and Muodoslompolo in the far north of Haparanda never had flowers when visited. However, most of the sites had years of both flowering *C. angustifolium* and nonflowering upon visit.

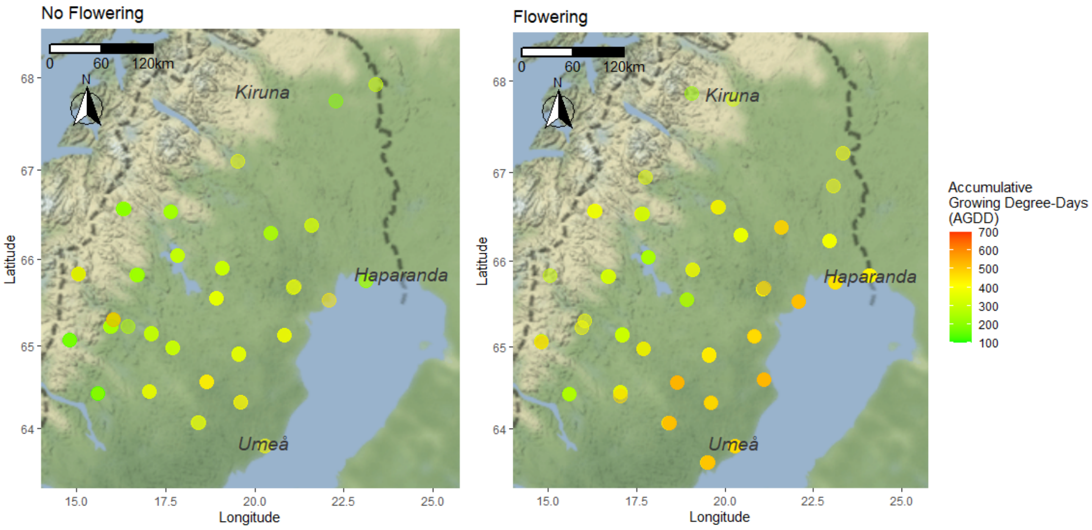

Figure 3. REGKVAL locations of not flowering and flowering locations and their respective AGDD throughout the years.

A comparison of the AGDD of the flowering period for the fireweed caught on the camera traps and the AGDD for the REGKVAL projects showed that the majority of the non-flowering REGKVAL locations were below the mean AGDD of the camera traps when flowering starts (Figure 4). However, flowering REGKVAL locations do not appear to show a distinct pattern with regard to the mean camera trap AGDD at the start of flowering (Figure 4). Only a few of the non-flowering REGKVAL locations were within the standard error of the camera trap AGDDs at the end of flowering. However, some of the flowering REGKVAL sites had AGDDs that approached the camera trap's mean AGDD at the end of flowering (Figure 4).

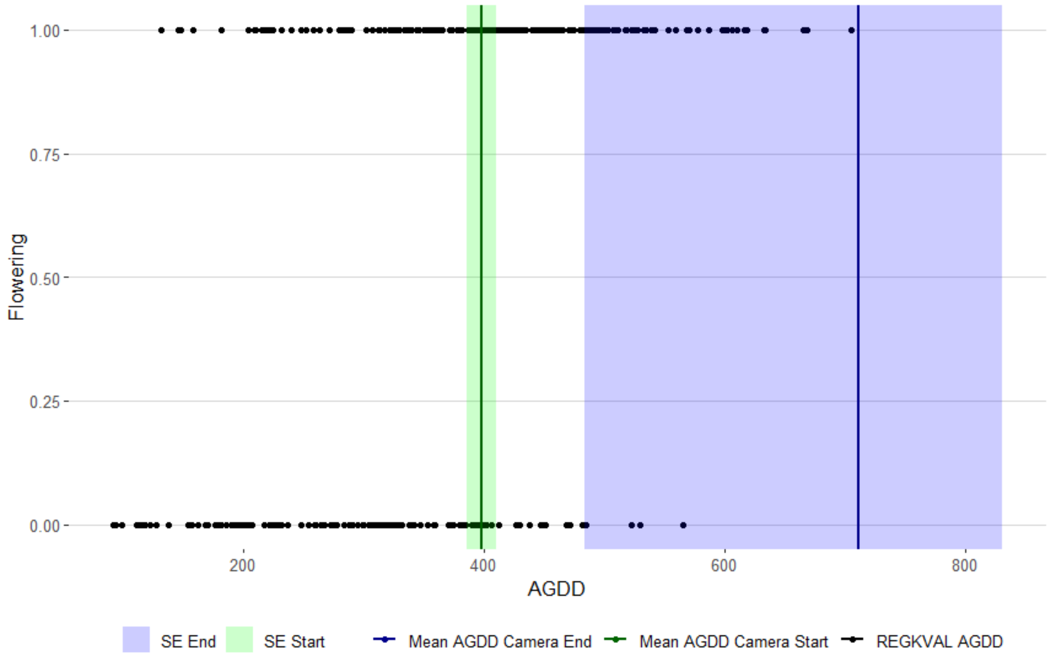

Figure 4. The REGKVAL project AGDD of flowering (1.0) and not flowering (0.0) sites, shown against the mean and standard error of the camera trap AGDD at the start (first observed flower) and end of flowering (day of all flowers shed).

Differences were found between flowering and non-flowering AGDD in the long-term dataset from the REGKVAL project. AGDD on flowering sites (mean = 415.9 °C) were higher than AGDD on nonflowering sites (mean = 302.2 °C, $t = 9.716$, $df = 299.49$, $p < 0.001$).

When comparing the AGDD from the camera traps, which had flowers on all sites, (mean = 508.8 °C) on July 20th, 2018 and the REGKVAL project's flowering sites (mean = 544.6 °C) during the REGKVAL data collection period of 2018, I found no apparent difference between the two data sets ($W = 43$, $p = 0.51$).

4. Discussion

The Welch's t-test showed no difference between the camera trap data and the long-term REGKVAL project's data. This suggest that the method of collecting data didn't impact the relationship between flowering and temperature accumulation. So, both the use of camera traps and collection method used in the REGKVAL project will yield a similar accuracy of calculating AGDD at flowering sites.

There was, however, a difference between flowering and nonflowering sites' AGDD in the REGKVAL project data. This could indicate that the majority of *C. angustifolium* start to flower after a certain AGDD (i.e., mean +/- SE). Knowing that *C. angustifolium* flowers after a certain AGDD suggests that we could use temperature accumulation to predict *C. angustifolium* phenology. This relationship could be used to predict future flowering but might also indicate when past flowering occurred. It could potentially show how climate change has affected the timing of flowering over time, and if it occurs earlier in the calendar year as time progresses (Sparks and Menzel 2002; Koca et al. 2006). Such premature flowering could cause mismatches between *C. angustifolium* and species whose phenology is not tightly tied by temperature, like bumblebees (Kudo et al. 2004). A mismatch between pollinators and flowering can result in reduced seed production (Kudo et al. 2004). This could potentially lead to temporal mismatch in the future where bumblebees might struggle to get enough nectar and *C. angustifolium* not being able to sexually reproduce efficiently, thus decreasing both populations. Other species that may be dependent on *C. angustfolium* phenology are ungulates, especially during lactation periods, which commonly occur early in the growing season, since females require a lot of energy at these times (Oftedal 2018). The energy content in *C. angustifolium* decreases during the growing season (Shively et al. 2019). Thus, shifting phenology forward in time would likely reduce the quality of forage available for lactating female and most likely reduce fitness (Parker et al. 2019). To mitigate the reduced forage quality would alternatively forage sources be ensured by forest measures and enhanced landscape conservation, for example having a good berry which is an important food source all year around (Spitzer 2019) but also promote less temperature sensitive forage.

Notably, the long-term data, the REGKVAL project, had sites that never flowered and sites that were always flowering when visited. Most of the variation in flowering across years can be observed in northern Norrbotten where many of the sites were either flowering or not flowering. This may be partially explained by the reduced sample size of northern sites (some only visited once), however among-site variation in altitude, latitude, and canopy cover may also play a role. It is possible that a higher altitude, latitude, but also wind have a decreased AGDD (Figure 4), thus affecting *C. angustifolium* flowering that seem to have strong relation with AGDD. Areas with too much shade will inhibit *C. angustifolium* from flowering (Myerscough 1980; Lieffers and Stadt 1994) which may be the case for some of these areas. Returning to the sites and noting how much shade the *C. angustifolium* are in might provide an explanation to why some sites never have flowers at the time of data collection.

Variable shade may also help elucidate why REGKVAL sites with no flowers present had the highest AGDD in some years. These years are 1991, 1994 and 2019 (Figure 3). Only the year of 1991 had a particularly low number of flowering sites; the other two years seemed to have a rather typical ratio of flowering and nonflowering sites. Alternatively, some sites may have been newly grazed or damaged by insects. Such damage has been anecdotally observed at some sites in recent years and additional standardized data collection could reveal if this plays a role in the detection of flowering phenology.

My method of using camera traps that were originally set up to catch images of animals (Pfeffer et al. 2018; Hofmeester et al. 2019) did not prove optimal in observing *C. angustifolium* phenology. Due to limited resolution, I was not able to determine the proportion of flowering *C. angustifolium* per site from the images, so I only observed when the first flower bloomed and when the last flower was shed. At the same time, the REGKVAL project data was limited as it did not have observations of the first and last day of flowering. The differences in observations between the short- and long-term data made it more difficult to compare the two datasets. Future studies could use phenocams with greater resolution to catch how phenology progresses in time. This data could then be more comparable with existing long-term datasets (like the REGKVAL project, which counts the percentage of ramets flowering per site) or herbarium samples, which could present similar information. Such studies may determine if the progression of flowering can also be predicted using temperature accumulation.

One more adjustment with the camera set up would be to set up more cameras in unburned areas where *C.* angustifolium grows. An option would be to set up the cameras at or near a REGKVAL project site and observe *C. angustifolium*. The fact that I only could use camera trap images in burned areas may have been a source of bias since *C. angustifolium* became more common after the fire (Engelmark 2013). Fire intensity and burn depth will also determine which species will emerge after fire (Schimmel and Granström 1996), which may affect the number of *C. angustifolium* present at the different burned areas since the sites burned with different intensities (Engelmark 2013). The fire may also provide an increased amount of sunlight (Nilsson 2005) which benefits *C. angustifolium* (Myerscough 1980). The comparison between the camera trap data and the REGKVAL projects data of flowering sites on the same date didn't show any differences in AGDD. So, it was not likely a huge bias since the differences in AGDD was not significant. However, it could be fruitful to make a comparison between unburned and burned areas proportion of flowering *C. angustifolium*. Burned areas should in theory have more flowering *C. angustifolium* than unburned areas (Myerscough 1980; Engelmark 2013).

The small sample size of the camera trap data may have affected the outcome of my results. I have tried to mitigate the potential errors of a smaller sample size and a non-normal probability distribution by using the Mann-Whitney U-test instead of the Welch's t-test on the camera trap data (Ruxton 2006). The smaller sample size may not give as accurate results from the analysis, high variability and biases, yet also prevent me from using a more suitable analysis method. To mitigate this potential error would be to install more camera traps with the intent of collecting *C. angustifolium* phenology data in order to get a sufficient amount to analyse.

This study provides preliminary evidence for a relationship between temperature accumulation and *C. angustifolium* flowering phenology and leads to recommendations for studies to develop the knowledge of this relationship. Future studies could narrow down the AGDD at which flowering occurs, and other factors that may affect this relationship (e.g., shade, physical damage). Hopefully will this study inspire to be applied on other species. The method may vary when applied on other species, for example if the temperature at which the species starts to grow is known then use that temperature as T_{BASE} when calculating GDD (McMaster and Wilhelm 1997). However, if it is not known then it should be set at the start of the growing season and the method of this study can be applied. There were also two methods of calculating GDD, explained by McMaster and Wilhelm (1997). Though the two calculation methods differed, both could be applied, and the one used in this study was the most widely used in simulation models. This study uses the E-OBS ensemble temperature data to show the relationship between *C. angustifolium* phenology and ensemble weather, which is a step away from using satellite or weather stations measurement to forecast phenology. Upcoming studies could use either weather stations or satellite temperature to measure the difference in AGDD and flowering between air temperature from satellites and ground temperatures from weather stations.

This study shows that *C. angustifolium* phenology can be predicted by using ensemble temperature accumulation as measurement. It also shows that there wasn't any difference in collection method between the short-term camera trap method or the long-term method to calculate AGDD at flowering sites. Which suggest that both methods can be used to predict if *C. angustifolium* would flower at a certain space and time. Future studies should further develop this idea of predicting phenology with more precision and examine the relationship between temperature and not only the presence of flowers, but also the full progression of flowering.

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Appendix

Appendix 1

Growing season definition used by SMHI

The definition of growing season that we use is:
The growing season starts the first day of the year as the daily mean temperature is at least + 5.0 ° C during the first period of at least four consecutive days where all four days have a daily mean temperature of at least + 5.0 ° C. The growing season ends the last day of the year as the daily mean temperature is at least + 5.0 ° C during the last period of at least four consecutive days where all four days have a daily mean temperature of at least + 5.0 ° C. The length of the growing season is the number of days from the beginning of the vegetation period to its end including the start and end days.

Appendix 2

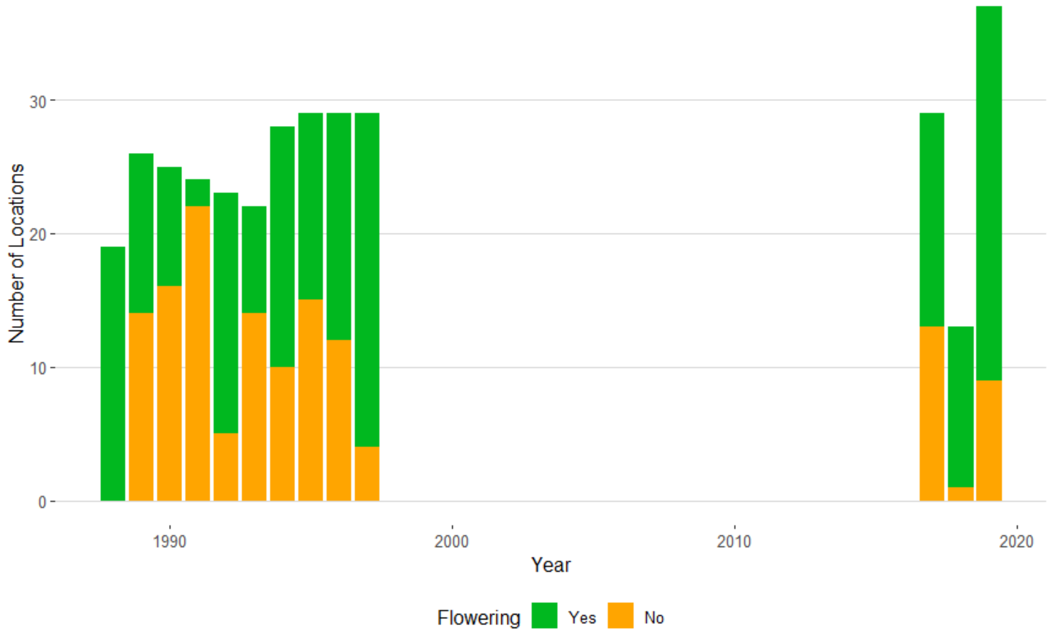

Figure A1. The number of REGKVAL project locations with flowering (Yes) and non-flowering (No) C. angustifolium per year.

Appendix 3

Figure A2. Image of *C. angustifolium* at first day of flowering, two images during flowering, and image of all flowers shed. The images include date which was noted at the first day of flowering and the date at which all flowers had been shed.

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