**Phenology**

**New references to read and add:**

Bjorkman et al 2015- arctic plant response to global change

Filippa et al 2015 – results of monitoring study

Bienau et al 2055 – asynchronous flowering can result from heterogeneous snow distribution patterns (so future work with indicator species should take this into account).

Legault and Cusa 2015 – Important to consider multiple drivers for arctic plant phenology

Bertin 2015 – results of assessing methods used in phenology studies of herbarium specimens using simulation. Discuss with relation to our methods and results.

Mohandass 2015 – alpine study using herbarium specimens and direct observations;

Beaumont et al 2015 – shift in phenology of Australian species, suggest ways to address knowledge gap including establishing observation networks supplemented with citizen science programs

Wang et al 2014 – Impacts of warming and cooling on phenology of alpine plants; suggests considering nonlinear temperature responses in future studies

Davis et al 2015 – herbarium records are reliable source of phenological change driven by climate

Rawal et al 2015 – herbarium records used to detect climatic signals in phenology in Australia

Park and Schwartz 2015 – herbarium records reveal temperature-dependent changes in phenology in SE US

Hart et al 2014 – herbarium specimens in one Himalayan species, over 10K records, show relationship to warming but no directional change over entire 125 years of collections

Calinger et al. 2013 – herbarium specimens in North-central NA, 141 species, showing average advance of 2.4 days/degrees C, with differences among plant functional groups.

Schmidt-Lebuhn et al. 2013 – beware of collection biases in herbarium specimens when interpreting results

Li et al 2013 – use of herbarium specimens to assess response to global warming in Tibet

One man, 73 years, and 25 species. Evaluating phenological responses using a lifelong study of first flowering dates By:[Bolmgren, K](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+OneClickSearch.do?product=WOS&search_mode=OneClickSearch&excludeEventConfig=ExcludeIfFromFullRecPage&colName=WOS&SID=2FrGSNcCm1zDsimm6jX&field=AU&value=Bolmgren,%20K" \o "Find more records by this author) (Bolmgren, K.)**[** [**1**](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=2FrGSNcCm1zDsimm6jX&page=1&doc=4#addressWOS:000317474400004-1)**,**[**2**](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=2FrGSNcCm1zDsimm6jX&page=1&doc=4#addressWOS:000317474400004-2) **]** ; [Vanhoenacker, D](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+OneClickSearch.do?product=WOS&search_mode=OneClickSearch&excludeEventConfig=ExcludeIfFromFullRecPage&colName=WOS&SID=2FrGSNcCm1zDsimm6jX&field=AU&value=Vanhoenacker,%20D) (Vanhoenacker, D.)**[** [**3**](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=2FrGSNcCm1zDsimm6jX&page=1&doc=4#addressWOS:000317474400004-3)**,**[**4**](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=2FrGSNcCm1zDsimm6jX&page=1&doc=4#addressWOS:000317474400004-4) **]** ; [Miller-Rushing, AJ](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+OneClickSearch.do?product=WOS&search_mode=OneClickSearch&excludeEventConfig=ExcludeIfFromFullRecPage&colName=WOS&SID=2FrGSNcCm1zDsimm6jX&field=AU&value=Miller-Rushing,%20AJ) (Miller-Rushing, A. J.)**[ [5](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=2FrGSNcCm1zDsimm6jX&page=1&doc=4" \l "addressWOS:000317474400004-5),**[**6**](https://cuvpn.colorado.edu/,DanaInfo=0-apps.webofknowledge.com.libraries.colorado.edu+full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=2FrGSNcCm1zDsimm6jX&page=1&doc=4#addressWOS:000317474400004-6) **]** INTERNATIONAL JOURNAL OF BIOMETEOROLOGY Volume: 57 Issue: 3 Pages: 367-375 DOI: 10.1007/s00484-012-0560-8 Published: MAY 2013

Links between plant species’ spatial and temportal responses to a warming climate – Amano et al 2014 Proceedings of the royal society B – Biological sciences

Maintenance of ecological niche by changing phenology – if not maintained with phenological changes then moved northward – so plants may not change their range and instead change phenology with temperature. Idea that temperature is what the plants are trying to maintain – avoid frost, keep fitness at flowering time – and this is done phonologically – earlier, or spatial, more northward…

1. 405 species, 400,000 observations (in Britain).
2. 6669 species spatial data at two census periods

If a species cannot track warming climate by advancing phenology will need to move to higher latitude (not possible if on top of mountain..)

Used daily mean temperature (central England temperature (CET).

“Only native species (native

status ¼ N or NH in the PLANTATT database [24]) whose indices

exceeded 19 years were used in this analysis, based on an

earlier study which reported that, in most species, relatively accurate

estimates of the relationship between flowering dates and

temperature can be obtained with 20-year data” – “one man, 73 years, and….”

Mean daily CET in the week starting from the first flowering date estimated by the species-level index for each year and species.

Looked at each month – what responsible for first bloom..

* Alpine species that are not changing their phenology with changing temperature may be at risk of climate change driven extinction because they cannot track northward??
* Mean they don’t have the phenotypic plasticity to survive change without range change?

Phenological plasticity will not help all species adapt to

climate change

ANNE DUPUTI\_E1 , 2 \* , ALEXIS RUTSCHMANN2 , 3 \* , OPH\_EL I E RONCE 4 and ISABELLE CHUINE2

2015

Advanced spring events due to phnotypic plasticity. Some of these plastic shifts are adaptive but some can be maladaptive.

Mean temperature of coldest month, mean temp of wamest month, numbr of chilling days, drought index, GDD above 5°C. total precipitation, precipitation during growing season, coefficient of variation of precipitations among season

Title: [Nonlinear flowering responses to climate: are species approaching their limits of phenological change?](https://cuvpn.colorado.edu/,DanaInfo=apps.webofknowledge.com+full_record.do?product=WOS&search_mode=GeneralSearch&qid=8&SID=1CmKcESlHrmd2KpZu5G&page=4&doc=40)

Author(s): Iler, Amy M.; Hoye, Toke T.; Inouye, David W.; et al.

Source: PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES  Volume: 368   Issue: 1624     Article Number: UNSP 20120489   DOI: 10.1098/rstb.2012.0489   Published: AUG 19 2013

Times Cited: [2](https://cuvpn.colorado.edu/,DanaInfo=apps.webofknowledge.com+CitingArticles.do?product=WOS&SID=1CmKcESlHrmd2KpZu5G&search_mode=CitingArticles&parentProduct=WOS&parentQid=8&parentDoc=40&REFID=454260126) (from Web of Science)

Title: [Long-term monitoring at multiple trophic levels suggests heterogeneity in responses to climate change in the Canadian Arctic tundra](https://cuvpn.colorado.edu/,DanaInfo=apps.webofknowledge.com+full_record.do?product=WOS&search_mode=GeneralSearch&qid=8&SID=1CmKcESlHrmd2KpZu5G&page=4&doc=39)

Author(s): Gauthier, Gilles; Bety, Joel; Cadieux, Marie-Christine; et al.

Source: PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES  Volume: 368   Issue: 1624     Article Number: UNSP 20120482   DOI: 10.1098/rstb.2012.0482   Published: AUG 19 2013

Times Cited: [1](https://cuvpn.colorado.edu/,DanaInfo=apps.webofknowledge.com+CitingArticles.do?product=WOS&SID=1CmKcESlHrmd2KpZu5G&search_mode=CitingArticles&parentProduct=WOS&parentQid=8&parentDoc=39&REFID=454260122) (from Web of Science)

Title: Growing degree-days: one equation, two interpretations

Gregory S. McMaster W.W. Wilhelm

Agricultural and Forest Meteorology 87 (1997) 291-300

Calculations of GDD differ and impact simulation models for duration of process. Depends on how the base temperature is incorporated into the equation.

1. where if (tmax+tmin/2) < tbase then use tbase.
2. If Tmax < tbase then tmax = tbase

Temperature Thresholds and Growing-Degree-Day Models for Red Sorrel (Rumex acetosella) Ramet Sprouting, Emergence, and Flowering in Wild Blueberry Scott N. White, Nathan S. Boyd, and Rene C. Van Acker 2015

Cumulative GDD = sum 1 to n (Tmean – Tbase) and when Tmean < tbase then GDD = 0 citing Gordon and Bootsma (1993)

Bases and limits to using ‘degree.day’ units. Bonhomme 2000

* Few biological phenomena occur above 45\*C.
* The development rate (eg getting to flowering) and temperature is only linearly related for a short range of temperature variation. Use degree.day sums while taking into account that non-linearity will have an influence on predictive power.
* In areas of fluctuating daily temperatures, there is some development due to the daily period when the temps rise above the threshold/base. So in these alpine environments the min will bring the average down so much, should take into account when the max is above some threshold.
* Temperatures below 10\*C result in no growth in corn. Alpine should be lower, at least 0 then.
* Variation in how predictive GDD on development – how close to the ground = more ground temp matters, if long days then there’s a larger difference between min and max, At least in alpine the growth habits will be similar – low mat forming things mostly.. should report the range of growth habits for included species
* Temperature threshold has only slight influence on precision of determining stage if average temperatures are well above threshold level – try to measure or estimate the temperature of the developing organ – look at the average temp of first bloom and set base near the average?

Ball etal 1995

GDD with base temperature of 0\*C – for grasses: Downy brome, Bromus tectorum L. #3 BROTE; bulbous bluegrass, Poa bulbosa L. # POABU; jointed goatgrass, Aegilops cylindrica Host. # AEGCY; Italian ryegrass, Lolium multiflorum Lam. # LOLMU; wild oat, Avena fatua L., # AVEFA; winter wheat, Triticum aestivum L. 'Stephens'; winter barley, Hordeum vulgare L. 'Hesk'; winter triticale, x Triticosecale 'Breaker.'

Talkkari, A.

Kellomaki, S.

Peltola, H.

Bridging a gap between a gap model and a physiological model for calculating the effect of temperature on forest growth under boreal conditions

Tree species, European GDD threshold +5\*C; Scots pine central Finland with mean annual temp of 2-6\*C.

Growth of Kochia scoparia, Salsola iberica, and Triticum aestivum Varies with Temperature Author(s): Cathy A. Nord, Calvin G. Messersmith and John D. Nalewaja Source: Weed Science, Vol. 47, No. 4 (Jul. - Aug., 1999), pp. 435-439

Examine influence of temperature on growth of weeds after seedling emergence

GDD = Tavg – Tbase

Tbase is 4C for cool season C3 type plants and 10C for warm season C4 plants

Phenology, growth, and fecundity of eight subarctic tundra species in response to snowmelt manipulations

By:Wipf, S (Wipf, Sonja)[ 1,2 ]

View ResearcherID and ORCID

PLANT ECOLOGY

Volume: 207 Issue: 1 Pages: 53-66

DOI: 10.1007/s11258-009-9653-9

Published: MAR 2010

Mathematical formulae for calculating the base temperature for growing degree days. Yang et al 1995

Selecting temperature at which below growth and development will cease.

Evaluation of several degree-day estimation methods in California climates. Roltsch et al 1999

Allen JC. 1976 A modified sine wave method for calculating degree days. Environ. Entomol. 5, 388 – 396. (doi:10.1093/ee/5.3.388)

Grasshopper community response to climatic change: variation along an elevational gradient. 2010. Nufio, Cesar R. McGuire Chris R. Bowers M. Deane Guralnick Robert P.

For detailed review of the concept of GDD, see Arnold (19601, Pruess (19831, Wang (19601, and Zalom et al. (1983).

**Papers citing Gallagher et al. 2009**

Chambers et al. 2013. PLOS ONE. Phenological Changes in the Southern Hemisphere. Meta-analysis of phenological drivers; advance in timing of spring events; temperature most frequently identified as primary driver (though in many cases that was only one considered); when precipitation considered, often played key role but direction of variation difficult to predict.

Li et al. 2013. Biodiversity and Conservation. Species-level phonological responses to ‘global warming’ as evidenced by herbarium collections in the Tibetan Autonomous Region. Growing realization that herbarium-based collections offer baseline data; looked at average flowering time; used mixed model with randomized blocks for 41 species (909 specimens), with altitude as the block and year and temp fixed effects and flowering time was the response variable; found earlier flowering time (0.5 days per year).

Keatley and Hudson. 2012. Austral Ecology. Detecting change in an Australian flowering record: Comparisons of linear regression and cumulative sum analysis change point analysis. CUSUM can detect multiple change points but linear regression cannot; but two methods agreed 84.6% of the time.

Diskin et al. 2012. International Journal of Biometeorology. The phenology of Rubus fructicosus in Ireland: herbarium specimens provide evidence for the response of phenophases to temperature, with implications for climate warming. Looked at temp vs date of first flower, full flower, first fruit, and full fruit with linear regression; supports use of multiphase approach to using herbarium specimens since prior work validated single phenophase work. Only one of five species examined had enough data to yield statistically significant results with temperature.

Panchen et al. 2012. American Journal of Botany. Herbarium specimens, photographs, and field observations show Philadelphia area plants are responding to climate change. Used regression analysis of date of flowering with year or with temp; 16 days earlier over 170 year period and 2.7 days earlier per 1C rise in temp; woody plants with short flowering duration best indicator of warming climate.

Proenca et al. 2012. Ecography. Phenological Predictability Index in BRAHMS: a tool for herbarium-based phenological studies. The main focus of such studies have been phenological changes which accompany warmer spring and autumn temperatures in northern temperate (Robbirt et al. 2011) or southern hemisphere alpine plants (Gallagher et al. 2009, Gaira et al. 2011, Zalamea et al. 2011).

Gaira et al. 2011. Biodiversity and Conservation. Potential of herbarium records to sequence phonological pattern: a case study of Aconitum heterophyllum in the Himalaya. Used herbarium records to look at flowering times along elevational gradient and through time; also compared to maximum winter temp and mean winter temp; used general additive model (GAM)

Robbirt, et al. 2011. Journal of Ecology. Validation of biological collections as a source of phenological data for use in climate change studies: a case study with the orchid Ophrys sphegodes. Rigorous test of validity of using herbarium specimens for phonological studies by comparing peak flowering time to climate from both herbarium and field observations, used mean spring temp. herbarium data corresponded closely with field observations.