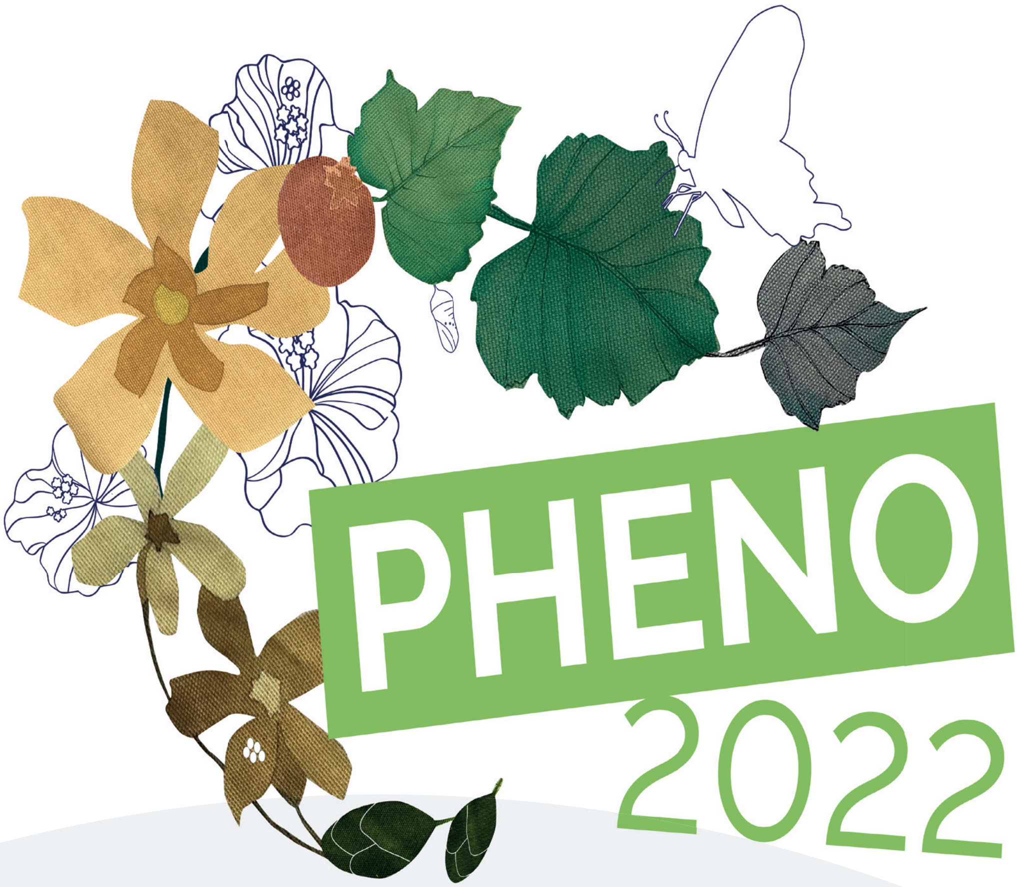


# PHENOLOGY 2022
# Phenology at the crossroads

The international meeting of the community working on phenology

June 20-24, 2022 | University Hannah Arendt - Avignon - France

Editors : Iñaki Garcia de Cortazar-Atauri - Isabelle Chuine
Isabelle Le-Mouellic - Marie Weiss

# PHENOLOGY AT THE CROSSROADS

The international meeting of the community working on phenology

June 20-24, 2022 | University Hannah Arendt - Avignon - France

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- **Pierluigi Calanca** (Switzerland)
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# Phenology 2022

# Phenology at the crossroads

*Climate change is modifying the phenological cycle of many species, directly affecting the functioning of ecosystems, species distributions, agriculture and the feedbacks between the biosphere and the atmosphere. Phenology has become an important topic for many societal and economic issues.*

*As a result, the community working on phenology has expanded considerably over the past 20 years, integrating other actors than scientists through participatory research action programs. Phenology has also gained interest from an increasing range of scientific disciplines (functional and evolutionary ecology, physiology, agronomy, genetics, climatology, remote sensing, aerobiology…).*

*For these reasons, we want to emphasize during this conference the fact that phenology is now at the crossroads of many different disciplines and actors, all working in providing insights and solutions to two enormous challenges that our societies are facing: climate change adaptation and mitigation and sustainable development.*




# PROGRAM

**Oral communications** will take place in **Amphitheater AT06**.
**Poster communications** will take place in **rooms 1-2-3** next to Amphitheater AT06

## Monday 20th June, 2022

| | | |
|---|---|---|
| **08:00 – 09:00** | **Registration**<br>University Hannah Arendt – Avignon<br>Entrance Hall 1st floor | |
| **09:00 – 09:45** | **Welcome address** | |
| **09:45 – 10:30** | **Keynote**<br>**Fulu TAO**<br>Spatio-temporal changes in major crops phenology and their drivers across China over 1981-2018 | |
| **10:30 – 11:00** | **Coffee break** | |
| **11:00 – 12:15** | **SESSION 4**<br>***Impacts of phenology on organisms, ecosystems, communities***<br>Chairs: Isabelle Chuine & Heikki Hänninen | |
| **11:00 – 11:15** | **Shouzhi CHEN**<br>Influences of shifted vegetation phenology on runoff across a hydroclimatic gradient | **S4-O1** |
| **11:15 – 11:30** | **Renan LE ROUX**<br>Wheat growing risks in France according to phenological sensitivities to climate change | **S4-O2** |
| **11:30 – 11:45** | **Pierluigi CALANCA**<br>Phenology and herbage yield and quality in Swiss permanent grasslands as linked to climate and climate change | **S4-O3** |

| | | |
|---|---|---|
| **11:45 – 12:00** | **Ilka BEIL**<br>Will our trees flush earlier and earlier? Insides from an extreme warming experiment | **S4-O4** |
| **12:00 – 12:15** | **Robert RAUSCHKOLB**<br>Flowering and leaf phenology are more variable and stronger associated to traits in herbaceous compared to tree species | **S4-O5** |
| **12:15 – 12:30** | **Poster Flash** | |
| **12:30 – 14:00** | **Lunch** | |
| **14:00 – 14:45** | **Keynote**<br>**Heikki HANNINEN**<br>Modelling as a tool for predicting and understanding phenology: A review | |
| **14:45 – 17:00** | **SESSSION 7**<br>***Phenology modelling***<br>Chairs: Annette Menzel & Raul Zurita Milla | |
| **14:45 – 15:00** | **Jonathan DAVIES**<br>Mapping flowering phenology using Species Distribution Models | **S7-O1** |
| **15:00 – 15:15** | **Mark D. SCHWARTZ**<br>New Developments in Continental-Scale Spring Phenological Modeling | **S7-O2** |
| **15:15 – 15:30** | **Marc PEAUCELLE**<br>Uncertainties in estimating budburst heat requirement when using local or gridded temperature compared to bud tissue temperature | **S7-O3** |
| **15:30 – 16:00** | **Coffee break** | |
| **16:00 – 16:15** | **Frank-M. CHMIELEWSKI**<br>Ecodormancy modelling – Some new clues after 8 years of research | **S7-O4** |

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|---|---|---|
| **16:15 – 16:30** | **Fabrizio CARTENI**<br>PhenoCaB: a new approach to model spring phenology of boreal conifers | **S7-O5** |
| **16:30 – 16:45** | **Lorena BALDUCCI**<br>Modelling budburst response to global warming across Canada | **S7-O6** |
| **16:45 – 17:00** | **Ignacio MORALES-CASTILLA**<br>Can phenology-based models of climate suitability inform quality? Insights from winegrapes | **S7-O7** |
| **17:00 – 17:15** | **Poster Flash** | |
| **17:15 – 18:30** | **Poster Session** | |

# Tuesday 21st June, 2022

| | | |
|---|---|---|
| **08:45 – 10:15** | **SESSION 7**<br>***Phenology modelling***<br>Chairs: Ellen Denny & Yann Vitasse | |
| **08:45 – 09:00** | **Mathieu LAPARIE**<br>Climate change and phenology in the pine processionary moth: stakes of better monitoring and predictions | **S7-O8** |
| **09:00 – 09:15** | **Phrutsamon WONGNAK**<br>Predicting the phenology of questing *Ixodes ricinus* nymphs in France with meteorological, bioclimatic, and land cover factors | **S7-O9** |
| **09:15 – 09:30** | **Luisa LEOLINI**<br>Does photoperiod affect the olive fruit fly seasonal cycle? A modelling approach | **S7-O10** |
| **09:30 – 09:45** | **Thibault MOULIN**<br>Application of a multi-species grassland model for analysing the response of phenology to climate change | **S7-O11** |

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|---|---|---|
| **09:45 - 10:00** | **Jianhong LIN**<br>A model of the inter-individual variability of leaf out that predicts frost damage in temperate deciduous tree populations | **S7-O12** |
| **10:00 – 10:15** | **Jerry GE**<br>Improving the temporal allocation of ammonia emissions using fertilisation days predicted with in-situ and remote sensed phenology information | **S7-O13** |
| **10:15 – 10:45** | **Coffee break** | |
| **10:45 – 12:15** | **SESSION 4**<br>***Impacts of phenology on organisms, ecosystems, communities***<br>Chairs: Ellen Denny & Yann Vitasse | |
| **10:45 – 11:00** | **Surendra RANPAL**<br>Pollen production of birch under differing environmental regimes in International Phenological Gardens across Europe | **S4-O6** |
| **11:00 – 11:15** | **Frederik BAUMGARTEN**<br>No risk–No fun. The penalty of spring frost damages on deciduous temperate trees | **S4-O7** |
| **11:15 – 11:30** | **Maxime CAILLERET**<br>Effects of drought on the seasonal dynamics of needle growth, wood production and sap velocity of Aleppo pine | **S4-O8** |
| **11:30 – 11:45** | **Dries LANDUYT**<br>Effects of phenology on community turnover in temperate forest understoreys : a model-based approach | **S4-O 09** |
| **11:45 – 12:00** | **Emilie FLEUROT**<br>Climate change, shifting flowering phenology and their consequences on the<br>reproduction of oak trees | **S4-O10** |
| **12:00 – 12:15** | **Ophélie RONCE**<br>Evolution of plant phenology under a changing climate: insights from quantitative genetics models | **S4-O11** |

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|---|---|---|
| **12:15 – 12:30** | **Poster Flash** | |
| **12:30 – 14:00** | **Lunch** | |
| **14:00 – 14:45** | **Keynote**<br>**Victor RODRIGUEZ-GALIANO**<br>Remote sensing and alternative techniques | |
| **14:45 – 16:45** | **SESSION 6**<br>***Remote sensing and alternative techniques***<br>Chairs: Marie Weiss & Alison Donelly | |
| **14:45 – 15:00** | **Emma IZQUIERDO-VERDIGUIER**<br>Extended Spring Index model assessment over the European continent | **S6-O1** |
| **15:00 – 15:15** | **Dessislava GANEVA**<br>Phenocam retrieval of barley's start and end of season | **S6-O2** |
| **15:15 – 15:30** | **Thierry AMEGLIO**<br>Continuous stem diameter variations as an innovative phenology tools for trees | **S6-O3** |
| **15:30 – 16:00** | **Coffee break** | |
| **16:00 – 16:15** | **Raul ZURITA-MILLA**<br>On the mapping of phenological regions via advanced clustering | **S6-O4** |
| **16:15 – 16:30** | **Johanna JETSCHNI**<br>Using phenology and aerobiology to evaluate the allergy risk in urban parks | **S6-O5** |
| **16:30 – 16:45** | **Raul LOPEZ-LOZANO**<br>Monitoring phenology of cherry-tree orchards from remote sensing: analysis of fAPAR time-series to identify flowering and the start of fruit growth | **S6-O6** |

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|---|---|---|
| 16:45 – 17:00 | **Poster Flash** | |
| 17:00 – 17:45 | **Poster Session** | **ISB Meeting** |
| 17:00 – 18:30 | | |

# Wednesday 22nd June, 2022

| | | |
|---|---|---|
| 09 :00 – 09 :45 | **Keynote**<br>**Nathalie BUTT**<br>Where have all the flowers gone? Phenological shifts and cascading impacts threaten biodiversity and ecosystem services in the Southern Hemisphere | |
| 09:45 – 11:45 | **SESSION 8**<br>***Impacts of phenological match and mismatch***<br>Chairs: Heather Kharouba & Mathieu Laparie | |
| 09:45 – 10:00 | **Heather KHAROUBA**<br>Lack of evidence for the match-mismatch hypothesis across terrestrial trophic interactions | S8-O1 |
| 10:00 - 10:15 | **Deirdre LOUGHNAN**<br>A global test of the drivers of shifting phenology and asynchrony | S8-O2 |
| 10:15 – 10:30 | **Yann VITASSE**<br>To what extent is gypsy moth egg hatching synchronized with the budbreak period of European trees under milder winters? | S8-O3 |
| 10:30 – 11:00 | **Coffee break** | |
| 11:00 – 11 :15 | **Irene MENDOZA**<br>Phenological mismatches increase the rate of forbidden links in a Mediterranean scrubland | S8-O4 |

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| **11:15 – 11:30** | **Sylvie ODDOU-MURATORIO**<br>Intertwining of fecundity, sexual and viability selection on spring phenology along an altitudinal gradient of European beech | **S8-O5** |
| **11:30 – 11:45** | **Julie GAUZERE**<br>Phenology and adaptive landscapes in future climate: what consequences for the maladaptation of tree populations? | **S8-O6** |
| **12:00 – 13:00** | **Lunch box** | |
| **13:00 – 22:00** | **Field trips and diner at Château Pesquié** | |

# Thursday 23rd June, 2022

| | | |
|---|---|---|
| **09:00 – 09:45** | **Keynote**<br>**Theresa CRIMMINS**<br>Making the most of volunteer-contributed observations: Recent advancements in data summary, visualization, and forecasting | |
| **09:45–10:30** | **SESSION 2**<br>***Phenology data: standards and protocols for collecting, processing and sharing***<br>Chairs: Elisabeth Wolkovich & Raul Lopez-Lozano | |
| **09:45 – 10:00** | **Jonas JÄGERMEYR**<br>A composite global crop calendar for agricultural modeling and climate change trend detection | **S2-O1** |
| **10:00 – 10:15** | **Nicolas DELPIERRE**<br>Higher sample sizes and observer inter-calibration are needed for reliable scoring of leaf phenology in trees | **S2-O2** |




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|---|---|---|
| **10:15 – 10:30** | **Marie LAUNAY**<br>Phenology of plant pathogenic fungi: why and how? | **S2-O3** |
| **10:30 – 11:00** | **Coffee break** | |
| **11:00 – 12:45** | **SESSION 1**<br>***Phenology data: standards and protocols for collecting, processing and sharing***<br>Chairs: Elisabeth Wolkovich & Raul Lopez-Lozano | |
| **11:00 – 11:15** | **Kate LEWTHWAITE**<br>Citizen scientists as phenology recorders; the challenges and benefits of mass public data collection | **S1-O1** |
| **11:15 – 11:30** | **Isabelle CHUINE**<br>When citizens are at the forefront of science | **S1-O2** |
| **11:30 – 11:45** | **Simon KLOOS**<br>NatureExplorer – an R Shiny application for citizen scientists researching climate change impacts on their own | **S1-O3** |
| **11:45 – 12:00** | **Iñaki GARCIA DE CORTAZAR ATAURI**<br>TEMPO - The French national network of phenology observatories | **S1-O4** |
| **12:00 – 12:15** | **Hans RESSL**<br>PEP725, the European phenological database, not just an update | **S1-O5** |
| **12:15 – 12:30** | **Ester PRAT**<br>Fenotwin :The digital twin of phenology | **S1-O6** |
| **12:30 – 12:45** | **Michel THIBAUDON**<br>Phenology in aerobiology network | **S1-O7** |
| **12:45 – 14:00** | **Lunch** | |

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|---|---|---|
| **14:00 – 17:00** | **SESSION 3**<br>***Phenology as a bio-indicator of climate change***<br>Chairs: Marie Keatley & Helfried Scheifinger | |
| **14:00 – 14:15** | **Zhaofei WU**<br>The sensitivity of ginkgo leaf unfolding to the temperature and photoperiod decreases with increasing elevation | **S3-O1** |
| **14:15 – 14:30** | **Ganesh THYAGARAJAN**<br>Long term fruiting response to climate in the mid-elevation evergreen forests of southern Western Ghats, India | **S3-O2** |
| **14:30 – 14:45** | **Elisabeth M. WOLKOVICH**<br>The illusion of declining temperature sensitivity with warming | **S3-O3** |
| **14:45 – 15:00** | **Bianca PLÜCKHAHN**<br>Global warming– Does it cause an increasing risk of damages due to spring frost | **S3-04** |
| **15:00 – 15:15** | **Jelle LEVER**<br>Mapping global warming effects on the plant seasonal cycle | **S3-05** |
| **15:15 – 15:30** | **Patricia MORELLATO**<br>Tropical phenology and climate change in the crossroads | **S3-06** |
| **15:30 – 16:00** | **Coffee break** | |
| **16:00 – 16:15** | **Jennifer M. FITCHETT**<br>Phenological advance of Jacaranda Bloom in Gauteng Province, South Africa | **S3-O7** |
| **16:15 – 16:30** | **Annette MENZEL**<br>Changes in the flowering intensity of European tree species – climatic and autocorrelation effects based on GAMLSS modelling | **S3-08** |
| **16:30 – 16:45** | **Eline LORER**<br>The effects of microclimate change on forest understorey flowering phenology | **S3-09** |

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|---|---|---|
| **16:45 – 17:00** | **Christine RÖMERMANN**<br>Habitat conditions should not be ignored when analyzing plant phenology and its relation to plant functional traits in herbaceous species | **S3-O10** |
| **17:00 – 18:30** | **Poster Session** | |
| **18:30 – 22:00** | **Cocktail at Avignon town hall & Gala diner & Awards** | |

# Friday 24th June, 2022

| | | |
|---|---|---|
| **09:00 – 09:45** | **Keynote**<br>**Akiko SATAKE**<br>Molecular phenology in trees | |
| **09:45 – 12:30** | **SESSION 5**<br>***Ecophysiological and genetic determinisms***<br>Chairs: Bénédicte Wenden & Pierluigi Calanca | |
| **09:45 – 10:00** | **Lumnesh Swaroop Kumar JOSEPH**<br>Individual and Interactive Effects of Elevated $CO_2$, Warming and Drought on the Phenology of Mountain Grassland | **S5-O1** |
| **10:00 – 10:15** | **Bénédicte WENDEN**<br>Transcriptomic analyses of molecular pathways involved in the regulation of bud dormancy in sweet cherry | **S5-O2** |
| **10:15 – 10:30** | **Benjamin TIFFON-TERRADE**<br>Phenological responses of potted grapevine cv. Syrah to severe intermittent shading | **S5-O3** |
| **10:30 – 11:00** | **Coffee break** | |

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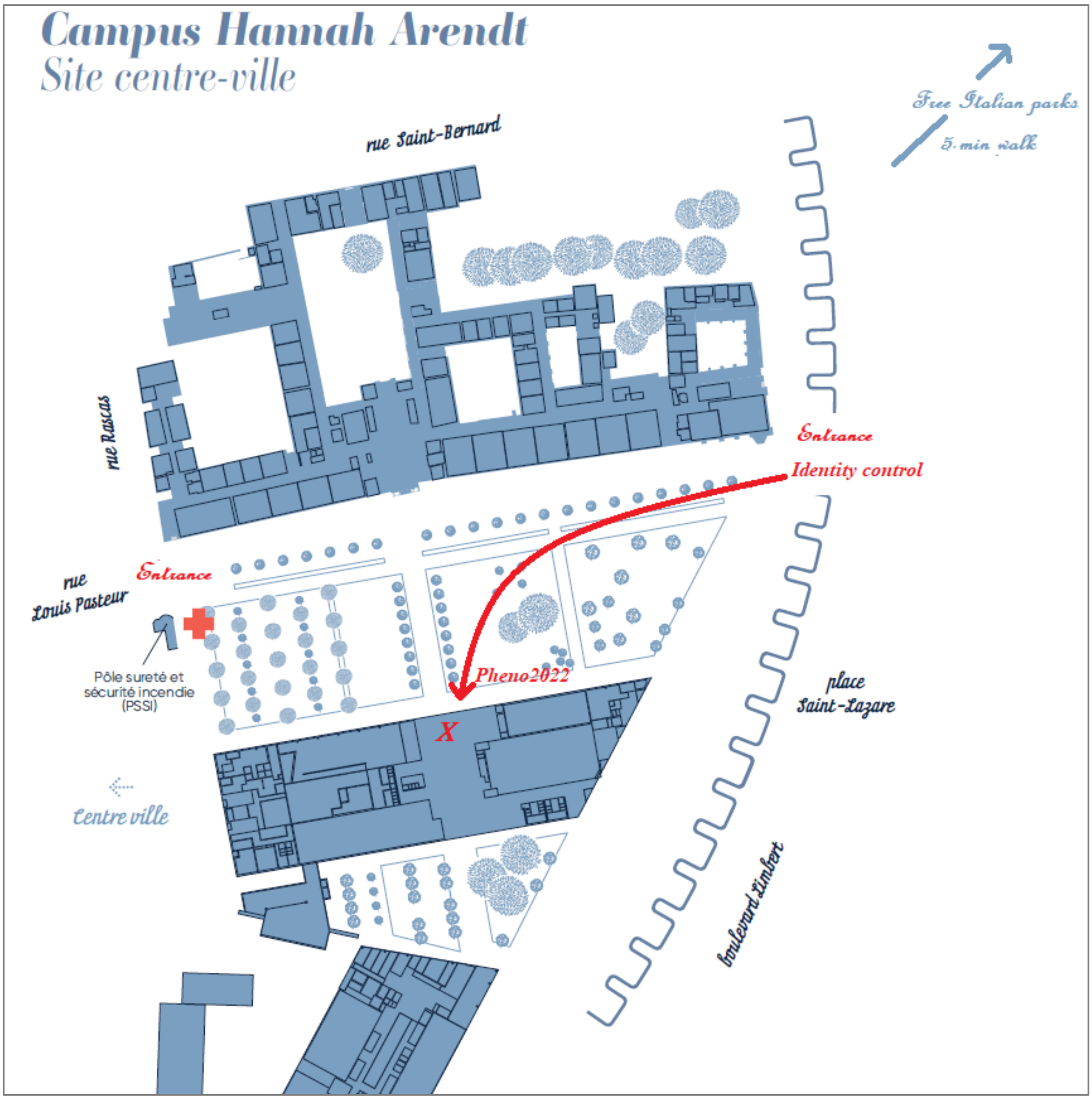
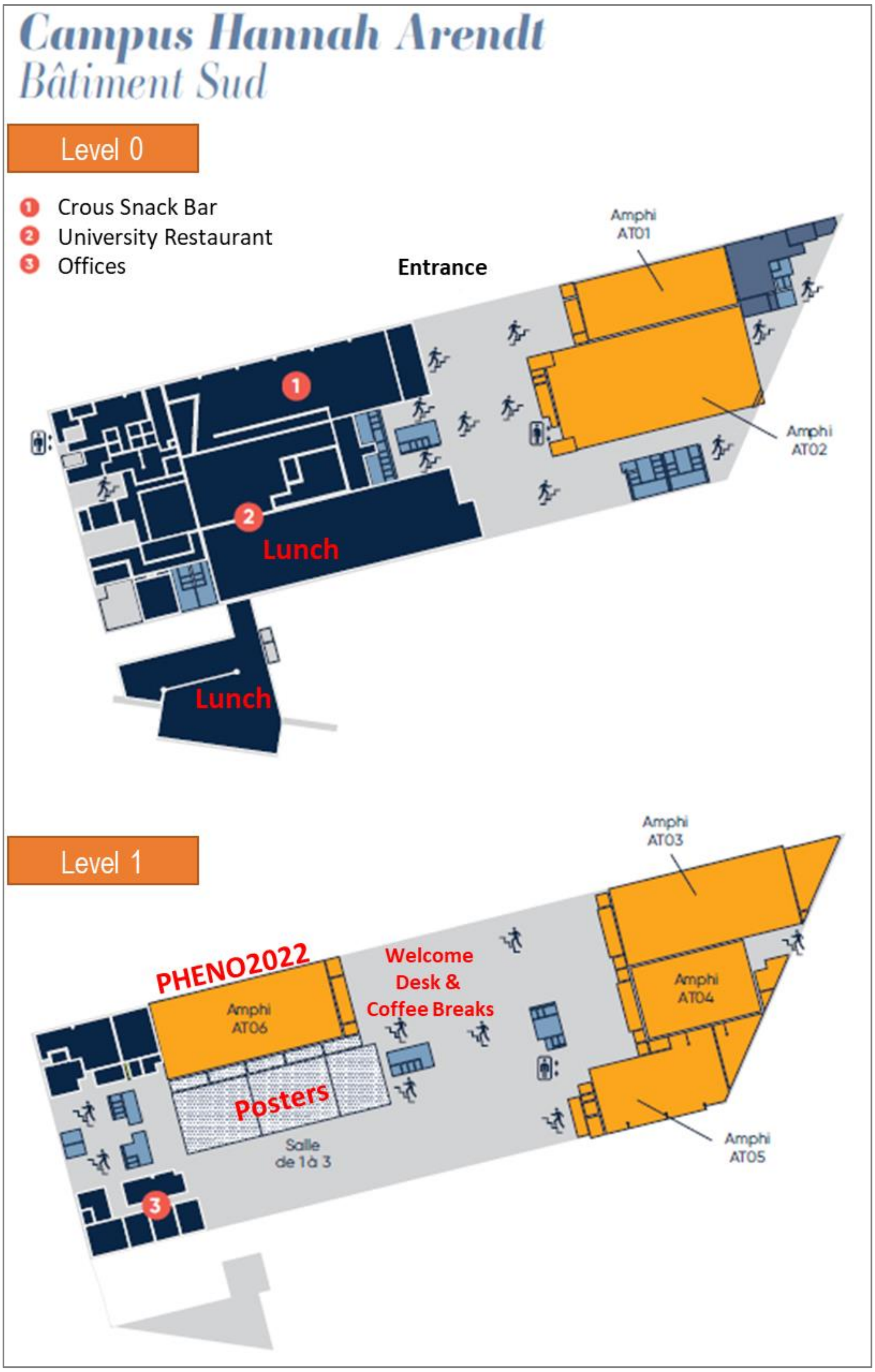
|---|---|---|
| **11:00 – 11:15** | **Léa VEUILLEN**<br>Aleppo pine primary growth response to drought in a long-term rainfall exclusion experiment | **S5-O4** |
| **11:15 – 11:30** | **Jean-Louis DURAND**<br>Effect of floral induction duration on heading date and morphogenesis in *Lolium perenne* | **S5-O5** |
| **11:30 – 11:45** | **Manuel G. WALDE**<br>Restoration of deciduous trees' vascular system takes place only shortly before budburst : evidence from isotopic labelled water | **S5-O6** |
| **11:45 – 12:00** | **Florence VOLAIRE**<br>Can summer dormancy enhance the persistence of perennial grasses under warmer climates? | **S5-O7** |
| **12:00 – 12:15** | **Solveig Franziska BUCHER**<br>Is inflorescence preformation in overwintering buds linked to plant functional traits and plant phenology? | **S5-O8** |
| **12:15 – 12:30** | **Eric DUCHÊNE**<br>Sustaining wine identity through intra-varietal diversification | **S5-O9** |
| **12:30 – 12:45** | **Conclusion** | |
| **12:45 – 14:00** | **Lunch** | |
| **15:00 – 17:00** | **Visit of the Pope Palace and the Pont d'Avignon** | |

# Maps


**1.- PHENOLOGY 2022 Conference. Avignon University – Campus Hannah Arendt**
(Lat. 43.949314; Long. 4.815547)
**2.- City Town** *(Mairie d'Avignon)*
(Lat. 43.949268; Long. 4.810543)
**3.- Gala diner – Espace Jean Laurent**
(Lat. 43.941778; Long. 4.806031)


Campus Hannah Arendt
Site centre-ville
rue Saint-Bernard
Free Italian parks
5 min walk
rue Rascas
Entrance
Identity control
rue
Louis Pasteur
Entrance
Pôle sureté et
sécurité incendie
(PSSI)
Pheno2022
X
place
Saint-Lazare
Centre ville
boulevard Limbert


Campus Hannah Arendt
Bâtiment Sud
Level 0
1 Crous Snack Bar
2 University Restaurant
3 Offices
Entrance
Amphi AT01
Amphi AT02
Lunch
Lunch
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PHENO2022
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# KEY NOTES




# Where have all the flowers gone? Phenological shifts and cascading impacts threaten biodiversity and ecosystem services in the Southern Hemisphere

Nathalie Butt[1], Kay Critchell[2]

[1] *School of Earth and Environmental Sciences, the University of Queensland, Brisbane, Australia*
[2] *School of Life and Environmental Sciences, Deakin University, Geelong, Australia*

Presenting author: n.butt@uq.edu.au

## Abstract

Climate change is already driving shifts in phenology, the timing of life-history events such as flowering, fruiting, egg-laying, birth, and migration, and this is set to increase. Although climate change is happening, and will continue to happen, globally, most of our ecological knowledge around its potential impacts on phenology is derived from temperate areas and ecosystems in the Northern Hemisphere, and information from the Southern Hemisphere is greatly lacking. This would not be a problem if biomes, ecosystems, species assemblages and species were the same in the Northern and Southern Hemispheres, but as they do, in fact, differ across many factors and scales, understanding gained from one hemisphere is not necessarily applicable to the other. In this talk I will detail the cascading processes driving ecological mismatch and outline the differences between the two hemispheres. Many species of fauna dependent on the flowering phenology of plants and trees provide ecosystem services vital for ecosystem function and resilience, and impacts on animals can feed back onto plants on an ecosystem scale. Pollination and seed dispersal, for example, are critical for forest regeneration, and decoupling of temporal relationships between plants and their dependent pollinators can have cascading ecosystem effects. Understanding how climate change affects phenology, and using shifts in phenology as indicators of climate change impacts, can make an urgent and significant contribution to the development of effective conservation strategies in unique, fragile and vulnerable Southern Hemisphere ecosystems.

**Keywords :** biodiversity conservation, climate change, ecosystem cascades, Southern Hemisphere, tree phenology, tropical forests




# Making the most of volunteer-contributed observations: Recent advancements in data summary, visualization, and forecasting

Theresa Crimmins[1]

[1] *USA National Phenology Network, School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona, USA*

Presenting author: theresa@usanpn.org

**Abstract**

The *Nature's Notebook* platform – the USA National Phenology Network's system for tracking plant and animal phenology – is used by participants ranging from backyard observers with an interest in nature to researchers and natural resource managers asking specific questions. Since the launch of *Nature's Notebook* in 2009, participants across the country have contributed a taxonomically rich and geographically-extensive dataset comprised of over 28M phenology records from nearly 18,000 sites and representing over 1,300 species. The different uses of the *Nature's Notebook* platform directly shape the phenology dataset maintained by the Network, leading to a dataset characterized by spatial bias (greater observations in urban and suburban areas than in rural areas) and taxonomic bias (greater observations for common, visible, and sessile species and species of interest for particular research questions). To ensure these data are utilized in the most appropriate ways to and to their maximum extent, we – the staff of the USA-NPN – are undertaking a variety of activities.

First, we acknowledge the unbalanced nature of the phenology observations maintained by the USA-NPN and are educating data users to ensure data are analyzed in the most appropriate and robust ways. We are actively developing tools and guidance to support data cleaning and proper use in analysis. These include enhancing the Network's R package, *rnpn*; improving discoverability of site conditions reported by observers; and flagging data that appear suspect. To minimize erroneous reports, USA-NPN staff continue to refine training materials and support and are developing functionality to allow observers to visualize and correct their observations.

Second, to inspire use of the data in novel applications, we periodically lead and formally document analyses. We are currently refining analyses demonstrating ways to capitalize on the intensity and abundance measures collected by observers. We also recently demonstrated an approach to leverage the opportunistic phenology observations contributed to *Nature's Notebook* to generate annual status assessments for phenological indicators. Finally, we are exploring the suitability of flowering observations contributed by volunteer observers to characterize airborne pollen across geographic regions.

In this presentation, I will share some of the ways the USA-NPN is supporting careful and proper data use and describe recent novel uses of the data contributed to *Nature's Notebook.* Many phenology networks are challenged by similar dataset biases and potential barriers to data use and may be inspired by these examples.

**Keywords :** application, data quality, data visualization, network.




# Modelling as a tool for predicting and understanding phenology: A review.

Heikki Hänninen[1], Rui Zhang[1], Jiasheng Wu[1]

[1]*State Key Laboratory of Subtropical Silviculture, Zhejiang A&F University, Hangzhou, China*

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## Abstract

The history of using models in phenonological research goes back to the early work of Réaumur in the 18th century. Since then new approaches, methods, and tools have been introduced, but the essential study question has remained the same: How environmental factors regulate the timing of seasonally recurring events in plants and animals? Most often the effects of climatic factors are examined, and for this reason the phenological research is closely connected to the discipline of biometeorology. In most cases the phenological events studied are developmental ones, i.e., they are indices of the ontogeny and development of the plant or animal individuals examined. Typical examples of these are spring leaf-out of vegetative buds in perennial plants and hatching of insects. However, in phenological research of animals also behavioural seasonal events, such as spring arrival of migratory birds, are studied. In all these cases the phenological events are visible to the naked eye (or to the binocular), which is why phenological data can often be readily collected also in various citizen science projects. Less often the timing of the developmental events is studied at the anatomical level with the aid of microscopy, but even then the essential study question is similar: when the event examined occurs? In all these cases phenological data is presented in terms of time. However, sometimes the concept of phenology is applied in a broad sense such that it covers the seasonal courses of physiological traits in plants and animals. For example, the time course of frost hardiness of various plant tissues may be studied, then rather than time, the unit of the phenological data is that of the trait frost hardiness, which is temperature.

As a result of the ongoing climatic change, this century has experienced a boom of phenological research. Even though only a subset of the published studies of phenology may be classified as modelling ones, the number of the modelling studies, too, is so high that it is not possible to give a comprehensive review of everything published in this field of science. Bearing that in mind I aim in my review to give an overview of the general principles and bottom lines of the research carried out in phenology modelling since Réaumur until now. Accordingly, I suggest the dichotomy of (1) prediction – (2) understanding for the two main approaches applied in phenological research. The first approach, which emphasises the accurate predicting (or projecting) the timing of the phenological events, is applied especially in the current global change research. For instance, when projecting the role of an ecosystem as a sink or a source of carbon it is essential to project the timing of the major phenological events, such as spring leaf-out and autumn leaf senescence. This approach is often characterized by the use of various big data, such as long-term phenological records, or remote sensed data collected with the aid of satellites; and also by the use of various statistical modelling techniques. The second approach emphasises the biological realism of the models developed: are the

relationships modelled real causal ones so that they describe real ecophysiological phenomena, which ultimately determine the timing of the phenological events? What can we learn with the models of the acclimation, i.e., the physiological adjustment of the plant/animal individuals to their seasonal environment; and adaptation, i.e., the genetic adjustment of the plant/animal populations to the seasonal environmental conditions that have prevailed during their evolutionary history? This approach is characterized by time-consuming experimental research, and thus smaller data sets than in the first approach; and also by the use of process-based dynamic models. The pros and cons of both approaches are discussed. Not surprisingly, it was found out that the dichotomy of the two distinctive approaches is actually an oversimplification, as many studies have attributes of both approaches. Nevertheless, I hope that this simplifying dichotomy will facilitate the scientific efforts in this growing field of science.

**Key words:** phenology modelling, climate change, process-based, big data

# Land surface phenology as indicator of global terrestrial ecosystem dynamics

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**Abstract**

Land surface phenology (LSP) is defined as the study of the vegetation phenology from multi-spectral satellite imagery. LSP approach is generally based on the analysis of timing of phenological metrics (or phenometrics) extracted from vegetation indices (VI) time-series. These phenometrics are considered as proxies of biological plant phenophases. The start of the growing season (SOS) is considered as a proxy of the spring phenophases (leaf unfolding or flowering), and the end of the growing season (EOS) is considered a proxy of the autumn phenophases (autumn colouring leaves and leaf fall). Therefore, LSP has played an essential role in monitoring the response of ecosystems to environmental changes. Although temperate and boreal ecosystems in the middle and high latitudes of the Northern Hemisphere have been studied extensively, some of them have not received the same attention (e.g., semi-desert ecosystems, Mediterranean ecosystems). LSP has generally not been well documented in the ecosystems of subtropical and tropical regions. The abundant cloud cover, the constant presence of aerosols, and the high density and diversity of numerous ecosystems make LSP extraction challenging.

The selection of satellite data (i.e., characteristics of satellite data (e.g., spatial and temporal resolution) and VI) and phenometric estimation methodology (i.e., smoothing techniques and phenometric extraction techniques) is a complex task. This selection should be based on both the characteristics of the ecosystems studied (e.g., dominant vegetation, vegetation density, plant species diversity, vegetation cover) and the prevailing atmospheric conditions (e.g., frequency of cloud cover, presence of snow cover, presence of atmospheric aerosols). Satellite image time-series have been primarily obtained from Advanced Very-High-Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments. These instruments have been providing near daily satellite data at medium-low spatial resolution (i.e., from 250 m to 8 km) for more than 20 years. However, although Landsat satellite images are available from the beginning of 1980s and their spatial resolution is of 30 meters, they have not been widely used for LSP estimation. Normalised Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Leaf Area Index (LAI) time-series. The phenological trajectories described by the IV could be influenced by different factors (e.g., cloud cover, sensor disturbances, mixing of the spectral signal of different plant organisms and non-plant elements included at the pixel level). Therefore, the VI time-series would require a certain level of pre-processing to reduce possible alterations on the phenometrics. VI time-series was denoising from different smoothing techniques (e.g., Savitzky-Golay filters, Logistic or Gaussian functions) and the phenometrics were generally extracted from threshold methods, derivative-based methods and/or autoregressive moving average methods.

In the coming years, the greater temporal coverage of recent satellites (Sentinel 1, Sentinel 2, Landsat 9), the development of new satellite products and observational networks, the launch of new satellite missions, the creation of new global and regional phenological products and the improvement of computational efficiency for processing geospatial data, could also help to improve the understanding of LSP patterns.

**Keywords:** Vegetation phenology, remote sensing, vegetation index, phenometrics.




## Molecular phenology in trees

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### Abstract

Plants that inhabit seasonally changing environments in temperate forests synchronize their leaf flushing and flowering time to coincide with appropriate seasons for growth, reproduction, and resting by responding to seasonal environmental cues such as temperature and photoperiod. In tropical forests where seasonal environmental cues are less available, there is a wide variation in phenological patterns and their climatic drivers. The difference in phenological patterns observed between temperate and tropical rainforests is a consequence of adaptation to the different environments. To understand the history of evolutionary alterations of the phenological traits in geographically diverse environments, synthesizing the body of knowledge from ecology/evolutionary and molecular/genetic studies is extremely useful.

A molecular phenology approach that monitors seasonal recurring gene expression patterns *in natura* has been used for a wide range of species, including herbs, trees in temperate and tropical rain forests. This field-based transcriptomics, called field transcriptome, is ideal to study mechanisms of flowering, fruiting, and dormancy at gene expression levels. By generating and analyzing transcriptomic data obtained from leaves, buds, and flowers sampled throughout the season, we can answer questions, such as how global gene expression profiles change in response to fluctuating environmental conditions in nature? What are the key genes associated with each phenological event? What genes are responsible for trait differences between species?

Here we introduce our recent study that characterized seasonal dynamics of global transcriptomics in multiple tree species. We generated monthly transcriptomics data over two years and extracted orthologus genes with which pairwise comparison between species is possible. Hierarchical clustering of the monthly expression profiles revealed clustering of winter and other seasons regardless of species. Transcriptional profiles other than winter were divided into summer and spring or fall. Expression profiles were similar between spring and fall regardless of different pheno-phase (bud burst and flowering in spring and fruiting in fall). We found that 27% of all orthologus genes differed in expression between species. Many of these genes are associated with pollination and female gametophyte development, suggesting that these genes are the basis for differences in reproductive phenology between species. We also compared transcriptional dynamics between temperate and tropical trees. Finally, we discuss about a mathematical model that integrates molecular phenology and climate data to predict future phenological changes in the face of global environmental change.

**Keywords :** transcriptomics, flowering phenology, fruiting, pollination, climate change

# Spatio-temporal changes in major crops phenology and their drivers across China over 1981-2018


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## Abstract

Investigating the spatiotemporal changes in crop phenology and the divers have important implications to understand crop response and adaptation to climate change. Here, the updated phenological observations with the longest time period (1981–2018) and the largest number of records for three major crops (i.e., rice, maize and wheat) in China were applied to investigate whether the response of crop phenology to recent climate warming declined, how crop responded to asymmetric warming, and how different drivers affected crop phenology change. The results showed wheat sowing date delayed but heading and maturity date advanced generally during 1981–2018. Trends in crop key phonological dates and growing periods between 1981–1999 and 2000–2018 changed heterogeneously across the agro-ecological zones. This inconsistence may be ascribed to the compound impacts of climate change and agricultural managements such as cultivar shifts. Climate warming impacts on growing period increased for winter wheat but declined for spring wheat in most regions from 1981–1999 to 2000–2018. Daily night-time temperature increased more than mean and daytime temperature, however vegetative growing period (VGP), reproductive growing period (RGP) and whole growing period (GP) were more sensitive to mean and daytime temperature than to night-time temperature. Daytime and night-time temperature had contrasting effects. Spring wheat was more sensitive to temperature than winter wheat, and RGP was more sensitive to temperature than VGP and GP. During 1981–2018, climate warming outweighed agricultural managements in affecting wheat phenology across China.  Rice responded to daytime and night-time warming differently and night-time temperature affected GP more. Climate change shortened GP by 4.5, 2.4 and 1.1 days/decade for wheat, maize and rice, respectively. Cultivar shifts offset totally the negative effects of climate change on crop phenology for rice and maize, but partially for wheat. Cultivar shifts played a dominant role in GP change in most regions for rice and maize, by contrast climate change played a dominant role in almost all regions for wheat. Our findings provide new insights into the spatiotemporal changes of crop phenology, as well as their drivers, across China in the past four decades.



**Keywords:** Adaptation, Agricultural management, Climate change, Crop cultivars, Crop growing period, Impact.




# ORAL COMMUNICATIONS

# SESSION 1




## S1.O1 - Citizen scientists as phenology recorders; The challenges and benefits of mass public data collection

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**Abstract**

To share experience and insight garnered from running a long-standing citizen science project, Nature's Calendar (NC), to communicate the challenges and benefits of a public recording phenology network.

The UK is privileged to have a long history of recording phenology, with the NC database holding nearly 3million records dating back to 1736 (Sparks *et al*, 2021). It is run by the Woodland Trust, a UK conservation charity, with one full-time staff member.
At present 69 species and over 150 seasonal events can be recorded. These were selected to continue historical datasets and be suitable for mass public data collection: easy to identify species and events that are considered both common and widespread across the UK. Some refinement has occurred in the last 21 years of the current system, which includes both online and postal recording via a seasonal form.

In recent years around 3,500 citizen scientists have recorded with NC per annum. The distribution of recorders is uneven and significantly south-centric (roughly following the population distribution). This creates a challenge for determining accurate UK averages. The recorder demographic being those within retirement age has been identified as a potential issue. Furthermore, there is a significant bias towards spring recording, exacerbating the lesser understanding of shifting autumn phenology (Sparks, 2021).

Analysis will be shared as to the relative success and challenges of various recruitment campaigns and varying tenure of citizen science recorders. Recording via postal forms renders significantly more records per citizen scientist, with considerably longer tenure also. Significant refinement in the process of adding records via the NC website has increased the accuracy and reliability of this dataset. However, challenges with both human error and the process of digital recording remain, and impacts on the dataset will be noted. For example, where significant media coverage has led to inaccurate records. However, the wider benefits of the citizen science approach will also be highlighted.

Phenology recording via citizen scientists has benefits beyond that of biological data collection. Whilst large volumes of records can be collected from a wide area, there are considerable challenges in the recruitment and retention of recorders and in ensuring a robust scientific dataset. However, ongoing analysis and evaluation has led to refined methods and continual improvement. The result is an expanding phenology database increasingly being used for scientific research, particularly on climate change impacts, at an international level (Büntgen *et al*, 2022).

**Keywords:** Phenology: Citizen Science: Nature's Calendar: UK.




Büntgen U., Piermattei A., Krusic P. J., Esper J., Sparks T., Crivellaro A. (2022). Plants in the UK flower a month earlier under recent warming. *Proc. R. Soc. B.* http://doi.org/10.1098/rspb.2021.2456

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Sparks T. (2021). Changes in the timing of autumn – the neglected season. Wood Wise: Evidence for Action. https://www.woodlandtrust.org.uk/media/49894/woodwise-spring-2021-evidence-for-action.pdf




## S1.O2 - When citizens are at the forefront of science

Isabelle Chuine[1], Iñaki Garcia de Cortazar-Atauri[2] & the TEMPO members[3] and volunteers of the Observatoire des Saisons[4]

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### Abstract

The 6th IPCC report stated that the 2010 decade had been the warmest on record worldwide, with the last six years being the warmest on record. We are currently in a transition period to a climate regime with rates of warming that will be well above historical averages and with increasing frequency of extreme climatic events. However, we lack reports on how this new regime will translate, specifically in terms of impacts for human populations and ecosystems. The earliest signature of climate change impact on ecosystems and biodiversity, which has been well documented during the last 20 years, is the modification of species seasonal activity, with cascading effects on species interactions, survival, geographical ranges as well as ecosystems productivity and feedback to the atmosphere. These changes have been so far linear with advancing activity onset at spring and delaying activity ending at autumn all along the 20th century, although those trends have decelerated during the last ten years in some regions, especially in plant species. Here we report on abnormal phenological events, which took place in Western Europe but also in other countries since 2015 at an unpreceded rate, and which do not follow the trends observed so far. For example, such events are winter blooming in plants that normally flower at spring. We strengthen the fact that these observations have been realized, for the vast majority, by citizens participating to citizen science programs dedicated to phenology and not by research institutes. We analyse the reasons for these abnormal phenomena, point the weaknesses in our institutional monitoring systems to collect such information, and discuss the consequences for biodiversity and ecosystems.

**Keywords:** vegetation phenology, abnormal activity, citizen science.




## S1.O3 - NatureExplorer – an R Shiny application for citizen scientists researching climate change impacts on their own

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### Abstract

Citizen scientist (CS) observations are increasingly needed and approved to be fundamentally valuable to understand and scientifically study climate change, as well as to promote and communicate climate change impacts to the general public. Observations of nature phenomena such as plant and animal phenology, treeline altitudes, and atmospheric allergenic pollen loads largely contribute to essential climatic related research questions. This study presents **NatureExplorer**, an integrated web-based toolbox to visualize, analyse, and explore climatic influences and impacts on nature in Bavaria, Germany. It is part of **BAYSICS**, the Synthesis-Information-Citizen Science Portal for Climate Change Research and Science Communication in Bavaria (www.baysics.de) by which CS can observe plant phenology, animals in cities, pollen release and distribution of related species as well as alpine tree line of 23 species.

Various functional units, easy and intuitive to use for CS, are implemented as well as being in ongoing development covering different aspects of the monitoring network. **PhenoTracker** gives an insight into the plant seasonality over time, (1) showing warming signals in historical time series in the form of our so-called "green warming stripes", (2) allowing the retrieval of localised past phenological records based on corresponding data of the German Meteorological Service and the interactive study of their relationships with temperature cues, as well as (3) producing interpolated phenological maps correlated with monthly temperatures. **TreelinePredict** simulates based on CS entries of tree line individuals, future tree lines and potentially colonized areas using climate indicators under current and future scenarios. Together with the practical experimental tool **TECCS** implemented, NatureExplorer performs as a standalone platform built with R shiny web framework using R programming language. Both data-based scientific analyses and educational efforts by inquiry-based learning are expected to be improved with the use of NatureExplorer.

**Keywords:** citizen science, climate change, phenology, tree line.




## S1.O4 - TEMPO - The French national network of phenology observatories

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**Abstract**

TEMPO is the French network dedicated to the long-term observation of the phenology of all living organisms (*https://tempo.pheno.fr/soere-tempo_eng/*). TEMPO is interested in all measured phenological variables that describe the annual cycle of any living organism, such as flowering, leafing, fruit ripening, leaf coloration of plants, and first appearance, date of reproduction or migration of animals. The main scientific objective of TEMPO is to understand and predict how climate change affects the seasonal rhythms of living organisms, and the subsequent consequences on the functioning and productivity of ecosystems, as well as on the dynamics of populations.

Currently, TEMPO gathers more than 250 researchers and technical staff structured around 10 observatories dedicated to the phenology of a particular taxonomic group or ecosystem (annual crops, arthropods, fishes, forest trees, fruit trees, grapevines, grasslands, pathogens and reptiles). TEMPO also includes several transversal working groups interested in the understanding of the genetic and physiological bases of phenology events such as plant dormancy and leaf senescence, innovative observation tools, phenology modelling tools, and processes to manage observation data following Open Science principles (FAIR). Finally, TEMPO integrates two citizen science programs: the *Observatoire des Saisons* (*https://www.obs-saisons.fr*); and the *Phenoclim (https://phenoclim.org/)* program which focuses on the observation of alpine phenology.

The objective of the presentation is to give an overview of the different achievements of the network since its creation: TEMPO data portal (https://data.pheno.fr) and the ongoing developments to improve the management and dissemination of the data, historical data rescue, harmonization and development of phenology scales and protocols, observation trainings, experimental work on the determinism of dormancy, development of climate services using phenology modelling, and also public outreach actions.

**Keywords:** vegetation, animals, protocols, databases, portal, citizen sciences, services, modelling.

## S1.O5 - PEP725, the European phenological database, not just an update

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### Abstract

"Phenology – the timing of seasonal activities of animals and plants – is perhaps the simplest process in which to track changes in the ecology of species in response to climate change" (IPCC 2007). PEP725, the Pan-European Phenological Database, is thought as a European research infrastructure to promote and facilitate phenological research. Its main objective is to build up and maintain a European-wide phenological database with an open, unrestricted data access for science, research and education. So far, 20 European meteorological services and 6 partners from different phenological network operators have joined PEP725. The PEP725 phenological data base (www.pep725.eu) now offers close to 13 million phenological observations, essentially starting with 1951, comprising more than 200 species and 69 growing stages based on the BBCH scale. The data base grows with about 100000 additional observations per year. Having accepted the PEP725 data policy and finished the registration, the data can be downloaded according to various criteria, e.g. by a specific plant or all data from one country.

To date (January 2022) we could count at least 94 peer - reviewed publications based on the PEP725, 9 of them published in Nature and one in Science. It appears that new avenues are entered in plant phenological research. Since remote sensing technology has been making big leaps forward with improved instruments and increasing resolution, Land Surface Phenology (LSP) is exploring its capabilities, especially experimenting with new and improved methods to correlate LSP with Ground Phenology (GP). A small but very active community continues to produce high quality research on plant physiological mechanisms and their relation with the atmospheric environment. Prominent appears the increase in the number of atmospheric variables, which have been related with plant phenology. Atmospheric brightening, for instance, rather unexpectedly counteracts warming induced delays in autumn phenology. Similarly unexpected is the plants sensitivity to light pollution. Humidity and wind apparently exert a discernible influence on spring and autumn phenology respectively. Plant phenology responds differently to daytime and night-time temperature trends.

The data base statistics demonstrate the great demand and potential of the PEP725 phenological data set, which urgently needs development including a facilitated access, gridded versions and near real time products to attract a greater range of users.

Finally, we would invite all, who have already used PEP725, to give us feedback!!! (markus.ungersboeck@zamg.ac.at; helfried.scheifinger@zamg.ac.at)

IPCC. 2007. Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK.

**Keywords:** PEP725, phenology, phenological network, phenological data base.

## S1.O6 - FENOTWIN: The digital twin of phenology

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### Abstract

FenoTwin aims to promote the culture of phenological observation among citizens as a tool for raising awareness of climate change and its effects on nature.

On the way to raising public awareness of the existence and effects of climate change, FenoTwin offers a double tool based on the Digital Twin concept applied to the observation of phenology. A Digital Twin is the generation or collection of digital data that represents a physical object. In addition to digitally representing the real state of phenology in the field as a phenological map, in FenoTwin the meaning also implies combining two twin ways of studying phenology: citizen science and remote sensing.

On the one hand, traditional phenological observation implies the dedication of volunteers to the observation of phenological changes that occur in their environment through citizen science observatories, some of which have many years of experience. Examples of those are the network of phenological observers of the Catalan Meteorological Service (FenoCat) and the Spanish Meteorological Agency, or the RitmeNatura citizen observatory.

On the other hand, advances in Earth observation technologies make it possible to obtain, from high-resolution satellite images from the ESA Copernicus program, adequate vegetation indices to monitor the degree of greenness of plant species, so that its phenological state can be accurately derived for some phenophases.

In FenoTwin the tool and the knowledge are co-created by the citizens themselves with the contribution of their phenological observations. Thus, citizens help to create, collectively, a database of phenological observations that, combined with data from remote sensing, allow the Digital Twin or phenological map of Catalonia to be generated, showing the evolution of phenological episodes over time and helping to visualize the impact of changing climatic conditions on the life cycles of vegetation.

FenoTwin is a powerful tool that will serve, on the one hand, as a vehicle to bring the knowledge and study of climate change closer to citizens, and on the other, to help scientists to complement the fragmented vision that can be obtained from space.

**Keywords:** digital twin, citizen science, remote sensing.




## S1.O7 - Phenology in aerobiology network

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**Abstract**

Pollen allergy is linked to airborne allergenic pollen. Aerobiology takes into account several parameters including the pollen emission by trees and herbaceous plants, the transport of these pollen grains by the wind and the health impact, for example the allergy symptoms.
In France, the pollen season extends from January to September depending on the season and the region: tree pollen from January to April, grasses from May to July, weeds including ragweed from August to September.

The measurement of pollens in the air enables the information of allergic people, health authorities and the medical profession but it is a data of reception of the grains on the pollen traps in the same way as on the respiratory tracts of the allergic people.
The observation of the phenological phases of flowering and pollination is an essential element to know in advance the risk of exposure of the population to pollen grains emitted by allergenic plant species.

The RNSA (2) uses various observation networks, including in particular a phenological observation network located in a dozen of cities representative of the main climatic and biogeographical regions of France. The botanical gardens of Antibes, Avignon, Brest, Lyon, Nancy… complete a phenological report each week which help us to have information on the state of flowering of the species.

The flowering data of the main allergenic species make it possible to validate the allergy risk index linked to exposure to pollen (RAEP) for the days or even the week to come.
In addition, when combined with pollen trap data, this information concerning the source of pollen emission allows the building of exposure curves that are essential for physicians and patients.

Thanks to phenological data in particular, information on the allergy risk linked to exposure to pollen is predictive and helps allergy sufferers. In addition, at the request of the Ministries of Health and Ecology, the RNSA published, in 2008, an electronic guide "vegetation in the city" (1) which aims to inform public or private decision-makers and landscapers, on the need to take into account the health component in the choice and maintenance of plant species set up in urban or peri-urban spaces.

(1) http://www.vegetation-en-ville.org/
(2) www.pollens.fr

**Keywords:** pollen, phenology, aerobiology.

# SESSION 2

## S2.O1 - A composite global crop calendar for agricultural modeling and climate change trend detection


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### Abstract

Plant phenology is an important and relatively well-studied climate change indicator. However, the majority of studies are focused on phenological changes in natural vegetation and only a few studied phenological trends in agricultural systems. Phenological changes in agriculture are more complex than in natural vegetation as they depend on, besides weather influence, farmers' decision making and management (e.g., planting dates, cultivar selection, crop rotations). Increasing temperatures are projected to reduce crop yields because they hasten reproductive development and, as a result, shorten the grain filling period. There is widespread expectation that farmers will mitigate projected yield losses by planting longer season hybrids, but there is mixed and unclear evidence on where and to what extent this is already happening. A number of regional studies have highlighted advancing observational climate change trends in phenological stages including anthesis and maturity dates, e.g. for wheat in China and Germany, and for maize in the US. But currently available observational data on crop planting and maturity dates are discrete and with limited spatial extent. A global comprehensive data product that allows analyses of how farmers are adapting to changing climatic conditions is missing.

A second motivation for creating such a data set is global crop modeling. State-of-the-art process-based crop models are limited by available input data and spatially explicit and detailed information on local planting and harvest dates are a critical example. The global crop modeling community is working with recently updated crop calendars for the major crops, but these are static in time, describing average conditions. Annually resolved inputs on planting and harvest dates would allow to calibrate the crop models better and this has the capacity to substantially improve model performance in terms of reproducing observed trends and inter-annual variability.

Here we present a global composite crop calendar product derived from various observational data sources including national agricultural ministries, CIMMYT and INRAE research sites, and phenological data bases such as pep725 and PHENO. Wherever possible we maintain an annual resolution, in many important breadbasket regions with data for more than 50 years.

This new data product is purely observation-based, gap-filled, and designed for the use in global agricultural modeling efforts, such as by AgMIP's Global Gridded Crop Model Intercomparison Project. But it also supports empirical studies that derive climate change trends in global crop phenology.

**Keywords:** crop phenology, global agriculture, climate change impact, adaptation, crop modelling




## S2.O2 - Higher sample sizes and observer inter-calibration are needed for reliable scoring of leaf phenology in trees

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### Abstract

Reliable phenological observations are needed to quantify the impact of climate change on tree phenology. Ground observations remain a prime source of phenological data, but their accuracy and precision have not been systematically quantified. The high subjectivity of ground phenological observations affects their accuracy, and the high within-population variability of tree phenology affects their precision. The magnitude of those effects is unknown to date.

We first explored the inter-observer variability in the timing of bud development and leaf senescence in trees using a unique dataset of seven observer inter-calibration sessions. Then, using tree phenological data collected in three European forests (n= 2346 observations for budburst, n= 539 for leaf senescence), we quantified how the "observer uncertainty" (accuracy of the observations) and the "population sampling uncertainty" (precision of the observations) combine to affect the estimates of the budburst and the leaf senescence dates.

The median observer uncertainty was 8 days for budburst (BBCH=7) and 15 days for leaf senescence (BBCH=95). As expected, the population sampling uncertainty decreased with increasing sample size, and was about 6 days for budburst and 10 days for leaf senescence for a sample of 10 individuals monitored per population (corresponding to the median sample size in the phenological literature). As a whole, the overall uncertainty of phenological observations could reach up to two weeks for budburst and one month for leaf senescence.

This paper quantifies for the first time the accuracy and precision of ground phenological observations in forest trees and as such offers tables to estimate the uncertainty of phenological data. We show that reliable estimates of budburst and leaf senescence require three times (n= 30) to two times (n= 20) larger sample sizes as compared to sample sizes usually considered in phenological studies. We further call for an increased effort of observer inter-calibration, required to increase the accuracy of phenological observations. These recommendations reduce the uncertainty of phenological data, thereby improving the estimation of phenological trends

over time, the response of phenology to temperature or the inference of phenological model parameters.

**Keywords:** ground phenological observations, observer uncertainty, accuracy, sampling uncertainty, precision.




## S2.O3 - Phenology of plant pathogenic fungi: why and how ?

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### Abstract

The timing of key events in fungal species life cycle has been studied at different spatial and temporal scales, in particular timing of reproduction (fungal fruiting) and more rarely timing of dispersal (spore release; Peay et al., 2012). However, the "phenology" of plant pathogenic fungi is rarely monitored, likely due to the difficulty to observe the different life stages of microscopic organisms, and has rarely been formally studied *per se* in the literature. To our knowledge, there is no global scale for rating the phenology of plant pathogenic fungi *sensu lato*. However, such a tool would make it possible to study, understand and compare the impacts of climate change and changing practices on plant health (Bebber, 2015; Corredor-Moreno & Saunders, 2020). In this respect, it could prove useful for surveying, anticipating, and managing situations at risk of epidemics, and thus facilitating the adoption of alternative methods. Fungal and fungal-like organisms belong to a large diversity of genera and species, differing in morphology or specific stages in life cycles for example. Despite this diversity, all pathogenic fungal divisions share some key features and development stages (e.g. spore, spore germination, mycelial growth, reproduction, conservation).

We developed the *FunScale*, a phenological scale adapted for plant pathogenic fungi. This scale was constructed by identifying life stages common to the different kingdoms and divisions (main and secondary stages) and specific to each division considered (tertiary stage). However, the use of this scale remains dependent on the observation of signs and symptoms on the host plant, which led us to develop a lexicon associated with an image database. We are currently testing the relevance and genericity of this scale on pathogenic fungi infecting different crops (annual and perennial), whose biological cycles are particularly contrasted. We argue that the proposed phenological scale will allow to examine the major biophysical evolutions, because the phenology of fungi reflects the variability of both biotic and abiotic environments. In particular, using a common phenological scale to monitor pathogenic fungal development will set the stage for a global assessment of the presence, absence, or predominance of a particular phase, the speed of succession of phenological phases, the synchronism shift between fungi and host plants, in a large range of environments and ecosystems. Finally, *FunScale* is also an

interesting methodological tool for modeling, either upstream to build or improve models, or downstream in a heuristic approach for model evaluation and questioning.

**Keywords:** climate change, crop disease, plant pathology, adaptive trait.

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# SESSION 3




## S3.O1 - The sensitivity of ginkgo leaf unfolding to the temperature and photoperiod decreases with increasing elevation

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### Abstract

Climate change-induced phenological shifts have exerted significant effects on the structure and function of terrestrial ecosystems. Spring leaf unfolding is triggered by a combination of winter chilling, spring temperature and photoperiod, yet the effects of these cues along elevation remains poorly understood. Based on the twigs collected from male and female gingko trees at three elevations on Tianmu Mountain in eastern China, we conducted a manipulative experiment with three temperature (10, 15, and 20 °C) and two daylength (8 and 16 h) treatments to investigate the elevation and gender differences in the response of ginkgo leaf unfolding to climate. We observed slightly earlier leaf unfolding dates in male twigs (1 day), and a higher heat requirement (growing degree hours) for leaf unfolding in female (14,334±588 °C) compared to male twigs (13,874±551 °C). Similar responses to temperature (temperature sensitivity, $S_T$=3.7 days °C$^{-1}$), photoperiod and elevation were observed across genders. The long photoperiod treatment shortened the time to leaf unfolding by 9.1 days, but temperature and photoperiod effects on leaf unfolding differed significantly depending on the elevation of the donor trees. Specifically, $S_T$ was higher (4.17 days °C$^{-1}$) and the photoperiod effect on $S_T$ was larger (decreased by 1.15 days °C$^{-1}$) at the lowest elevation than at the higher elevations ($S_T$=3.26 days °C$^{-1}$; decreased by 0.48 days °C$^{-1}$). This may be related to environment-induced local adaptations and self-protection mechanisms of trees at high elevations to avoid frost damage. Our results indicate that the photoperiod and genetic adaptations to local environments influenced the warming-induced phenological responses in ginkgo, but these responses were generally similar between the genders. For a given species, individuals in different climates may exhibit different phenological responses to higher

temperatures, with individuals in warmer regions likely becoming increasingly limited by the photoperiod as the climate warms further.

**Keywords:** climate change, temperature sensitivity, photoperiod, elevation, twig cutting experiment, gymnosperm

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## S3.O2 - Long term fruiting response to climate in the mid-elevation evergreen forests of southern Western Ghats, India.

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### Abstract

Long term phenological observations in the temperate regions have established that climate change can lead to rapid and considerable shifts in phenology. Consequently, several phenological monitoring stations across the world was established in tropical regions in the 1990s and data from these are now emerging. Tropical phenology is complex with the frequency of flowering and fruiting not strictly tied to the annual calendar and phenological response to climate may not be linear. Here we describe the phenological patterns of trees in a wet evergreen forest in the Kalakad Mundanthurai Tiger Reserve of Western Ghats, India based on a long term dataset where 729 individual trees belonging to 90 species were monitored every month from Jan 1991 to April 2021. We link the fruiting patterns to rainfall and temperature available at the site to establish its response to climate. Fruiting appears to be positively related to minimum temperature. Rainfall did not have any effect but the number of rainy days had a significant positive effect on fruiting. Fruiting has also decreased over the 30 y period and so is minimum temperature. Fruiting was also negatively affected by strong *Elnino* events. It, therefore, appears that the fruit production in the forest is likely to decline over time and along with *Elnino* events that affect fruit production, a negative consequence on the frugivore community can be expected in the area. However, more nuanced analysis is needed for firmer conclusions.




## S3.O3 - The illusion of declining temperature sensitivity with warming

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**Abstract**

Temperature sensitivity—the magnitude of a biological response per C—is a fundamental concept across scientific disciplines, especially biology, where temperature determines the rate of many plant, animal and ecosystem processes. In phenology, it is a commonly used metric, taking the place of earlier estimates over time (e.g., change in days per decade). Recently, multiple studies using forms of linear regression have found temperature sensitivities decline as temperatures rise: either over time with anthropogenic warming or across space (e.g., in urban heat islands). Such findings may suggest climate change is reshaping biological processes, with major implications for forecasts of future change. However, a simple alternative explanation for observed declining sensitivities comes from the use of linear models to estimate non-linear temperature responses.

We show using simulated and real data how linear estimates of sensitivities will appear to decline with warming for events that occur after a cumulative thermal threshold is met—a common model for many biological events. Corrections for the non-linearity of temperature response in simulated data and long-term phenological data from Europe remove the apparent decline. Our results show that rising temperatures combined with linear estimates based on calendar time produce observations of declining sensitivity—without any shift in the underlying biology.

Current methods may thus undermine efforts to identify when and how warming will reshape biological processes, but improved methods can help. We close by reviewing fundamental issues in both simple statistical approaches and more complex process-based models in phenology, and how approaches using simulated data and better metrics of uncertainty may improve our estimates.

**Keywords:** climate change, temperature sensitivity, bias, regression, statistical artifacts




## S3.O4 - Global warming – Does it cause an increasing risk of damages due to spring frost

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**Abstract**

We analysed whether the probability of plant damages due to spring frost has increased in the recent past despite global warming.

Long-lasting phenological observations, as they are realised in Germany partially for more than 100 years, clearly show changes in phenological development due to climate change.

An enormous shift was determined in spring. For example, the cherry blossom started about 10 days earlier in the period 1991 to 2020 than in the period 1961 to 1990.
Contemporaneous springtime cold air invasions still take place despite global warming. Even though they generally weakened, they now hit further developed plants.

For a better understanding, we analysed, whether changes in probability of spring frost damages have occurred during the past decades. For this purpose meteorological and phenological data from the period 1961 to 2020 have been statistically evaluated. Therefore late frost events have been examined in combination with the early plant development, taking into account different phenological stages of fruits and agricultural crops (e.g. cherry and apple blossom, germination of corn and sugar beet). Depending on the plant, we defined different temperature threshold values below which relevant damage is expected to occur.

In the recent past the analysis shows changes in the probability of damages due to spring frost. Depending on the culture the risk has decreased in some German regions, while it has increased in other areas Therefore it cannot be inferred that the risk of spring frost damage due to climate change is decreasing. Instead, in the near future damaging spring frost still has to be expected, partly even with increasing frequency!

**Keywords:** global warming, phenological development, spring frost, plant damages

## S3.O5 - Mapping global warming effects on the plant seasonal cycle


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### Abstract

Studying the effects of global warming on the plant seasonal cycle is important because this helps forecasting changes in the interactions between vegetation growth, carbon sequestration, albedo effects, and the climate, and because changes in the plant seasonal cycle may lead to mismatches in species interactions affecting ecosystems and biodiversity. To this end, we provide a global outlook on biogeographic patterns in the interrelationships between climate warming and global land surface phenology using satellite data. More specifically, we determine the annual period of highest correlation between the mean air temperature and the onset of 'spring green-up', 'summer maturity', 'autumn green-down', and 'winter dormancy', and the approximate strength of temperature-phenology interrelationships during this period using regression analyses. Phenology metrics were obtained from the MODIS Global Land Cover Dynamics Product over the period 2001-2018. The mean air temperature was determined using ERA5 data.

We found that, globally, the onset of spring green-up, summer maturity, and autumn green-down correlate strongly with temperature fluctuations within the same period of the year, i.e. roughly one or a few weeks prior to green-up. Particularly strong temperature-phenology interrelationships, i.e. +7 days earlier per degree temperature increase, were found in coastal areas for the onset of spring green-up, while equally strong effects were found for the onset of maturity and green-down in (increasingly) more continental, humid or semi-humid areas. In arid or semi-arid regions, we found strong delays in these metrics of +7 days per degree temperature increase. The interrelationships between temperature and the onset of winter dormancy were less straightforward.

Interestingly, areas in which vegetation growth appears to be most sensitive to a change in temperature are not necessarily the same as the areas in which the change in phenology was largest over the period 2001-2018. This is because the effects of climate change were not distributed equally over the globe. Largest shifts in the onset of spring green-up were observed in regions that experienced the strongest warming trend during the relevant period of the year, i.e. North-West Canada and Alaska (–8 days/decade). Observed changes in the onset of autumn green-down, on the other hand, appear to have remained relatively minor because the change



in temperature has been smaller in the areas in which the onset of green-down appears most sensitive to a change in temperature.
These findings may have large implications for our view on the interrelationships between climate change and global land surface phenology.

**Keywords:** climate warming, plant seasonal cycle, phenology, remote sensing

## S3.O6 - Tropical phenology and climate change in the crossroads.

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**Abstract**

Phenology is and ancient science of nature observation that reflects the interest of mankind on their surroundings, their curiosity regarding the recurring cycles of plants they need for food bur also for medicine, handcraft, comfort, and wellbeing. Tropics are well known for its incredible number of plant species across all life forms, their high dependence on animals for pollination and seed dispersal, delivering key ecosystems services. Tropical phenology is a complex issue as much as the study of tropical diversity.

Temporal responses of plants to climate are hard to track on tropical systems from individual plants, species to ecosystems. Therefore, attribute phenological shifts to climate change remains a challenge, and yet few studies were able to link phenology of tropical biomas to climate change. The recent IPCC Report WGII point out the lack of information and need of further investigation. Along with, the United Nations have prepared a new UNEP Frontiers Report putting phenology and mismatch in the frontline of research for the next year and again pinpoint our shortage of information. Here we propose several ways to reach a robust knowledge regarding temporal responses and shift of tropical phenology to climate change. We highlight some ways are 9i) reviews and synthesis, unlocking literature and old observations; (ii) use of herbarium records, to recover long term patterns and responses; (iii) applications of evolutionary and modeling tools to search for clade's sensitiveness to changes on their phenological niche; (iv) combine observations and experiments to understand temporal mismatches; (v) networking- develop citizen science initiatives and monitoring networks to collect more comparative data over large special scales; (vi) experiments - impose climate scenarios to tropical plants (e.g. $CO_2$ enrichment – FACE, drought experiments, transplants); (vi) new technologies which may maximize our understanding at large scales (new remote sensing tools).

I discuss the ways forward to achieve a consistent progress in our knowledge of tropical plant phenology and their responses to climate change, and welcome collaborative ideas and insights.

**Keywords:** Flowering phenology, Climate change, Mediterranean ecosystems keyword5.

# S3.O7 - Phenological advance of Jacaranda Bloom in Gauteng Province, South Africa


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## Abstract

The Gauteng Province in the northern interior of South Africa is transformed into a purple vista each spring with the bloom of Jacaranda mimosifolia (Bignoniaceae). These trees were introduced from Brazil in the 1800s into the suburbs of Johannesburg and Pretoria to beautify the cities. The distinct appearance during flowering, the abundance of the trees, and the symbolism for the two cities has resulted in reporting of peak flowering events in local newspapers throughout the past century. This provides a valuable phenological record, particularly in southern Africa where phenology is seldom recorded. Analysing these reports of Jacaranda mimosifolia flowering, an advance of 2.1 days per decade is calculated for the period 1927–2019. This occurs against a backdrop of statistically significant annual and monthly temperature increases of ~0.1−0.2 °C/decade for Tmax and ~0.2−0.4 °C/decade for Tmin, and non-uniform change in rainfall. This phenological advance is most significantly related to winter climatic conditions, including Tmax, rainfall and frost occurrence. The strongest phenological driver is June Tmax, at a rate of 4.3–5.3d/°C across the City-Region. This advance reflects the response of the tree to regional climate warming, which poses threats to the species and the urban forest in the long term when thresholds for adaptation are surpassed.



**Keywords:** jacaranda, flowering, blossom, climate, Gauteng City Region.

## S3.O8 - Changes in the flowering intensity of European tree species – climatic and autocorrelation effects based on GAMLSS modelling


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### Abstract

The masting behaviour of tree species and its consequences for ring growth and food webs may represent important ecological impacts of climate change. However, the focus of recent studies has mainly been on (short records of) seed production and is thus insufficient for determining long-term changes. Flowering intensity is therefore a valuable complement to studies on masting. A 66-year continuous dataset of regional flowering intensities, comprising eight tree species (*Alnus glutinosa*, *Fagus sylvatica*, *Larix decidua*, *Quercus petraea*, *Quercus robur*, *Picea abies*, *Pinus sylvestris*, and *Pseudotsuga menziesii*) was recompiled based on historical observations in Germany. A GAMLSS (Generalized Additive Models for Location Scale and Shape) model was applied to analyse flowering intensity and its relationship with weather factors (temperature, precipitation, and drought), time and provenance effects.

Mean flowering intensity index scores significantly increased over time for all species (from 0.01 $year^{-1}$ to 0.02 $year^{-1}$, except for *Alnus*), while temporal variability decreased and congruence between species increased. Temperature was the strongest explanatory climate variable, with growing season temperature in the 1st year before flowering predominantly increasing and in the 2nd year before flowering mostly decreasing intensity. Drought, assessed by SPEI24, consistently decreased flowering intensity and year (as a proxy for increasing atmospheric $CO_2$ concentrations) increased it. Only for *Fagus* and *Pinus*, there was a stronger association of flowering intensity with the areas of provenance.

Flowering intensity was thus mainly influenced by cyclical but oppositely acting factors of the previous year growing season (negatively acting flowering intensity, positively temperature) and the pre-previous year growing season (positively acting flowering intensity, negatively summer temperature as well as long-term drought conditions). Consequently, the periodicity of flowering intensity between full flowering and no or weak flowering can be attributed both to environmental drivers and probably to resource depletion from past masting. As atmospheric $CO_2$ concentrations and temperature will continue to rise in the future and drought periods may intensify, flowering intensities are likely to continue to increase, with various consequences for (seed) masting, allergenic pollen calendars, and relationships in pollinator and food webs that need to be further studied.




## S3.O9 - The effects of microclimate change on forest understorey flowering phenology

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### Abstract

Climate change is giving rise to redistribution and local extinction of species globally and is becoming an increasingly dominant threat to biodiversity and the functioning of ecosystems. In an attempt to cope with their changing environment, many species are altering the timing of their life cycle events, such as flowering. Forest understorey species experience climate buffering from the tree canopy, meaning that their phenology is most likely driven by microclimate, i.e. temperature and light availability at the forest floor, rather than macroclimate. Microclimates are regulated by the canopy structure, and canopy change resulting from forest management interventions will thus also affect the microclimate experienced by the understorey vegetation. Following microclimatic changes, species-specific phenology shifts can alter competitive relationships between species, possibly affecting community composition and associated ecosystem functioning. Therefore, understanding how climate warming and light availability – and their interactions – drive plant phenology and uncovering the ensuing communities' response is crucial to develop strategies to prevent future biodiversity loss and maintain forest functioning.

The aim of this study is to assess the impact of microclimate warming and light availability on understorey flowering phenology. More specifically, the study aims to answer three research questions: (1) How sensitive is understorey flowering phenology to microclimate change? (2) Does light availability influence this sensitivity? (3) Are these sensitivities related to specific plant traits? To investigate this, we monitored flowering of ten temperate forest understorey species (e.g. *Anemone nemorosa* and *Hyacinthoides non-scripta*) and collected microclimate data in two ongoing mesocosm experiments in the Aelmoeseneie Forest in Gontrode, Belgium from February until October 2021. The experiments apply treatments of warming (through open-top chambers or IR heaters) and illumination (representing forest management) in a full-factorial design to experimental communities. We derived timing start, peak and end of flowering and also determined flowering season length. Using mixed effects models we assessed the effects of temperature and light availability on these 4 phenological variables for every studied species. Moreover, additional analyses will assess the relation between the species-specific phenological sensitivities and their traits (e.g. height and specific leaf area).

We conclude that understorey species' flowering phenology is indeed greatly affected by warming and illumination, but an interspecific variability in these responses is observed. Moreover, we emphasize the importance of gathering microclimate data, as the phenological temperature sensitivities in our experiment were up to two times higher than in relation to macroclimate warming, as reported by previous studies.

**Keywords:** climate change, light availability, forest understorey, flowering phenology, experiment.




## S3.O10 - Habitat conditions should not be ignored when analyzing plant phenology and its relation to plant functional traits in herbaceous species

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### Abstract

There is an increasing body of literature indicating that phenology is a fingerprint of climate change, as variations in temperature and precipitation have been identified as the most important drivers of plant phenology. It has also been shown that species respond to these variations in climate in a species-specific way. This study aims at investigating the effect of habitat conditions on the phenology as well as on the link between phenology and plant traits on the local scale.

We selected 16 herbaceous species occurring in (i) semi-dry grasslands, (ii) mesophilic grasslands and (iii) the Botanical Garden within the city of Jena (Central Germany) to investigate the influence of habitat conditions on intraspecific patterns in plant phenology and functional traits. Leaf and flowering phenology were monitored on a weekly basis from April to October 2020, and all populations were characterized with respect to whole plant, leaf and floral traits and abiotic site conditions. We used multivariate statistics (PCA) to analyse species- and habitat-specific patterns in phenology and traits. We ran boosted regression trees (BRT) to investigate the relative impact of traits on the timing of leaf out, start senescence, first flowering day, maximum flowering intensity, flowering duration, and fruiting accounting for different habitat conditions.

The PCAs clearly indicated that local habitat conditions had a stronger impact on species-specific trait compared to phenology patterns in all populations growing in the three habitats. Populations in mesophilous grasslands showed a rather consecutive flowering pattern indicating temporal niche segregation whereas the populations of the same species displayed flowering synchrony in semi-dry grasslands. The BRTs showed that reproductive traits such as generative height, flower density and flower size were most important in influencing first flowering day, maximum flower intensity and flowering duration but also leaf senescence and fruiting. The relevance of the predictors as well as the direction of influence depended on the habitat.

We concluded that habitat conditions strongly affect the phenology and the traits as well as their associations of grassland species on the local scale. Thus, local information on the habitat should not be neglected when studying phenology, functional traits or their associations also in large-scale studies.

**Keywords:** flowering phenology, senescence, semi-dry grasslands, mesophilous grasslands, botanical gardens

# SESSION 4




# S4.O1 - Influences of Shifted Vegetation Phenology on Runoff Across a Hydroclimatic Gradient

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**Abstract**

Climate warming has changed vegetation phenology, and the phenology-associated impacts on terrestrial water fluxes remains largely unquantified. Based on remote sensing-based vegettion datasets and hydrological station observed river runoff from six river basins across a hydroclimatic gradient from northeast to southwest in China, the relative contributions of the vegetation (including spring and autumn phenology, growing season length and gross primary productivity) and climatic factors affecting the river runoffs over 1982-2015 were investigated by applying grey relational analysis. We found that the average growing season lengths in humid regions (190 ~ 241 days) were longer than that in semi-humid regions (186 ~ 192 days), and the average growing season lengths were consistently extended by 4.8 ~ 13.9 days over 1982-2015 period in six river basins. The extensions were mainly linked to the delayed autumn phenology in the humid regions, and to advanced spring phenology in the semi-humid regions. Across all river basins, the grey relational analysis results showed that precipitation ($r = 0.74$) and soil moisture ($r = 0.73$) determine the river runoffs, and the vegetation factors especially the vegetation phenology also affected the river runoffs (spring phenology: $r = 0.66$; growing season length: $r = 0.61$; autumn phenology: $r = 0.59$), even larger than the contribution from temperature ($r = 0.57$), but its relative importance are climatic regions dependent. Interestingly, the spring phenology is the main vegetation factor in the humid region for runoffs reduction, while both spring and autumn growth phenology are the main vegetation factors in the semi-humid region. This paper reveals diverse linkages between climatic and vegetation factors, and runoff in different hydroclimatic regions, and provides insights that vegetation phenology influences the ecohydrology process largely depending on the local hydroclimatic conditions, which improve our understanding of terrestrial hydrological responses to climate change.

**Keywords:** vegetation phenology, runoff, climate change, semi-humid and humid regions, river basins.




# S4.O2 - Wheat growing risks in France according to phenological sensitivities to climate change.

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**Abstract**

The feasibility and success of wheat cultivation, one of the three most produced cereals in the world, depend to a large extent on the climate. However, wheat reacts differently to abiotic stressors depending on the phenological stage when the stress occurs. Climate change alters the intensity and frequency of many types of climatic risks, as well as the (a)synchronicity of these risks with the sensitive phenological phases of wheat. This study explores these issues.

In a first step, we estimated the calendar dates when the sensitive phenological stages of wheat occurred, using a photo-thermal phenological model that accounts for vernalisation requirements (Brisson et al., 2009). We evaluated the predictive accuracy of the phenological model on two contrasted cultivars (a very early and a very late maturity cultivar) against observations from the national Epiphyt database via the TEMPO portal. A second time was dedicated to build ecoclimatic indicators, i.e. climatic indicators corresponding to the main phenological periods, in order to improve forecasting and address climatic risks during key stages (Caubel et al., 2015). This approach, already implemented for corn (Caubel et al., 2018), was here spatially harnessed for wheat in France with a 64 km² resolution for past (1980's) and future climate scenarios with the emission scenario RCP 8.5 (2100) using three Global Circulation Model- Regional Climate Model models.

Simulation errors from phenological modeling were of about 2 days for the 'ear 1 cm' stage, and about a few days for the other stages, with significant variations depending on the cultivar considered. The phenological model was then used to estimate key phenological stages for climate scenarios from the recent past and the far future (2100), and ecoclimatic indicators were computed for each of the phenological periods of interest. From the ecoclimatic analysis, it appeared that climatic risks for wheat are unlikely to drastically change in the near future (2050). By contrast, climatic risks are projected to increase both in terms of occurrence and magnitude by the end of the century.

Importantly, thermal and drought stresses during the crop cycle are projected to increase, with important changes during the grain filling period and strong impact on yield. New types of stresses (drought, heat waves,…) are projected to emerge in the future, with different spatial distributions.

The study will further explore the projected impacts of future climates and explore different adaptation strategies, including cultivation of earlier-maturing cultivars.

**Keywords:** climate change, soft wheat, ecoclimatic indicator, climatic risks.

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# S4.O3 - Phenology and herbage yield and quality in Swiss permanent grasslands as linked to climate and climate change

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## Abstract

Grasslands deliver important ecosystem services, providing in first place forage. Yet, retaining yield and quality in the face of climate change is becoming a challenge. Guidelines for the timing of harvesting often resort to phenology, highlighting the key role of the latter. As monitoring phenology in species-rich permanent grasslands by direct observation requires specific knowledge and can be time consuming, there is an increasing interest for proxies that can be computed in real-time from readily available data, in particular temperature.

In this contribution we discuss the relationships between temperature sum (growing degree-days, GDD) and various aspects of grassland phenology, yield and quality, using data from a three-year experiment on 23 intensively managed permanent grasslands characterized by different functional types and located across Switzerland. At each site, replicated plots were established in 2017 and managed thereafter following common practice. Phenology of key species was monitored at regular intervals, and a representative phenology index (SED) inferred from these data based on previous work. Harvested biomass (4 successive harvests across different subplots during the first growth cycle) was analyzed for protein and fiber content. Following suggestions by INRAE, GDD were calculated considering only temperatures above 0°C and prescribing a ceiling temperature of 18°C.

With respect to spring growth, we find a strong positive relationship between SED and GDD. Owing to the link between phenology and growth, we further find a strong positive relation between herbage yield and GDD, as well as a strong negative relationship between protein and fiber content and GDD. Our results indicate that a first harvest between 650 and 750 GDD could provide the best trade-off between forage yield and quality.

Applying these findings in conjunction with an ensemble of climate change scenarios, we assessed future shifts in the optimum time window for the first utilization. Results suggest that across our sites the ongoing trend toward earlier phenology is likely to continue at about the same pace as currently observed, i.e., -2.5 days (10 yrs)$^{-1}$, until at least 2050, irrespective of emission scenario.

**Keywords:** phenology, permanent grasslands, yield and forage quality, climate change.




## S4.O4 - Will our trees flush earlier and earlier? Insides from an extreme warming experiment.

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**Abstract**

Ongoing climate warming has led to a clear advancement in spring phenology of trees. However, this advancement is slowing down despite continuous climate warming, because reduced chilling during winter delays spring phenology. How will this end up if climate warming goes on?

What will happen, if the chilling requirements are not met because climate warming goes on? Will the advancing effect of warming be compensated by the delaying effect of reduced chilling? Or even overcompensated?

We experimentally investigated the impact of extreme warming from September till flushing on two common European tree species. The control temperature was 3°C above the long term mean, and the elevated temperature was ca. 4°C above the control. Both species still unfolded their leaves earlier under elevated temperature. But no all buds were able to flush. While normally all buds of those species flush, under the extreme warming bud survival reduced to 80% in Fagus sylvatica and to 90% in Betula pendula.

To reveal the underlying mechanism, we tracked the development of dormancy depth over the whole period. Under elevated temperature, dormancy induction in autumn was delayed. The peak of dormancy was lower, dormancy release rate was almost similar under both temperature regimes from January onwards, and only in the last weeks before leaf out, dormancy release and leaf flushing was accelerated by warm temperatures. The short growing season that resulted from our extreme warm temperature apparently caused an incomplete dormancy cycle as reflected by its shallow dormancy depth at its peak, which lead to irregular flushing and reduced bud survival.

**Keywords:** tree leaf phenology, dormancy depth, temperate forest trees, bud survival, climate warming.




## S4.O5 – Flowering and leaf phenology are more variable and stronger associated to traits in herbaceous compared to tree species

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**Abstract**

We present a case study of the PhenObs network that focusses on the phenology of herbaceous species, which are largely underrepresented in phenology research as it is mainly focused on trees and shrubs so far. More specifically, the aim of this network is to link phenology and traits for a better understanding of phenological events and shifts in response to environmental conditions and climate change. In this study we investigated how different phenological events during the annual life-cycle of plants from leaf-out to senescence differ between herbaceous and woody species and how they interact with functional traits.

To answer these questions, we recorded multiple generative and vegetative phenological stages of 21 herbaceous and 19 woody species in the Botanical Garden of Jena during the growth period in 2021 following the PhenObs protocol (Nordt et al. 2021). We measured functional traits for which relationships to flowering phenology has been shown (specific leaf area, leaf dry matter content, leaf thickness and leaf chlorophyll content). To assess whether herbaceous and woody species differ in the timing of phenological stages, we used Welch's two-sample t-test and the Wilcoxon rank sum test. To investigate whether the relationship between phenology and traits are consistent between the growth forms, we ran linear models with the phenological stage as the dependent and traits as explanatory variables; growth forms were included as covariates.

We found evidence that the studied herbaceous species in comparison to the woody species showed a larger variability in phenology. Furthermore, for the initial growth and leaf unfolding we found the most relationships between functional traits and phenological events, whereas only one trait (LDMC) correlated with the flowering duration. Finally, species-specific patterns of the phenology could be mainly explained by the measured functional traits for the herbaceous species, whereas trees showed only weak correlations between phenology and functional traits.

This work is a clear example of how useful phenological observations in botanical gardens can be to study and understand the complex relationships between plants' phenology and functional traits. However, further research is needed to investigate avenues to use widely available trait data to predict species-specific phenology.

**Keywords:** Botanical Garden, Functional Traits, PhenObs, Phenology.




Nordt, B., I. Hensen, S. F. Bucher, M. Freiberg, R. B. Primack, A. D. Stevens, A. Bonn, C. Wirth, D. Jakubka, C. Plos, M. Sporbert, C. Roemermann (2021) The PhenObs initiative: A standardised protocol for monitoring phenological responses to climate change using herbaceous plant species in botanical gardens. *Functional Ecology*, 35**,** 821-834.




## S4.O6 - Pollen production of birch under differing environmental regimes in International Phenological Gardens across Europe

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### Abstract

The network of the International Phenological Gardens (IPG) and their cloned plant species allow analysing phenological responses to climate change while excluding genetic variations. This particular feature of common genetic background is not only useful for phenological research but can also be used to study other plant characteristics such as pollen production. Some studies examining the relationship between temperature and pollen production suggested that warmer conditions result in higher pollen quantities. However, the relationship between temperature and pollen production is not satisfactorily understood yet.

This study focuses on downy birch (*Betula pubescens* EHRH.) pollen production and we sampled catkins prior to anthesis during 2019-2021 from 38 IPGs (11 European countries, 46 birch trees). The selection of IPGs was based on the availability of cloned birch trees from different climatic conditions. Pollen production was estimated using a mixed sample resulting in 418 microscope slides, which were screened for their birch pollen quantities. Meteorological data were obtained from the E-OBS dataset (0.1° regular grid).

Most of the trees were characterized by a diverse pollen production at catkin level widely ranging between $6\times10^3$ to $7\times10^6$ grains. The average pollen production per catkin is estimated at $1.8\times10^6$ grains. The strongest relationship was detected between the number of catkins per square meter of tree crown and temperature, which was most pronounced for Sep-Oct-Nov 2019 ($r_s$=0.510, $p$=0.004). In addition, we found significant and positive correlations of pollen production per flower and per catkin with proceeding autumn temperatures, which were strongest in 2021 ($r_s$=0.634, $p$<0.001; $r_s$=0.429, $p$=0.018).

This European study demonstrates that global warming can exert an influence on pollen production of birch and therefore on human health. However, the correlations between pollen production and temperature vary within the investigating years, which might be attributed to other abiotic and / or biotic influences. To disentangle the relative importance of climatic effects on pollen production, a collaboration between scientists from Landscape Ecology, Phytomedicine and Environmental Medicine further investigates the complex system of plant-environment within the DFG project pollenPALS (655850).

**Keywords:** Pollen production, Birch, International Phenological Gardens.

## S4.O7 - No risk – no fun: The penalty of spring frost damages on deciduous temperate trees


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### Abstract

In many parts over Europe, the warming-induced advance of leaf-out timing has outpaced the slower advance of stochastic frost occurrences. As a consequence, many tree species have shifted their spring phenology into a period where freezing temperatures are likely to exceed species-specific resistances, causing large-scale canopy defoliations –visible even on satellite images. Here we examine the penalty of damaging spring frost events on saplings of four deciduous tree species as well as their recovery potential in relation to different leaf-out timing.

In February 2019 we placed 240 saplings of *Prunus avium, Carpinus betulus. Quercus robur* and *Fagus sylvatica* in a cooling chamber to control and manipulate leaf-out timing. Transferring cohorts of saplings to a warm climate chamber resulted in 4 leaf-out dates per species, spanning/covering the potential range of natural leaf emergence. In addition, another cohort of saplings was kept outside and exposed to ambient climatic conditions. Shortly after leaf-unfolding each cohort was exposed to 2 intensities of artificial frost aiming at partly or fully killing the leaves, before planting them outside under a shading net simulating forest understory conditions at the research facility near Zurich. Re-greening, biomass increment, NSC-reserves and senescence in relation to unfrozen control saplings were assessed and analyzed.

Most species survived the simulated frost event except for ~30% of *Carpinus* saplings. Short term recovery in terms of canopy regreening occurred within a month and reached ~40% (*Fagus*, *Carpinus*) to ~80% (*Quercus*, *Prunus*) of the leaf area of unfrozen control saplings. Long-term recovery showed a clear priorization of NSC-recovery over growth, resulting in barely any (*Fagus*, *Carpinus*) to ~50% (*Quercus*, *Prunus*) of the biomass increment of control saplings during the first growing season but a full recovery of NSC. Within a species, earlier leaf-out generally led to overall better short- and long-term recovery.

While *Prunus* and *Quercus*, despite of contrasting freezing resistances, were able to quickly recover their canopy foliage after frost, *Fagus* and *Carpinus* poorly recovered in terms of leaf area and growth increment with *Carpinus* eventually failing at all. Strategies to cope with freezing damages observed here include the deployment of reserve buds, the ability to resprout from the stem base, lower C/N-ratio in recovering leaves and overcompensation of NSC-reserves to be used in the following growing season. Such mechanisms may provide competitive advantage for some species and reshuffle the cards of evolution with increasing frequency of damaging frost events and other stressors.



**Keywords:** budburst, freezing resistance, phenology, recovery.




## S4.O8 - Effects of drought on the seasonal dynamics of needle growth, wood production and sap velocity of Aleppo pine

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### Abstract

There is a large and increasing number of studies focusing on the phenology of specific tree organs, such as leaf onset and senescence or the cambial activity, which increased our knowledge on their main environmental or ontogenic drivers. However, we still lack an integrated approach that simultaneously analyze the development of different organs from the needle to the shoot and the stem, and their impact of tree functioning such as its water use.

To partly fill this gap, and to analyze the impact of drought on these intra-annual growth patterns, we studied Aleppo pine (*Pinus halepensis*) development at the long-term monitoring site of FontBlanche (2008-2021). There, seven trees have been monitored in a control plot, and four trees in a rainfall exclusion plot where 30% of the rain have been excluded by PVC gutters. We measured the main environmental drivers (meteorological and soil conditions) and sap velocity with automatic captors (e.g., Granier probes) ; primary growth, i.e., leaf and shoot elongation manually on a monthly basis ; secondary growth, i.e., xylogenesis with automatic dendromicrometer and micro-cores taken every ~15 days ; and water potential and xylem embolism punctually over the summer season.

By combining data from these different sources and resolutions, we reported different lags between leaf, shoot and stem phenology, with a high inter-annual variability, and which are mainly due to the polycyclic behavior of *P. halepensis* (Girard et al. 2011). There was also a strong impact of drought on all these components. For instance, sap velocity was lower in the exclusion plot than in the control plot. This reduction was neither due to xylem embolism, that remained similar between treatments, nor to changes in secondary growth, but rather to a reduction in primary growth and in total leaf area (Moreno et al. 2021).

Globally, our results highlight the strong interest of a simultaneous monitoring of the phenology of the different tree compartments, and suggest an acclimation of *P. halepensis* to drought through a reduction in primary growth.

**Keywords:** Pinus halepensis, primary growth, xylogenesis, sap velocity, drought.

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## S4.O9 - Effects of phenology on community turnover in temperate forest understoreys: a model-based approach

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### Abstract

The majority of phenology research in temperate forests is oriented towards the tree layer, using satellite, phenocam or field observations to derive phenological shifts as a response to climate warming. Far less is known, however, about phenology changes occurring in the understorey of temperate forests, the herbs and grasses growing on the forest floor. In this biotic layer, phenology responses can have a drastic impact on a species' fitness, since periods of high light availability can be shortened or elongated depending on the strength of phenology responses occurring in the overstorey. As these alterations in species' fitness are likely species-specific, with a low impact on evergreen species and a potentially high impact on vernal species, we expect that alterations in understorey phenology can give rise to community turnover in the understorey.

In this study, we investigate the importance of species-specific phenology shifts for community turnover, based on microclimate and phenology measurements in a mesocosm warming experiment and by integrating these data into a process-based model to simulate understorey dynamics.

Based on our phenology observations, carried out in 2021, we found that phenology shifts in the understorey are species-specific and a lot stronger than previously reported. We also found that incorporating the observed phenology shifts in the model significantly affects the modelled carbon gain and fitness of the investigated species.

We conclude that understorey phenology is an important process that needs to be accounted for when predicting impacts of climate warming on shifts in understorey composition in temperate forests.

**Keywords:** climate warming, understorey, temperate forest, process-based modelling, community dynamics




## S4.O10 - Climate change, shifting flowering phenology and their consequences on the reproduction of oak trees

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### Abstract

Many tree species display masting, i.e., population-scale very large inter-annual fluctuations in seed production, implying locally synchronized trees. Although masting plays a key role in the dynamics of temperate forest ecosystems, its future in the context of climate change remains largely unknown.

Based on empirical datasets from large network survey of pollen and fruiting dynamics of oak populations in mainland France, combined with modeling work, we provide evidence that (i) flowering phenology partly controls pollen limitation and reproductive failure in oak tree populations and (ii) pollen phenology and pollen limitation have evolved over the last 30 years, yet differently depending on the regions considered.

Our work highlights the urgent need to account for flowering phenology in setting up accurate predictions on the future of masting and that of the forest ecosystem dynamics.

**Keywords:** Phenology, Climate change, Oak Masting, Pollen limitation, Reproductive strategy.




# S4.O11 - Evolution of plant phenology under a changing climate: insights from quantitative genetics models.

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## Abstract

Plant phenology, such as the timing of bud burst in spring for trees or the timing of flowering in many species, shows strong plastic responses to a warming climate. Interestingly, these phenological traits also often show rapid genetic evolution in the context of a changing climate and there has been discussion about the potential of such adaptive changes to mitigate the negative effects of climate change. In this talk I will summarize the findings of several modelling studies conducted in a large collaborative project, which have shed light on this issue. Our work explores in particular the evolutionary consequences of the fact that variation in phenology commonly affects who mates with who in a population. First, individuals can often mate only with other individuals with a similar phenology (e.g. with overlapping flowering time), which is described as assortative mating. Second, individuals with atypical phenology may have less mating opportunities than others. Variation in the number of mates generates sexual selection, which can conflict with natural selection on phenology imposed by climate. We used quantitative genetics models of adaptation to a changing environment to explore these questions, assuming that some phenological trait (e.g. flowering time) is partly determined by genes at several loci, and partly by a plastic response to temperature. We found that assortative mating can facilitate rapid genetic evolution of phenological traits by maintaining a greater genetic variance for these traits in a changing climate than for other adaptive traits under random mating. However, we also predict that assortative mating and the sexual selection it generates may also have, in the past, shaped the evolution of phenotypic plasticity for phenology along climatic gradients, such that the traits expressed in a changing climate deviate from the optimal values favoured by natural selection. These last predictions do not only provide new explanations for observed patterns of phenotypic and genetic variation of phenology along environment gradients, but also suggest caution when inferring the adaptive value of plasticity from these patterns. Our prediction that assortative mating speeds up evolution may explain why most examples of contemporary evolution in response to climate change concern phenology.

**Keywords:** evolution, quantitative genetics, phenotypic plasticity, gene flow, assortative mating.

Godineau, C., **Ronce, O**†. Devaux C†. 2021. Assortative mating can help adaptation of flowering time to a changing climate: insights from a polygenic model. Journal of Evolutionary Biology, DOI: 10.1111/jeb.13786

# SESSION 5




# S5.O1 - Individual and Interactive Effects of Elevated $CO_2$, Warming and Drought on the Phenology of Mountain Grassland

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**Abstract**

Mountain grasslands are exposed to multiple global changes, which can cause significant phenological shifts. While the individual effects of elevated $CO_2$, climate warming and drought events on grassland phenology have been studied to some degree, understanding of the interactive effects of these global change drivers is still limited. In a multifactor global change experiment on a managed montane grassland typical for many parts of the Alps, with 3 periodic cuts (end of May, July, and September), we tested the individual and combined effects of elevated CO2 (+300 ppm), warming (+3°C) and severe summer drought on canopy- and species-level phenology. We classified the data into 4 growing periods based on the cuts and derived the canopy-level phenological transition dates from Green Chromatic Coordinates (GCC) time series calculated from phenocam images. On weekly basis field phenological observations were conducted to monitor species-specific phenological shifts under different treatment conditions using BBCH codes. Our preliminary findings show that warming, both individually and when combined with elevated $CO_2$, led to early green-up, while summer drought, both under ambient conditions and when combined with warming and elevated $CO_2$, advanced senescence. Across all treatments non-leguminous forbs expressed earlier green-up and earlier senescence in comparison to grasses and legumes, though effects were also strongly driven by species identity. Overall, our first findings suggest distinct non-additive effects of interacting global change drivers on the phenology of mountain grassland.

**Keywords:** Phenological shifts, Grassland, Phenocam, Interactive effects, Global change drivers.

# S5.O2 - Transcriptomic analyses of molecular pathways involved in the regulation of bud dormancy in sweet cherry


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## Abstract

In temperate trees, optimal timing and quality of flowering directly depend on adequate winter dormancy progression, regulated by a combination of chilling and warm temperatures. In the current context of climate change, fruit trees are impacted by the increasing temperatures during the dormancy period and shifts in phenological phases are observed, including earlier flowering and budbreak dates, leading to dramatic damages due to late frosts. Consequently, it becomes urgent to acquire a better understanding of bud responses to temperature stimuli in the context of climate change in order to tackle fruit losses and anticipate future production changes.

Recent work highlighted some physiological and molecular events happening during bud dormancy in trees. However, we still lack a global understanding of transcriptional changes happening during bud dormancy. In order to explore the molecular pathways involved in the regulation of dormancy and flowering, we conducted several fine tune temporal transcriptomic analyses of sweet cherry (*Prunus avium* L.) flower buds throughout bud development under different environments using next-generation sequencing. Results allowed us to identify the signalling pathways specifically activated during the different phases of dormancy, and to differentiate the endogenous cues from the signals regulated specifically by environmental conditions.

These global transcriptomic approaches, based on various genotypes and environments, provide large datasets for further analyses, including molecular-based modelling and could lead to the identification of candidate genes and signalling pathways for breeding new cultivars better adapted to future environmental conditions.



**Keywords:** candidate genes, dormancy, flower buds, multiple environments, *Prunus avium* L., RNA sequencing




# S5.O3 - Phenological responses of potted grapevine cv. Syrah to severe intermittent shading.

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## Abstract

Phenological advance in response to global warming has been largely documented for grapevine (Martínez-Lüscher et al., 2016). As a result, grape ripening is exposed to increasingly dry and hot episodes that can dramatically affect yield (Greer et al., 2019). Shading might be a solution to release water stress and delay ripening by decreasing plant temperature (Lu et al., 2021). However, shading has also negative impacts on photosynthesis that can limit these expected benefits. Compared to shading nets, agrivoltaics, consisting in photovoltaic panels placed over crops, can provide intermediate light reduction while jointly producing green energy. In addition, by using mobile panels shading can be restricted to certain phenological phases. However, appropriate design and control of mobile agrivoltaic devices require better knowledge on grapevine behaviour under intermittent shading such as that produced by panels over vines.

To evaluate the effects of intermittent shading on grapevine phenology and berry ripening, a two-year trial with two pools of plants was conducted outside at Montpellier (South of France) on young potted grapevine (cv. Syrah). A severe intermittent shading was created with a row of horizontal panels of 2 m wide placed 2.4 m above the ground. Subsets of plants were installed below the shading panels during different phenological periods. Budburst, flowering and veraison were followed three times a week. From veraison to harvest, a moderate water deficit was applied to half of the plants. The same shading and watering treatments were repeated over two successive years. The evolution of berry volume throughout ripening and sugar concentration at harvest were characterized for each shading and watering treatment. Dates of mid phenological stages were determined at plant scale using logistic regression.

Shading treatments modified within canopy temperature at hourly scale but without significant effect on mean daily air temperature due to compensation between day and night effects. Budburst and flowering dates were not affected by this severe intermittent shading over the two years of treatment. However, shading delayed veraison particularly for well-watered plants in the second year of treatment, thus delaying both the onset of sugar loading and the harvest. Berry diameter increased later and to lower values for plants shaded before veraison.

It is concluded that intermittent shading produced by panels can shift ripening into a cooler period compared to unshaded plants. However, a strong decrease of available radiation during berry formation may lead to irreversible yield issues, conversely to shade application after veraison.

**Keywords:** grapevine, shading, phenology, climate change, agrivoltaics

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## S5.O4 - Aleppo pine primary growth response to drought in a long-term rainfall exclusion experiment

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**Abstract**

The impact of increasingly frequent and intense droughts on the secondary growth of Mediterranean trees has been widely studied (e.g Gazol et al., 2018). However, little is known regarding their effects on primary growth, and especially on its phenology. Yet these traits could provide more promising indicators of climate change compared to the commonly used secondary growth indices (Vennetier, 2013).

To tackle this question, we have been monitoring Aleppo pine primary growth since 2008 on more than 200 branches of eleven trees. Four trees were included in a long-term rainfall experiment, reducing 30% of natural precipitations (site of Fontblanche, SE France), thus simulating a sustained increase in drought intensity. We measured shoot and leaf development stage and elongation, as well as the number of yearly growth units (as Aleppo pine is prone to polycyclism) and ramifications. The measured branches differed in their architectural order, expositions and vertical positions within the canopy.

Our study shows that primary growth traits were clearly modified in the first years of the rainfall exclusion experiment. Shoot and needle development were delayed by 15-30 and 10-15 days compared to the control plot in 2009 and 2010, respectively. However, these differences were not consistent in the following years. Responses of second order shoot length, polycyclism and needle longevity were also not consistent over time. In contrast, needle length and third order shoot length proved to be the most sensitive long-term traits. The impact of rainfall exclusion on both traits was rapid, strong and persistent over time, even though third order shoot length response was delayed by a year. Needles were shorter by 15.7% on average over the 2008-2017 period in the rainfall exclusion plot (Moreno et al., 2021). Needle length thus seems to be the most responsive, reliable and easy-to-assess indicator of drought stress. These results provide new insights into how Aleppo pine adapts its primary growth phenology to prolonged drought conditions.

**Keywords:** Pinus halepensis, phenology, primary growth, rainfall exclusion, drought

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## S5.O5 – Effect of floral induction duration on heading date and morphogenesis *Lolium Perenne*

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**Abstract**

In perennial grasses, the reproductive development consists of a series of phenological events that strongly affect the ecological and agronomic functioning of grasslands. The heading of the spike from reproductive tillers is a major phenological event used for grassland management and ranking of cultivar earliness. Heading results from processes that take place several months earlier such as the floral transition and vegetative growth. The interactions between the vegetative and reproductive development are poorly understood, making it difficult to predict the phenology of perennial grasses for different genotypes and environments. The aim of the present work was to assess how the duration of the floral induction (FT) affects the vegetative and reproductive morphogenesis of *Lolium perenne*.

Three cultivars of perennial ryegrass were exposed to four temperature and photoperiod regimes in order to modify the duration of FT. In treatment T0, plants were continuously exposed to high temperatures (HT) and long days (LD). In T1, T2 and T3, plants were first exposed to low temperatures (LT) and short days (SD) for 9 weeks in order to complete the primary induction. Then, plants in T1 were immediately exposed to HT-LD while plants in T2 and T3 were respectively maintained in HT-SD for 3 and 6 weeks before being transferred to HT-LD. Leaf production and elongation rate as well as heading date were monitored on the main tillers of 312 plants.

None of the T0 plants exhibited spikes as expected from the absence of LT during their development. In T1, T2 and T3, the number of spiked plants ranged from 58-81% for the earliest cultivar Bronsyn to none for the latest one Tryskal. For Bronsyn, heading occurred significantly later as the duration of the HT-SD period increased (heading date T3 > T2 > T1). Nevertheless, T2 and T3 plants were the fastest to reach heading when expressed in days after exposure to LD. In the same time, the total number of leaves increased with the duration of the HT-SD period as plants remained longer in a vegetative stage. Taken together, these observations indicate that the rate of floral induction depends on the number of leaves on the tiller. Finally, our results showed a positive and additive effect of LD and FT on the rate of leaf elongation.

This study highlights that strong interactions exist between the vegetative and reproductive development in grasses. Improving the prediction of grasslands phenology therefore requires to further characterize the effect of the environmental conditions on these interactions as well as their genetic diversity.

**Keywords:** floral induction, heading date, *Lolium perenne*, photoperiod, reproductive phenology, morphogenesis.




## S5.O6 - Restoration of deciduous trees' vascular system takes place only shortly before budburst: evidence from isotopic labelled water

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### Abstract

Temperate trees react to chilling temperatures during winter by getting progressively more sensitive to warmer temperatures (forcing temperatures) without visible changes. This complicates the calibration of phenological models, which estimate this transition statistically. At the molecular level, callose plugs regulate water flow from the tree's vascular system into bud tissues during winter dormancy. However, it is not yet clear when and how these callose plugs are degraded and the water flow restored.

Here we aimed at quantifying the reconnection of buds to tree's hydraulic system (xylem) prior to bud break in five common temperate tree species at two sites in Switzerland (450 m elevation and ~3°C temperature difference) using isotopically labelled water during winter 2019/2020. We expected that restoration of the water flow between xylem and bud meristem would correspond to bud's sensitivity to forcing temperatures.

We sampled twigs from 5 individuals per species and site every other week (total of 14-16 sampling campaigns) from October 2019 to April 2020. At each sampling date, tree cuttings were recut at 10 cm length, put into 50 mL conical tubes containing 10 mL isotopically labelled water ($\delta^2H \approx 2000$ ‰) and placed into a climate chamber for 24 h at 20 °C with constant light (forcing conditions). In addition, another set of cuttings was put into deionized water in the same climate chamber to monitor bud development as an indication of thermal time to budburst under forcing conditions. The statistical analysis was done using Bayesian generalized linear mixed effect models.

High water flow into buds was detected at the end of October and beginning of November, whereas water flow decreased at the end of November and remained relatively low until the initiation of budburst during spring. In addition, there were significant differences in label uptake between sites at few occasions indicating an effect of temperature on water flow despite winter dormancy. Time to budburst decreased and budburst success increased with increasing chilling for all species during winter 2019/2020 but no correlation was found between thermal time to budburst and bud's water uptake ability.

Isotopically labelled water seems to be a reliable proxy to determine hydraulic flow from xylem into bud meristem. However, our results suggest that an increase of water flow between xylem and bud takes place only shortly before budburst and is therefore neither a good proxy for dormancy release nor for marking the transition between chilling and forcing sensitivity.

**Keywords:** winter dormancy, $\delta^2H$ labelling, deciduous trees

# S5.O7 - Can summer dormancy enhance the persistence of perennial grasses under warmer climates?

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**Abstract**

The persistence of perennial herbaceous species is threatened by increasing aridity. However, summer dormancy is a strategy conferring superior survival to grasses adapted to hot and dry summers (Volaire and Norton, 2006). The role of temperature on the induction of summer dormancy was investigated in the perennial grass *Dactylis glomerata* to analyse the potential expression of this strategy under warmer climates. We tested seven populations of *D. glomerata* originating from Morocco to Norway across the same latitudinal gradient in a five-site experiment. Plants were grown from autumn in pots under full irrigation for one year mostly under open-air shelters. Foliage senescence was assessed from end of spring until autumn. The maximum plant senescence under summer irrigation indicated the level of dormancy expression. Summer dormancy onset, release, expression and duration were modelled as a function of climatic variables. From north to south, the duration of summer dormancy of the Mediterranean populations of *D. glomerata* lasted from 0 to 122 days. Dormancy expression of *D. glomerata* was positively correlated with the sum of temperatures from winter onset ($R^2$=0.57) and with the mean of minimum temperatures in summer ($R^2$=0.73). Dormancy onset, release and duration were also positively correlated with thermal time from winter onset, while the duration of summer dormancy was longer as maximum temperatures increased. Mapping the European regions with climates allowing the expression of summer dormancy in *D. glomerata*, showed that the potentially inductive areas for this strategy may expand in parallel with increasing summer aridity under a future climate warming scenario.

The large phenotypic variability of the expression of summer dormancy in *D. glomerata* was driven by temperature, suggesting that this strategy may have a greater role in higher latitudes to increase plant survival over the predicted hotter and drier summers (Gillespie and Volaire, 2018, Shihan *et al.*, 2022).

**Keywords :** climate change, cocksfoot, Dactylis glomerata, perennial grass, temperature

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## S5.O8 - Is inflorescence preformation in overwintering buds linked to plant functional traits and plant phenology?

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### Abstract

Strong seasonality with pronounced winters is one of the major obstacles for plants in temperate regions. Plants adapt to this shortened growing periods by forming preformation buds in the previous year. Preformation buds can vary in their degree of preformation (Schnablová et al. 2021), from just primordia to entire inflorescences being pre-formed and also in size and number of the pre-formed organs. In this study we want to test, the degree to which the existence of preformation buds affect phenology in plant populations across eleven Botanical Gardens in the northern hemisphere within the PhenObs network (https://www.idiv.de/en/phenobs.html) to test its association with plant functional traits.

We analysed the degree of inflorescence preformation in addition to monitoring plant phenology across 87 herbaceous species between 2017 and 2021 following the PhenObs protocol for monitoring phenology (Nordt et al. 2021). We focussed on different phenological stages to capture the entire growth period of the plants from initial growth in spring, over flowering phenology, the developments of fruits and senescence in autumn. We additionally assessed leaf and floral traits within the gardens.

We found that the degree of bud preformation has an impact on phenology, however, more so on generative phenology than on vegetative phenology. When flowers were pre-formed in the previous year, the species flowered much earlier and displayed fruits earlier, yet the timing of leaf out or senescence was not affected by bud-preformation. Also the variability of phenology across different temperature regimes were affected by it. Bud preformation was higher in smaller plants and lower in plants with high CN ratio. In addition to that, bud preformation was higher in species with lower flower numbers and sizes.

In addition to plant functional traits, the inflorescence preformation is a fundamental characteristic of plants determining the timing of life-history events. As this ability is genetically conserved this has to be taken into account when studying species-specific changes in phenology.




**Keywords:**, Botanical Gardens, bud preformation, floral traits, global change ecology, leaf traits.

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## S5.O9 - Sustaining wine identity through intra-varietal diversification

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### Abstract

With contemporary climate change, cultivated Vitis vinifera L. is at risk as climate is a critical component in defining ecologically fitted plant materiel. While winegrowers can draw on the rich diversity among grapevine varieties to limit expected impacts (Morales-Castilla et al., 2020), replacing a signature variety that has created a sense of local distinctiveness may lead to several challenges. In order to sustain wine identity in uncertain climate outcomes, the study of intra-varietal diversity is important to reflect the adaptive and evolutionary potential of current cultivated varieties.

The aim of this ongoing study is to understand to what extent can intra-varietal diversity be a climate change adaptation solution. With a focus on early (Sauvignon blanc, Riesling, Grolleau, Pinot noir) to moderate late (Chenin, Petit Verdot, Cabernet franc) ripening varieties, data was collected for flowering and veraison for the various studied accessions (from conservatory plots) and clones. For these phenological growing stages, heat requirements were established using nearby weather stations (adapted from the GFV model, Parker et al., 2013) and model performances were verified. Climate change projections were then integrated to predict the future behaviour of the intra-varietal diversity.

Study findings highlight the strong phenotypic diversity of studied varieties and the importance of diversification to enhance climate change resilience. While model performances may require improvements, this study is the first step towards quantifying heat requirements of different clones and how they can provide adaptation solutions for winegrowers to sustain local wine identity in a global changing climate. As genetic diversity is an ongoing process through point mutations and epigenetic adaptations, perspective work is to explore clonal data from a wide variety of geographic locations.

**Keywords:** Adaptation, Climate change, Clone, Diversification, Identity, Intra-varietal, Vitis vinifera.

# SESSION 6




# S6.O1 - Extended Spring Index model assessment over the European continent

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**Abstract**

The present work assesses the quality of the Extended Spring Index (SI-x) products over the European continent at 1 km spatial resolution. For this, we use phenological observations from the European PEP725 dataset and evaluate the spatial distribution of the errors considering different time ranges and elevations.

The SI-x models were developed by Schwartz et al. in 2013 as an extension of the original models which required the accumulation of chilling requirements. The SI-x models provide the dates of first “Leaf” and “Bloom” as the average of the dates for three indicator plant species Lilac (*Syringa chinensis* “Red Rothomagensis”)) and two kinds of Honeysuckle (*Lonicera tatarica* “Arnold Red” and Lonicera korolkowii “Zabeli”)). The SI-x models require as an input, the maximum and minimum daily temperatures to define the accumulation of short- and long-term variables that are used to calculate the previously mentioned products. In 2018, Izquierdo-Verdiguier et al. scaled up the computation of the SI-x models using a specialized cloud computing platform. This work allowed us to run the SI-x models at high spatial resolution and at continental scales. A downscaled European Observation dataset containing the required maximum and minimum daily temperature products as grids with a spatial resolution of 1km (Moreno et al, 2015) was used to produce the Leaf and Bloom indices over the European continent for the period 1950 to 2017. The quality of these indices was assessed using *Syringa vulgaris* observations mostly distributed across central Europe. The mean root square error (RMSE) as well as the mean absolute error (MAE) were used to evaluate the precision of the models, the mean error (ME) to determine the bias and the Pearson's correlation (R) to measure the goodness of the model fit. Our preliminary results show a clear bias in the dates of both leafing and blooming without highlighting any either elevation or temporal range in any specific European region. The bias reached up top 15 days for the Leaf index and almost 40 days for the Bloom index. Given these results, we attempted to recalibrate the SI-x models with European data. However, this recalibration of the model did not substantially reduce the bias indicating a thorough analysis of model structure might be needed to properly model the European Lilac observations.

**Keywords:** spring onset, SI-x models, high spatial resolution, continental scale, phenology observations.




## S6.O2 - Phenocam retrieval of barley's start and end of season

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**Abstract**

Phenocams record changes in vegetation throughout the growing season by capturing multiple images per day using the visible, and sometime the near-infrared portions of the electromagnetic spectrum. Changes in crop phenology are known as phenophases and include start of season (SOS) and end of season (EOS). The aim of our study is to investigate the relationship between crop emergence (SOS) and harvest (EOS) estimated from Phenocam vegetation indices and in-situ measurements.

We studied a barley field in France in one growing year. Firstly, we pre-processed the phenocam data with phenopix [1]. The pre-processing steps include drawing of region of interest (ROI) on an image, extracting of digital numbers from red, green, and blue bands from a seasonal series of images, computing Gcc index [2] and image filtering. Secondly, we performed times series interpolation and phenological parameters extraction with DATimeS [3]. Five methods were tested for times series interpolation: Fourier transform with linear term, nearest neighbour, Gaussian Process Regression, double logistics curve, and Whittaker. Even after filtering the phenocam data is very noisy, therefore we included smoothing methods: Savitzky–Golay and moving average. For the phenological parameters extraction, we tested different percent of the seasonal amplitude. Thirdly, we calculated goodness-of-fit metrics between the pre-processed and smoothed and interpolated data in R (www.r-project.org, last accessed March 28, 2022). The studied goodness-of-fit metrics are MAE, RMSE, relative RMSE, normalized RMSE, Pearson correlation coefficient, and coefficient of determination. Fourth, we calculated the difference in days between the in-situ SOS and EOS and the modelled ones.

The best performing smoothing and interpolation methods, with the best goodness-of-fit metrics, are not the one that perform the best for extracting the SOS and EOS. This is due to the noisy phenocam data and the goodness-of-fit metrics privileging the close relation between the original, noisy data, and the modelled. The Savitzky–Golay smoothing with 7-days span and 2 degrees with Sigmoid interpolation and 5% seasonal amplitude gave the best results for SOS and EOS, 5 and 8 days respectively difference between in-situ and modelled data.

The present study presented the preliminary results of the project Pheno-sense (COST action SENSECO) and showed that freely available tools exist to perform the analysis of time series of phenocam data for extraction of phenological parameters such as emergence and harvest. Our next steps are to include more sites, test other vegetation indices and improve on the smoothing of the noisy phenocam data.

**Keywords:** In-situ phenophase data, Phenocam, Phenological indicators, Senseco, Time-series analysis.

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## S6.O3 - Continuous stem diameter variations as an innovative phenology tools for trees

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### Abstract

The diameter variations of tree or shrub stems reflect a complex signal related to several components: irreversible radial growth, reversible dehydration/rehydration of elastic living cells, thermal expansion and contraction of the organ, and expansion or contraction of dead conducing elements due to the increase or relaxation of internal tensions.

The recent development of highly accurate micro-dendrometers (sub-micron sensitivity) on sensor holders avoiding any problem of thermal expansion of the support allows a very reliable and non-invasive measurement of these variations in diameter and the associated temperature.

Finally, the use of wireless (radio) and connected technology (LoRa or Sigfox network) allows the consultation of these data in real time and remotely.

This presentation will therefore focus on the acquisition of a few time series of main branch diameter variations of walnut and apple trees in orchards. It will focus on how to acquire important phenological and physiological traits of tree development, such as: date of last frost in spring, date of the onset of leaf transpiration, date of the onset of cambial growth, date of cambial growth cessation, date of leaf transpiration cessation, date of first frost in autumn, total length of growing season, number of freeze/thaw cycles during the leafless period, ...).

These indicators, focused on the actual physiological and phenological responses of the trees, derived from diameter variations will be compared to more classical measurements to determine the phenology and physiology of the trees, such as frost resistance ($LT_{50}$: Electrolyte leakage), MTB (mean time to bud break), date of endodormancy release by forcing test and date of bud break.

**Keywords:** Bud burst, Leaf fall, Frost damage, Secondary Growth, Cold hardiness.

# S6.O4 - On the mapping of phenological regions via advanced clustering

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## Abstract

An increasing number of gridded phenological products have emerged over the past years. These products are often the result of running phenological models over large areas or analysing data collected by Earth observation products. In this contribution, we show how to use advanced clustering methods to make sense of these phenological products. More precisely, we show how to use our open-source Python package, Clustering Geo-Data Cubes (CGC), to extract and map phenological regions as well as their change in space and over time. A unique hallmark of our CGC package is that it provides easy access to co- and tri-clustering methods, thereby overcoming a major limitation of traditional clustering-based approaches that can only analyse the data from either a spatial or a temporal dimension. We illustrate our work by analysing long and high spatial resolution time series of the so-called Extended Spring Indices at continental scales.

**Keywords:** spring onset, spatio-temporal analysis, data mining, clustering.




## S6.O5 - Using phenology and aerobiology to evaluate the allergy risk in urban parks

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### Abstract

Aerobiological data of a specific location is believed to be the most accurate information for evaluating the allergy risk of people allergenic against specific pollen species. Nevertheless, obtaining these data is time-consuming and costly. Therefore, this study intends to assess the allergy risk from various perspectives – from general to specific – including allergy risk indices as well as phenology and aerobiological data using the model species birch.

The study was conducted in a medium-sized (2.2 ha) urban park “Hofgarten” in Eichstätt, Germany that consists of 231 trees, including two birch trees (*Betula pendula* Roth). We assessed two specific indices that refer to the overall allergenic potential of the park ($I_{UGZA}$ and $I_{ISA}$). To assess phenology, the birch trees’ phenological stages were recorded from 2017 to 2020 using the BBCH code. For the same period, aerobiological data were generated using an adjacent volumetric (roof-top) and gravimetric pollen trap. We evaluated the characteristics of the *Betula* pollen seasons, including integrals, start, peak and end dates. To gather information on the pollen exposure at different locations within the park, we conducted pollen measurements at breathing height for one season. Bi-hourly values were used to assess their appropriateness for predicting daily pollen levels.

The allergenic potential of the park was $I_{UGZA}$ = 0.173 and $I_{ISA}$ = 0.018 pointing to a low risk. Our phenological data revealed variations in the onset dates of birch flowering between the years (range 6th April to 19th April). In all years, the start date of the pollen season was earlier than the local onset date of flowering (mean difference 7.5 days). The smallest temporal difference was in 2020, when pollen season started six days earlier. The intensity of the birch pollen season however, can only be reported using the Seasonal Pollen Integral (SPIn) derived from aerobiological data. We recorded the most intense pollen season in 2018 (SPIn = 9,053 pollen*day/m³). Furthermore, we observed a large variation between pollen concentration recorded at roof-top and nose height.

Aerobiological data provide a detailed description of the allergy risk as it considers actual exposure. However, further studies should incorporate symptom data, e.g., crowdsourced via the Bavaria-wide BAYSICS app, to account for the impact of exposure on individuals.

**Keywords:** aerobiology, allergy risk, *Betula*, phenology, urban green space, aerobiology




## S6.O6 - Monitoring phenology of cherry-tree orchards from remote sensing: analysis of fAPAR time-series to identify flowering and the start of fruit growth.

Raul Lopez-Lozano[1], Papa Khaly Diop[1], Dominique Courault[1], Claude Doussan[1], André Chanzy[1], Marta Debolini[1], Pierre Rouault[1], Fabrice Flamain[1], Guillaume Pouget[1]

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### Abstract

The Sentinel 2 constellation, operational since 2015 as part of the earth observation (EO) Copernicus program (European Commission) provides open access to global observations at 10 m spatial resolution with a revisit frequency between 3 and 5 days. The combination of both, high temporal and spatial resolution, enables a priori the use of remote sensing data to monitor in-season vegetation phenology through the analysis of time-series. Recent studies from Meroni et al., (2021) or Mercier et al., (2020) have demonstrated the potential of Sentinel data to derive phenological dates of herbaceous crops through the analysis of vegetation indices time-series. In tree orchards, by contrast, the presence of grass in the soil background joint with differences in management practices (e.g. weed control, mowing frequency, type of irrigation…) can introduce large uncertainties in the interpretation of satellite time-series.

This study analyses the use of Sentinel 2 time-series to monitor flowering and fruit onset in a set of 13 plots located at the south-east of France during 2021, including orchards with different ages, cultivars, tree density and management practices (bare soil and grass as background). In these plots, fAPAR (fraction of photsynthetically active radiation) time-series from Sentinel 2 were extracted, and ground measurements of fAPAR of the trees, the background, and the whole canopy were taken using hemispherical cameras. I*n situ* annotations of tree phenology were conducted as well between budburst and fruit growth stages.

The analysis of fAPAR over the 13 plots show that canopy greening starts at the end of March, with a rapid increase immediately after the full flowering (BBCH65). In mid-May, fruit starts to grow (BBCH69) once full leaf area expansion has taken place. The growth and senescence dynamics of the grass background in many of the plots have a strong impact in the canopy-level fAPAR, confirmed with the ground measurements, thus making difficult to establish a direct relationship between flowering dates and fAPAR. To remove the influence of grass, we propose a fAPAR normalized per season, using as a reference the fAPAR value at day 70 (before flowering) and the seasonal maximum fAPAR (after leaf expansion). Our results demonstrate that BBCH65 stage can be well identified with a normalized fAPAR of 0.2 in most of the plots, whereas BBCH69 stages coincides with a normalized fAPAR of 1.0. Such simple approach permits to infer two essential phenological stage in cherry-tree orchards with a relatively small influence of the background.

**Keywords:** Sentinel 2, orchards, soil background, understorey grass, fAPAR.

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# SESSION 7




## S7.O1 - Mapping flowering phenology using Species Distribution Models

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**Abstract**

Different species attune to different environmental cues to trigger phenological development, and we often lack a full understanding of which cues dominate, and how cues may interact or vary spatially. Predicting species phenology across space and phenological change across time has, therefore, proved challenging. Here, I suggest how it may be possible to construct flexible models for timing of green-up, first-flower or other phenological events by co-opting statistical tools from the species distribution modelling literature.

Using data from WorldClim and the National Phenology Network (NPN) database, I use the Random Forest Machine Learning algorithm to predict flowering phenology for the common lilac, *Syringa vulgaris*, across North America. In these models, phenological events (flowering) are fit as presence-only data, and day of year and monthly climate are predictors of observing the event. I then aggregate species in the NPN database to generate maps of co-flowering species across the growing season. Last, I compare daily phenological projections generated using current and future climate models.

The Random Forest algorithm was able to fit complex non-linear functions to monthly climate summaries, and generate maps showing the probability of observing *Syringa vulgaris* flowering in a given location on a given day. I demonstrate that these projections can be easily aggregated to produce weighted maps showing the richness of co-flowering species. Comparing predictions using current and future projected climate scenarios indicate that shifts towards earlier flowering are more pronounced in the western US early in the flowering season, with some delays in the eastern US, and that the flowering season is generally extended to later in the year.

Using statistical tools from the species distribution modelling literature it is possible to generate a probability map of observing a particular species' phenological event in a particular location on a given day, given the climate of that location. This information might be of interest to researchers exploring novel species interactions and potential for phenological mismatches under future climate change.

**Keywords:** Random Forest, species distribution models, flowering phenology, climate change.




# S7.O2 - New Developments in Continental-Scale Spring Phenological Modeling

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## Abstract

This paper reports preliminary results from a three-year project that will develop, validate, and apply continental-scale models of spring plant phenology for dozens of species using data collected at National Ecological Observatory Network (NEON) and USA National Phenology Network (USA-NPN) monitoring sites.

Raw phenological information was downloaded from the USA-NPN database. This included individual leaf and flower phenometrics for all observations of all species, 2009 to 2020. These data were cleaned to ensure quality control. Environmental data used in the project were Northeast Regional Climate Center gridded maximum and minimum air temperatures for the continental USA, as well as daily daylight hours, estimated from latitude and day-of-year. Using these inputs, daily Growing Degree Days, Growing Degree Hours, and Chilling Hours were calculated over multiple scenarios at all phenological observation sites. We then employed the R package "phenor" (Hufkens et al. 2018) to optimize model parameters (base temperature and form--thermal time, parallel, alternating, and sequential) using generalized simulated annealing for six target species which were among the most observed in the database. Lastly, we did an initial test for spatial dependence by splitting the phenological data for red maple (*Acer rubrum*) into three groups based on mean annual temperature, and then building separate models. Previous work using latitudinal variations suggested that this approach could improve model performance (Liang & Wu 2021).

In all cases, the model forms performed similarly to one another, with simple thermal time models emerging among the most effective (by Mean Absolute Error, MAE) in most cases. However, the "best" model differed among species. The best MAEs varied for most species between 5.3 to 9.3 days, with only one species, white oak (*Quercus alba*), notably higher at 17.2 days. Breaking up the red maple data based on mean annual temperature showed promise even using a simple thermal time model. Compared to a model of all locations (MAE: 8.6), the coldest group had considerable MAE improvement (5.8), the middle group showed similar accuracy (9.3), and the warmest group was hardest to predict (16.5).

These initial model tests strongly suggest that development of accurate continental-scale models of spring plant growth stages are achievable using the USA-NPN database. Further, the promising test of spatial variation in thermal response based on annual temperature groupings, indicates that adaptive model forms will likely improve overall accuracy across the entire range of individual species.

**Keywords:** modelling, spring phenology, continental-scale, predictability.

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# S7.O3 - Uncertainties in estimating budburst heat requirement when using local or gridded temperature compared to bud tissue temperature

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**Abstract**

The aim of this study was to evaluate the potential error of quantifying the heat requirement for leaf unfolding of temperate broadleaves trees, expressed in Growing Degree Days (GDD), when using air temperature instead of bud temperature. Besides, we identified which environmental variables are mostly responsible for this discrepancy using a simple energy budget model adapted for buds.

We exposed saplings of 4 temperate broadleaves to two different light regime (ambient full sun or ~70% shade) and two albedo treatments (buds painted either in black or white) in an experiment conducted north-eastern Switzerland. For each treatment and species, we computed GDD reached at the time of budburst using either *in situ* bud temperature recorded inside bud tissues by thin probe sensors or air temperature from local microclimate, a nearby weather station, or gridded dataset as commonly used in phenology studies. We quantified the error propagation in GDD required to budburst across the different temperature datasets versus the "actual" temperature sensed by the buds. We then explored how the differences in bud/air temperature and GDD relate to other climate variables (e.g. radiation, wind) by calibrating and running a simple energy budget model for buds with the different climate datasets.

Daily bud-air GDD differences ranged between -45 and +25 degree days at the local scale among species and treatments. This difference was further exacerbated when using distant air temperature data, translating in potential days of errors from 0 to more than 20 days across datasets. More importantly, bud and air GDD courses were nonlinear over the preseason.

Daily bud GDD was on average lower than air GDD for all species and treatments in our study because bud temperature was lower than air temperature during the night all over the preseason.

The energy budget model well captured the diel variability in bud temperature. Diurnal and nocturnal bud temperature were driven by radiation and by a complex combination of factors driving the sensible heat of buds, respectively.

Heat requirement of buds computed with air temperature is unprecise and biased and depends on bud traits and solar radiation, as most of the buds in mature forest are fully exposed

to sun before budburst. The propagation of error when using air temperature can lead to wrong interpretation of the sensitivity of phenology to warming. Energy budget modeling could help improve phenology studies by integrating the effects of other meteorological variables on bud temperature.

**Keywords:** leaf unfolding, microclimate, heat requirement, phenology modelling, energy balance.




## S7.O4 - Ecodormancy modelling - some new clues after 8 years of research

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**Abstract**

Predicting the onset of fruit tree blossom under changing climatic conditions is of great importance for horticulture. Models used for this purpose should be physiologically based, as far as possible. Pure optimised phenology models carry the risk of unrealistic predictions due to a misinterpretation or an oversimplification of metabolic processes in plants.

On the basis of multi-year observational, analytic and experimental data from the sweet cherry orchard at Berlin-Dahlem (cv. 'Summit') it was possible to show that during ecodormancy (time between endodormancy release $t_1$ and beginning of ontogenetic development $t_1$*) the effectiveness of forcing temperatures for bud development is not comparable with the forcing effect of identical temperatures after beginning of ontogenetic development. The reason is that during ecodormancy forcing is still depressed by the phytohormone abscisic acid (ABA), so that shortly after endodormancy release a huge amount of heat (~16,000 GDH) is necessary to force cherry blossom under controlled conditions. Although this forcing requirement decreases during ecodormancy by nearly 50%, it can never be accumulated in the orchard, so that during this time buds are protected against premature development. During ecodormancy, bud's ABA content also gradually decreases by about 50 % until $t_1$* and by 80 % until the stages 'tight' and 'open cluster', so that forcing becomes stepwise more effective, mainly after $t_1$*. This would explain the frequently described negative exponential relationship between the chill and heat requirement of perennials after endodormancy release, which however is the result of the decreasing ABA content in the flower buds. A significant correlation between chill accumulation during ecodormancy and the subsequent heat accumulation until blossom did not exist for 'Summit'. Thus, the calculation of chill units during ecodormancy in phenology models has probably no meaning and is only a proxy for the declining ABA content in the buds.

The misinterpretation of the ecodormancy phase in phenological models can have substantial consequences for the estimation of the species and cultivar specific chill requirement and for the physiologically based scheduling of relevant phases for chill- and heat accumulation.

**Keywords:** *Prunus avium* L., cv. 'Summit', phenological models, ecodormancy, chill- and heat requirement, abscisic acid.

# S7.O5 - PhenoCaB: a new approach to model spring phenology of boreal conifers


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## Abstract

Traditional phenological models mostly rely on the use of chilling and thermal forcing (temperature sum or degree-days) to predict budbreak. Because of the increasing impact of climate and other stressors, a mechanistic model representing the growth and physiological responses of plants to both abiotic and biotic factors is urgently needed to better predict budbreak.

Here we present an original mechanistic model based on the physiological processes taking place before and during budbreak, calibrated for several conifer species. This model, described by a set of six Ordinary Differential Equations, simulates the phenology and growth dynamics of a conifer branch as representative of the whole tree. The main assumption of the model is that phenology is driven by the carbon status of the plant, which is closely related to environmental variables. The carbon balance is thus modelled from autumn to winter when aboveground organs exhibit cold acclimation and dormancy and from winter to spring and summer when deacclimation starts leading to growth resumption. The explicit effect of natural defoliation by spruce budworm *Choristoneura fumiferana* was also considered.

The model has been first calibrated in a field experiment with data from 2011 to 2019 where natural defoliation by spruce budworm started in 2016. Validation was then performed across 20 field sites covering a large area of Québec (Canada). In general, the model proved to accurately predict the observed date of budbreak with an absolute average error of 2.5 days. The tested sites were subjected to different intensities of defoliation by spruce budworm, showing that the model is capable of providing good predictions also under biotic stress.

The novel approach provides a potential useful tool to develop forest management strategies and optimize forest protection programs against pest attacks under changing climatic conditions.



**Keywords:** bud phenology, carbon balance, boreal conifers, defoliation, mechanistic model.




## S7.O6 - Modelling budburst response to global warming across Canada

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**Abstract**

Bud development is significantly driven by temperature and photoperiod. These abiotic factors have a crucial impact on the physiological and growth processes involved in the annual plant dormancy–activity cycle, shown by bud phenology. Spring bud phenology has been suggested as a critical indicator of climate change and herbivores' disturbances recently. Climate change is predicted to increase temperature, particularly in high latitudes. However, as the effect of warming on bud phenology is not linear, understanding the species-specific response to the warming scenario need to be considered across Canada.

In this study, we applied a phenological model based on the physiological processes involved in budbreak (PhenoCaB). We modelled bud phenology responses to global warming scenarios of three of Canada's most important conifers species (*Abies balsamea*, *Picea glauca*, and *Picea mariana*). The proposed phenological model (PhenoCaB) was developed by integrating a georeferenced platform, called BioSIM, which provides temperature-drive simulations models. We computed spatial changes of bud phenology using two climatic scenarios of anthropogenic greenhouse gas emissions, considered as Representative Concentration Pathways, RCPs, (RCP4.5 and RCP8.5) during two future periods 2021-2050, and 2071-2100 on a regional scale. These predictions were compared with the budburst results obtained from the recent Climatic Normals (1981-2010). The results showed that species reached similarly under climate scenarios, but the impact on budburst differed regionally at local scale in the northern latitudes. This study demonstrates that a biological model based on physiological processes integrated with a weather-driven simulations model could successfully increase the accuracy and realism of global warming simulations at the regional scale.

**Keywords:** Bud phenology, modelling, climate change scenarios, *Abies balsamea, Picea glauca, Picea mariana,* gridded temperature and solar radiation data

## S7.O7 - Can phenology-based models of climate suitability inform quality? Insights from winegrapes.

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### Abstract

Predicting the effects of climate change on agriculture is a must to successfully inform crop adaption to future climate. Forecasts usually characterise climate axes over a fixed or variable period that would ideally account as accurately as possible for critical phenological stages of crop development—i.e., ripening. If climate over such period coincides with that of previous years when the crop performed well, then climate would be assumed as suitable. While this approach is useful to estimate where and when climate will be suited for a crop to develop, it says little about whether alleged suitability correlates with other quality metrics of interest for growers. Using winegrapes as a case study, we examine the relationships between climate suitability and oenological traits commonly linked to berry quality such as sugar and acidic contents for a set of Iberian winegrape varieties. Further, we test model sensitivity to using a fixed temporal window for ripening—i.e., 30 days following veraison—versus using a flexible, phenology-constrained, period for ripening. We found highly variable responses across winegrape varieties and an overall lack of strong relationships between climate suitability as determined by bioclimatic envelope models and oenological features. This is, years hindcasted as climatically unsuitable for winegrowing did not differ systematically in recorded berry composition from suitable years. It follows that, forecasts of climate suitability aimed at informing growers not only about prospects for plant development but also about the potential quality their crop would reach, will need to explicitly incorporate information on quality in the definition of the baseline period considered as climatically suitable.

**Keywords:** *winegrape, climate suitability, crop quality, forecast, climate change*.




## S7.O8 - Climate change and phenology in the pine processionary moth: stakes of better monitoring and predictions

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### Abstract

Climate change and increasing climate stochasticity can considerably impact the spatio-temporal dynamics of insect populations. The pine processionary moth is an important pest in Europe causing economic losses and health hazards due to airborne urticating setae released by its winter-active caterpillars. The IPCC cited this species as an insect whose northward expansion is causally related to climate change because barriers to feeding and development in previously unsuitable habitats are being removed by air warming. Although the role of winter warming on these distributional changes is now established in the North of its range, to date the consequences on phenology and the mechanisms of phenological variation within and among populations remain understudied. Yet, an increasing phenological variation has been observed since the last decade, with the occurrence of atypical (pre-winter) pupation processions (which mark the end of larval development) in some regions and years, presumably partly related to meteorological factors. Historical and experimental data suggest that this species' phenology results from both genetic factors and a complex plastic compound combining phenomenons of phenological stress avoidance and resynchronization in some instars, which may impact spread potential into different bioclimatic regions. Understanding variations of phenology in time and space is crucial not only to better assess the impacts of climate change and the expansion potential of populations, but also to better mitigate urtication risks and control populations, since the efficiency of associated methods often depends on accurate timing to target vulnerable instars. We developed a phenological model calibrated on experimental data on developmental rate under controlled conditions, and validated with past and present field observations. The development of automated monitoring tools (i.e., adult trapping, in turn indicating the timing of egg-laying due to the short lifespan of adults, used to initialize the model) proved being a turning point for studying phenology in this species. Prototypes targeting pupation processions, another key phenological event which corresponds to the highest health hazards, are now also being developed to standardize and expand the monitoring beyond the typical pupation season. This will allow comparing observational data of pupations (including atypical ones) to simulations, and their combination will allow producing alerts and maps of pupation-related health hazards.

**Keywords:** insect, heterogeneity, Lepidopteran, modelling, stochasticity




## S7.O9 - Predicting the phenology of questing *Ixodes ricinus* nymphs in France with meteorological, bioclimatic, and land cover factors.

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### Abstract

In Europe, *Ixodes ricinus* ticks (Acari: Ixodidae) are the most common vector for diseases such as Lyme borreliosis and tick-borne encephalitis. Meteorological conditions, particularly temperature and relative humidity, affect their life cycles and vital ecological processes like mortality, development rate, and host-seeking (questing) behaviour. Variations in these meteorological factors influence tick abundance dynamics, questing activity phenology, and, ultimately, human-tick exposure risks throughout the year.

The current study aimed to examine the activity of questing *I. ricinus nymphs*, the most important life stage for disease transmission, across a variety of climatic region types in France over a long period of observation. This study also aimed to assess the effects of environmental factors such as meteorological, bioclimatic, and habitat characteristics on the variations of *I. ricinus* nymph questing activity.

Questing activity was observed using repeated removal sampling with a cloth-dragging technique at approximately 1-month intervals in 11 sampling sites from 7 tick observatories in France from 2014 to 2021, involving 631 sampling campaigns. A mixed-effects negative binomial regression model was used to assess the effects of environmental factors.

Three phenological patterns were observed for questing nymphs, which potentially follow a climatic gradient: 1) a unimodal pattern with a summer peak and complete winter pause (cold climates); 2) a spring-autumn bimodal phenological pattern (intermediate climates); 3) a unimodal pattern with a spring peak without winter pause (warm climates). The regression analysis revealed that phenological patterns and inter-annual variations in questing activity were associated with meteorological variables at various lag times. In addition, moderate forest fragmentation with transition borders with agricultural areas was one of the land cover characteristics that supported the highest baseline abundance.

Through a long-term observation, we provided baseline knowledge on the phenology of questing *I. ricinus* nymphs in France. Our findings can be used to develop ecological hypotheses about the effects of climate change on the distribution, abundance, and phenology of this tick species and tick-borne diseases. Finally, the phenology of *I. ricinus* activity predicted by our model could potentially be employed to develop tick-borne disease prevention tools, which could help to reduce Lyme borreliosis cases in France.

**Keywords:** *Ixodes ricinus* ticks, Phenological patterns, Questing activity, Meteorological conditions, Habitat characteristics.




## S7.O10 – Does photoperiod affect the olive fruit fly Seasonal cycle? A modelling approach

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### Abstract

The Olive Fruit Fly (OFF), *Bactrocera oleae* (Rossi), is the main pest affecting olive trees in Mediterranean basin. The detrimental impacts of OFF on olive oil production and quality determine relevant farm economic losses in many areas. In this context, simulation models can play a crucial role in predicting seasonal OFF dynamics so as to identify appropriate treatment strategies for insect control. Despite most of models are based on temperature, due to the direct effect of this parameter on insect developmental rate (Belcari et al., 1989; Marchi et al., 2016), other factors such as photoperiod have also been found affecting OFF dynamics (Baratella et al., 2017). Since the importance to provide predicting tools able to accurately detect OFF cycle, the aim of this study is to integrate the photoperiod effect in the model of Belcari et al. (1989), based on thermal unit accumulation, for improving OFF generation estimates. Specifically, the simulation of OFF dynamics is based on the Growing Degree Hour (GDH) estimation, needed to accomplish the thermal requirement of the insect generation, re-scaled using a photoperiod factor which evaluates the sensitivity of the insect to daylength. The two versions of the model (original and implemented version) have been calibrated and validated on sample datasets of OFF captures in Tuscany (http://agroambiente.info.regione.toscana.it/) and applied on a second sample dataset of Marche (http://www.assam.marche.it/), central Italy, taking into account the spatio-temporal variability of climate conditions in both regions (e.g. coastal and inner areas, different years). The results show general higher performances for the model with the photoperiod effect ($\overline{R^2}$ = 0.60; $\overline{RMSE}$ = 19 days, all generations simulated) compared to the original one ($\overline{R^2}$ = 0.52; $\overline{RMSE}$ = 22 days, 3 of the last generations not simulated), on average for calibration, validation and application procedures. In particular, the photoperiod effect, accelerating the OFF cycle at the end of the season, allows the estimate of all pest generations, which are not always identified by the model exclusively focused on thermal accumulation. In latter case, the lower temperature at the end of summer, reducing the GDH rate, prevents to satisfy the thermal requirement and to detect the insect generation. These findings represent a first step to develop an effective tool for accurately monitoring and predicting the *B. oleae* (Rossi) cycle under present and future climates.

**Keywords:** *Bactrocera oleae* (Rossi), Photoperiod, Thermal unit accumulation, Olive fruit fly modelling, Olive tree.

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# S7.O11 - Application of a multi-species grassland model for analysing the response of phenology to climate change

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## Abstract

European permanent grasslands represent a backbone for dairy and meet production, and are hotspots of biodiversity, providing important ecosystem services to society. Understanding how climate variability and change affect the botanical composition of permanent grasslands is essential for assessing climate effects not only on forage quantity but also quality. In this respect, phenology plays a key role, because plant species growing in permanent grasslands can differ significantly with respect to rates of development and temperature thresholds.

In this contribution, we question how a grassland model simulating cover composition in an explicit manner can help appreciating the response of the overall phenology of a grassland assemblage to climate variability and change. We use *DynaGraM*, a recently developed process-based model for simulating community dynamics in multi-species managed grasslands. Earlier we already demonstrated that *DynaGraM* is capable of representing the composition of permanent grasslands in the French Jura Mountains by comparing model outputs with floristic relevés. We also presented results indicating that increasing temperature and aridity, by altering the relation diversity-productivity-stability, lead to long-term shifts in botanical composition, but that these shifts are clearly mediated by management.

This modelling approach brings an interesting perspective on the understanding of processes linking the dynamics of the cover functional diversity, the response to climate change and the phenology of the assemblage. Focusing on the phenology of permanent grassland in the French Jura, here we show that *DynaGraM* outputs unfold an earlier onset of growth and higher developmental rates in response to rising temperatures. While this is not surprising, we find again measureable differences depending on type and intensity of management, which we trace back to differences in the phenology of dominant species. Although further work is certainly required to improve the model formulation and parameterization, we argue that *DynaGraM* represents a useful tool for testing hypotheses, conducting sensitivity analyses and developing impact assessments.

**Keywords:** permanent grassland, plant community dynamics, phenology, climate change, process-based models.




## S7.O12 - A model of the inter-individual variability of leaf out that predicts frost damage in temperate deciduous tree populations

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### Abstract

Spring phenology is a key indicator of terrestrial plants and ecosystems response to climate change. To date, phenological studies are mostly oriented to the analysis of the average date of budburst or leaf senescence in tree populations, and largely overlook the within-population variability of leaf phenology. Meanwhile, there are similar defects in the study of spring frost based on phenology. In this study, spring frost was defined that the daily minimum temperature which was below -3°C occurred within 25 days after budburst. We used a large dataset, which consists in observations of budburst acquired over 257 species-site-years at the scale of individual trees in Orsay, Barbeau and Fontainebleau forests located close to Paris in France, to construct a model predicting the progress of budburst in populations of five temperate deciduous tree species (*Quercus petraea*, *Fagus sylvatica*, *Fraxinus excelsior*, *Castanea sativa* and *Carpinus betulus*) and an additional dataset collected for 19 site-years over 12 sites in France to assess the model ability to predict spring frost.

We have constructed a chilling-influenced heat sum model, hereafter *nCiHS model*, in order to simulate the within-population variability of budburst in our tree populations. To this aim, we considered the forcing requirement to budburst as a normal distribution, instead of a unique value as in the original model. The *nCiHS* model can accurately predict the within-population variability of bud burst inside a population, with an average error of 8.3 days and a percent error of 22 %. We further compared the predictions of our *nCiHS* model to frost observation data. Compare to the model which predicted the average date of leaf out over one tree population, the *nCiHS* model is more precise at predicting frost damage, not only for the late trees, but also for the early trees in the population. Moreover, the *nCiHS* model is able to quantify the frost exposure of a tree population in a given year (namely, what proportion of the tree population was damaged). In a retrospective analysis, we found frost risks increase since 1960 for temperate deciduous trees. Our findings suggest *nCiHS* model reveals the with-population variability of leaf out and predict frost more comprehensive over one tree population, which can inform decision-making in forestry management.

**Keywords:** spring phenology, within-population variability, temperate deciduous trees, phenological model, frost damage.




# S7.O13 - Improving the temporal allocation of ammonia emissions using fertilisation days predicted with in-situ and remote sensed phenology information

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**Abstract**

Ammonia emissions to the atmosphere have severe effects on ecosystems due to acidification and eutrophication as well as on human health through the formation of fine particles. As the dominant source, agricultural activities emit ammonia mainly through livestock manure, including management and application. Unlike manure management emissions, manure and mineral fertiliser application emissions are profoundly variable in space and time. The emission timing for application depends on, e.g., crop type, local climate, soil conditions, and legislative practices. Therefore, an accurate prediction of fertilisation day is essential for a better temporal allocation in ammonia emission modelling.

This study describes the improvement of temporal allocation in ammonia emission modelling using an empirical model Dynamic Agricultural Practices PrEdictoR (DAPPER), which predicts the days of three key field operations (sowing, fertilisation, and harvesting) across North-western Europe. Similar to the TIMELINES model, DAPPER was first built with a thermal sum approach. First, spatially explicit reference thermal sums of sowing and harvesting were derived for various arable crops using the phenological and meteorological data between 2003 and 2019. Secondly, for regions without phenological records, the LUCAS crop statistics and multi-temporal Sentinel-2 observations were used to derive the timings for the corresponding crops. Thirdly, relationships between reference thermal sums and meteorology, soil conditions, legislative practices were investigated to obtain an empirical quantification to interpolate the reference thermal sums all over North-western Europe. Fourthly, the fertilisation days in 2020 and 2021 were predicted with DAPPER and validated with the phenological data. Finally, the prediction was used as input for the temporal variability of ammonia emissions from manure and fertiliser application in the LOTOS-EUROS model. Simulated concentrations were then compared to in-situ measurements and IASI and CrIS satellite observations.

The evaluation of the predicted sowing, fertilisation, and harvesting days with the phenological data suggests significant improvement in the DAPPER predictions compared to TIMELINES. The improvement was especially evident for winter crops since they are more affected by meteorology. The improvement in the temporal distribution of ammonia emission estimates illustrated by the comparison of surface concentration and total columns emphasises the value of applying this method to the emissions of other air pollutants during agricultural practices (e.g., particulate matter from agricultural machinery).

**Keywords:** ammonia, emission, phenology, remote sensing.

# SESSION 8




## S8.O1 - Lack of evidence for the match-mismatch hypothesis across terrestrial trophic interactions.

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### Abstract

Phenological mismatch—the consequences of shifts in the timing of species interactions (i.e. asynchrony)—is a rapidly expanding area of research critical to predicting the consequences of climate change for communities and ecosystems. These mismatches—if present—are expected to have wide-reaching implications for ecosystem structure and functioning. However, after decades of theoretical and empirical studies, from single systems, we still have no general ability to predict the outcomes of phenological asynchrony due to climate change. We, along with others, have argued this failure is due to a disconnect between the underlying ecological theory (i.e., match-mismatch hypothesis) and the phenological responses to climate change currently documented. Despite these claims, no study has quantitatively assessed the evidence for the match-mismatch hypothesis.

Here, we present the first meta-analysis of pair-wise trophic species interactions in terrestrial systems to evaluate evidence for the prevalence of negative fitness impacts of asynchrony. We also examine whether studies that meet the assumptions of the match-mismatch hypothesis are more likely to find a mismatch.

Our synthesis included 687 study-site-years from 20 studies, representing 26 interactions from 1960 and 2016. Despite a large range of synchrony to asynchrony to test the match-mismatch hypothesis within studies, we did not find general support for it. Across all interactions, the relationship between fitness and relative timing was linear rather than quadratic and we only found support for the hypothesis in 15% of the interactions. Further, assumptions of the hypothesis were not always met.

Our results suggest that this hypothesis is unlikely to be a widely applicable theory. While a closer examination of studies suggests that some major assumptions appear more critical to finding evidence of mismatch than others, our results show that this hypothesis does not explain the key factors underlying the structure of pair-wise trophic interactions across many terrestrial systems. Given the complexity of ecological systems and the need to make accurate predictions about the impacts of climate change on biotic interactions, a greater mechanistic understanding of these factors is needed.

**Keywords:** mismatch, asynchrony, trophic interactions, climate change, fitness.




## S8.O2 - A global test of the drivers of shifting phenology and asynchrony

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**Abstract**

Changes in climate have altered the phenologies of many species globally, often causing advances in the timing of life history events. Some species, however, have experienced delays in their phenologies, or no changes at all. Shifted phenologies have the potential to alter the synchrony of interacting species, such as plants and their pollinators. Thus, accurate predictions of phenological shifts are essential for understanding how climate change will alter species interactions and community structure. In trying to detect general trends in phenological responses previous research has explored the relationships between the variation in phenology across species and functional groups, physiology, or geography. These studies found contrasting trends in how functional groups have responded to rising temperatures, with results depending on whether they focus on interacting species, or observations from studies of single species.

Here we present a new meta-analysis, combining data from previous major meta-analyses to test for differences in the rate of phenological changes across trophic levels, habitat types, and types of phenological data.

On average, we observed an advance in most species' phenologies, but we did not observe differences across groups of species or suites of interactions. We also observed no differences in the changes in the synchrony of species known to interact to those estimated from single species data. Shifts in phenology did not relate to latitudinal gradients, or the magnitude of changes in temperature, and showed no strong phylogenetic effects.

These results illustrate the high variation in species responses to climate change and suggest a need to better account for the inherent variation in species phenology in future analyses for us to improve our understanding of the mechanisms driving the observed trends.

**Keywords**: Phenological shifts, climate change, asynchrony, trophic mismatch, species interactions




## S8.O3 - To what extent is gypsy moth egg hatching synchronized with the budbreak period of European trees under milder winters?

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**Abstract**

Global warming is affecting the phenological cycles of plants and animals, altering the complex synchronization that has been established between species over thousands of years of co-evolution. Here we examined the impact of warmer winter conditions on the budburst dates of deciduous tree species and on the egg hatch of a generalist leaf-feeding insect, the gypsy moth (*Lymantria dispar*), whose vitality depends on the synchrony between egg hatch and leaf emergence of the host tree.

In November 2019, we sampled twig cuttings of six common temperate trees in a forest nearby Zurich, Switzerland. The twigs were placed in plastic boxes filled with distilled water and installed in four different temperature treatments that consisted in reducing chilling and increasing forcing during winter and spring. We used two controlled open top chambers, one at ambient temperature and one at +5°C warming, and two greenhouses with a heating system that prevented the temperature from falling below either 5 or 10°C during winter. Gypsy moth eggs from different egg masses were installed simultaneously with the twigs. Heat requirements to budburst/hatch in the different treatments were analyzed using generalized linear mixed effect models.

The different temperature treatments caused substantial differences in the budburst dates of the tested species as well as in the egg hatch of the gypsy moth. The success of budburst significantly decreased in both greenhouses irrespective of species, likely due to the lack of chilling. No significant advance in budburst date was found for species requiring high amounts of chilling such as lime, maple and beech in response to warmer temperatures, whereas earlier budburst was found for species requiring lower chilling such as oak or hornbeam. Interestingly, while gypsy moth egg hatch coincided with budburst timing of most tested tree species under ambient conditions, it only matched budburst timing of oak, hornbeam and, to a lesser extent, elm under warmer winter conditions.

Our results show that under current winter conditions, gypsy moth egg hatch is well synchronized with leaf emergence of a set of deciduous trees species commonly found in Europe but that this synchrony get reduced to only a few species under warmer conditions. Our results suggest that the preference of gypsy moths for oaks and hornbeams over other species may not only be due to the diet quality of their leaves, but also to the increasing phenological mismatch with other species.

**Keywords:** budburst, chilling, phenology, gypsy moth.




## S8.O4 - Phenological mismatches increase the rate of forbidden links in a Mediterranean scrubland

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**Abstract**

In order for two organisms to interact, a basic requisite is that they both coincide in space and time. In the case of seed dispersal by birds, climate change and other anthropogenic stressors are affecting the phenology of both the birds and fruiting plants. In particular, fruiting or spring bird migratory timing have consistently been recorded to be occurring earlier with increased temperatures, especially in the Northern Hemisphere. If interacting species are responding differently to these changes, in either their timing of life-cycle events or use of space, there will also be disruption to ecological services such as seed dispersal. We define this as a *phenological mismatch*. These phenological mismatches accumulate, leading to forbidden links (*i.e.*, interactions that do not take place irrespective of sampling effort) in an interaction network. Despite the obvious connection between phenology and seed dispersal, we are completely unaware to what extent future global-change scenarios will lead to overlap in disruption of activities (i.e., increased frequencies of forbidden links), and thus affect the prevalence of ecological interactions.

This study aims to analyse the prevalence of phenological mismatches over short and long temporal scales, by combining both empirical observations of seed dispersal by frugivorous birds and simulations under different climatic scenarios. Our empirical data come from a Mediterranean lowland scrubland in SW Spain (Hato Ratón, Doñana Natural Area). Bird censuses and phenological transects were performed to estimate the abundance of birds and fruits in 1981-1983 and repeated later in 2019-2021, also documenting the species interactions. We generated different models simulating phenological change, in which phenophases changed either in timing or duration. Results showed that the number of forbidden links almost doubled in 2019-2021 compared to 1981-1983, in relation to phenological and abundance changes. Simulated scenarios presented a higher influence of phenological uncoupling when changes affected phenophase duration rather than timing. Our results demonstrate the vulnerability of mutualistic interactions to phenological shifts induced by global changes, and the need to include phenology in biodiversity assessments.

**Keywords** birds, fleshy-fruited, forbidden links, mismatches, Hato Ratón




## S8.O5 - Intertwining of fecundity, sexual and viability selection on spring phenology along an altitudinal gradient of European beech

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**Abstract**

Plant phenological traits often display clinal genetic variation along climatic gradient, suggesting that these traits mediate local adaptation. However, various clinal patterns are observed, e.g. co-gradient vs counter-gradient patterns, suggesting complex evolutionary processes involved. Multiple physiological processes can drive selection on plant phenological traits, with possible interactions among them. Moreover, the viability and fecundity components of selection are particularly difficult to distinguish in plants, where vegetative and reproductive phenologies are closely synchronized. Finally, interference with sexual selection may arise from assortative mating, that is the positive correlation between mates for flowering time. Our objective here is to disentangle the components of selection on spring phenology in a major tree species, the European beech.

We used phenological survey to estimate the timing of budburst (TBB) in respectively 147 and 192 adult trees at low and high elevation along a steep altitudinal gradient spanning over less than 1km (Mont Ventoux, SE France). Male and female individual fecundities were estimated using respectively paternity analyses of 1414 seedlings and parentage analyses of 473 seedlings in a spatially explicit mating model approach. Fecundity and sexual selection were investigated by regressing fecundity against TBB and mating opportunities, estimated from phenological mismatch within the mating neighbourhood. Viability selection was estimated through the effect of TBB on frost damages, in a common garden experiment where 20 maternal progenies from each plot were grown.

First, assortative mating was significant only at the low-elevation plot, where spring phenology was more spread out. Secondly, phenological mismatch with neighbours reduced male but not female fecundities at both plots. Thirdly, female fecundities revealed directional selection for earlier TBB at both plots, with a stronger selection gradient at the cooler, upper plot. Finally, seedlings with later TBB showed less frost damages in the common garden, but only in families from the high-elevation plot.

Our results suggest that selection on spring phenology combines (1) stabilizing selection through the male reproduction function to maximize mating opportunities, (2) directional selection for earlier TBB through the female reproductive function to maximize the timing of fruit maturation (3) directional selection for later TBB to reduce damages due to late frost. Such

intertwining of sexual, fecundity and viability selection calls for an integrative approach to predict the evolution of spring phenology under changing climate.

**Keywords:** budburst phenology, selection gradient, Bateman's gradient, parentage/paternity analyses, Mixed-Effect Mating Model (MEMM).

## S8.O6 - Phenology and adaptive landscapes in future climate: what consequences for the maladaptation of tree populations?

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### Abstract

With climate change, many species may express traits that are mismatched with their new environment. Such mismatch should cause increasing maladaptation, i.e. a reduction of population mean fitness over time. Mismatch can be reduced by phenotypic plasticity, through which individuals express different trait values depending on the environment, or by genetic evolution, through which individuals with genes producing traits better fitted to the environment increase in frequency in the population across generations. Unfortunately, we often have limited knowledge of which exact trait value is optimal in which environment, thereby reducing our capacity to quantify this mismatch. We here propose to take advantage of our good understanding of the causal relationships between phenological traits, climate, and performance to predict such optimal values and how they vary in future climates.

Here, we used the PHENOFIT model to investigate variation in fitness landscapes for the budburst date of three major European tree species (*Fagus sylvatica*, *Quercus petraea*, *Abies alba*). This model was extensively validated using tree distribution data and phenological observations. We performed our simulations under historic climate and using two climatic scenarios (RCP 4.5, 8.5) and for well-studied populations located along an elevation gradient in the Pyrenees Mountains.

We predicted advanced spring leaf unfolding dates with future climate warming. This advancement is less pronounced in warm – low-elevation –than in cold -high-elevation – populations. We also predicted that climate change will substantially modify the shape of the fitness landscapes. More precisely, for the deciduous species and high-elevation populations, we predicted a shift toward earlier optimal budburst date with climate warming. However, budburst dates maximizing reproductive success covered a much wider range of trait values than under historic conditions, especially at low elevations. Consequently, we predicted a decrease in the strength of directional selection for earlier spring phenology. Finally, in the warmest conditions, we predicted a decline of the maximal fitness (9 % decline for oak at 100 m, and 10 % decline for fir at 800 m). Our results therefore suggest that maladaptation will occur because of a decrease in absolute fitness and population growth, and not because of a change in relative fitness due to increasing phenotypic mismatch for budburst date.

**Keywords:** Climate scenario, selection gradient, phenotypic optimum, phenological mismatch, phenology modelling.

# POSTERS

# SESSION 1




## S1.P1 - The Phenological Network of Catalonia: seven lessons learned in 8 years

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**Abstract**

The Phenological Network of Catalonia (FenoCat) was established in 2013 as a citizen science initiative to collect new phenological data and recover lost observation sites, with the main goal to create an effective indicator of climate change impacts. In these 8 years of life we have learned some lessons that have helped us to evolve:

(1) Phenological series are interrupted when a person cannot observe due to illness, change of place of residence, or aging. Team observation guarantees long term continuity of the series, therefore we signed collaboration agreements with entities that manage natural parks, and we also have the collaboration of some schools.

(2) It is important to maintain contact with other research entities that carry out activities in the field of phenology. For this reason, we have signed collaboration agreements with the *Institute of Agrifood Research and Technology* (*IRTA*) and the *Center for Ecological Research and Forestry Applications* (*CREAF*).

(3) COVID-19 pandemic forced the population to lockdown. The urban observers had to interrupt the observations, while the rural ones were able to continue their observations without problems -from their own homes-, emphasizing the great importance of the observations in rural areas.

(4) It is essential to know the metadata of each observation site, since they help us to understand the reason for certain phenological behaviors, specially when comparing the same species in different sites. That is why we are carrying out a metadata registration campaign, visiting all the observers, and identifying the individuals for future preservation.

(5) Data recording must be a pleasant experience for the observer. It is important to have a simple and robust data entry system. We have developed a web application to facilitate recording of phenological data. Through this system, an observer can compare his own records with those of the entire network.

(6) It is interesting to hold an annual meeting of phenological observers where they can meet and share their experiences -although meetings have been held virtually in the last two years due to the pandemic-.

(7) It is necessary to know the variety of the cultivated plant species to provide quality data to the Pan European Phenological database. For this reason, we are initiating a genetic identification program for fruit trees and cereals, with the active collaboration of observers.

Although we have learned a few things, we know that we still have a long way to go.

**Keywords:** Management network, series preservation, web application, metadata, genetic identification, quality.

# S1.P2 - PHENEC: a French national project on the role of phenology in species distribution and in their management in a changing climate


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## Abstract

The project PHENEC, funded by the French National Research Agency (ANR) (2019-2024) aims at determining how phenology shapes the spatial distribution of species in a changing climate. Our research hypothesis is that variability in phenology drives species distribution and notably their spread rates (Robinet et al. 2015). By changing the time window of some biological stages, the population could either survive better and accelerate the range expansion to favorable nearby areas, or instead, individuals could be exposed to more stressful conditions leading to the decrease of population abundance, and thus range pinning or even contraction. These conditions are not exclusive: some conditions of climate warming could be favorable or detrimental for populations depending on the geographical area. Both responses (phenology and distribution changes) should be jointly analyzed to deeply understand the overall effects of climate warming. The main difficulty is a lack of knowledge on the mechanisms driving both changes. The mechanism was elucidated only for few species regarding phenology change and only for few species regarding distribution change. In PHENEC, we consider the pine processionary moth (PPM), *Thaumetopea pityocampa* (Denis & Schiffermüller) (Lepidoptera, Notodontidae), known to expand its distribution northwards and toward higher elevations (Battisti et al. 2005, Rosenzweig et al. 2007). Model simulations, based on observations and experimentations, are being conducted to reveal these underlying mechanisms. PHENEC has also an important applied objective: understanding and anticipating the changes in phenology will improve pest management methods targeting particular life stages. In the context of reducing the use of phytosanitary chemicals and favor biocontrol, there is a societal need to improve the effectiveness of environmental-friendly pest management methods. For that purpose, the scientific progress done in our understanding of the effects of climate warming combined with the use of new technologies and citizen science will be a cornerstone to improve these methods. Alerts in real-time based on weather forecasts will be issued for pest management. To achieve these objectives, we monitor the PPM phenology and its variability (Task 1), test experimentally the thermal requirements for development and thermal limits of each life stage (Task 2), and model the phenology and its inter-relation with distribution (Task 3). To reach the applied objective, we develop new management tools (Task 4). Main outputs will be presented in the poster.




**Keywords:** phenology shift, range expansion, climate change, forest insect, pine processionary moth.

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Robinet C, Laparie M and Rousselet J (2015) Looking Beyond the Large Scale Effects of Global Change: Local Phenologies Can Result in Critical Heterogeneity in the Pine Processionary Moth. *Frontiers in Physiology*, 6:334. doi: 10.3389/fphys.2015.00334

Rosenzweig C., Casassa G., Karoly D. J., Imeson A., Liu C., Menzel A., et al. (2007). "Assessment of observed changes and responses in natural and managed systems" in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson (Cambridge: Cambridge University Press), 79–131.




# S1.P3 - DIVAE: a French network of experimental orchards to study climate change impact on phenology

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**Abstract**

Common garden experiments have been used to understand the phenotypic plasticity in various agroecosystems such as forest, steppes or grapevine for decades. Such long-term studies highlighted the role of global change in driving phenological processes. However, such long-term monitoring sites have been very rare for fruit trees, probably due to the frequent turn-over in varieties in the commercial orchards.

During the PERPHECLIM project, observatory orchards were planted in 2014 across France. Six INRAE sites were selected based on their contrasting environmental conditions (i.e. Mediterranean, oceanic, continental and montane climates) to extensively monitor relevant phenological stages. This network, called DIVAE, aims to record, study and publish the phenology data for further analyses of the impact of climate change on fruit tree phenology.

The experimental orchards are composed of genetically identical cultivars of four fruit tree species: apple, apricot, peach and sweet cherry. Among each species, five cultivars characterized by constrated phenology were selected to measure phenological observation in a large range for each species. Standardized observation guidelines, and recurrent intercalibration sessions were defined for phenology observations, including budbreak, flowering, fruit ripening and leaf fall.

Analyses of the first years of data confirmed the impact of environmental conditions on phenology in the young trees. Long-term monitoring will provide a better assessment of the phenotypic plasticity in phenological traits for fruit tree crops. It provides a unique network for developing non-destructive experiments in which the effects of environment, tree genotype and their interactions can be studied. Future studies can build on the modelling of existing datasets or acquire new traits to refine the understanding and prediction of orchard tree biology.

**Keywords:** Apple, Apricot, Fruit trees, Peach, Phenology, Sweet cherry.

# SESSION 2




## S2.P1 - Modified BBCH scoring for apple (Malus x domestica Borkh.) reproductive phenology

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### Abstract

Phenological shifts have been regarded the most prominent and reliable biological indicator of climate change, and the BBCH scale has been developed to quantitatively track phenology in agricultural and natural systems. A BBCH scale dedicated for pome fruits was first developed by Meier et al. (1994), and in 2019 a scale for apple trees was devised by Martínez et al. We adopted the 2019 scale for an *in situ* ecophysiological research on apples, and we deemed that some fine-tuning can be further made on this scale. In the study, at least 100 buds from each of the five trees of eight-year-old grafted ‘Red Windsor, ‘Discovery’, and ‘Egremont Russet’ apples were tagged in February 2019 before bud break. The timing, pacing, and duration of the reproductive phenophases were monitored once to twice weekly using the BBCH scale. With the R program, data were subjected to ANOVA and means were separated using the Tukey’s HSD test.

We made adjustments in the apple BBCH scale during fruit development (macrostage 7) and fruit maturation (macrostage 8). In the original identification keys, macrostage 7 starts right after fruit set and scores increased thereafter with increase in fruit diameter. On the other hand, BBCH scores during macrostage 8 is based on the extent of skin colour change. However, these identification keys do not apply in the apple cultivars of our study. First, there was wide overlap between increase in fruit size and change in surface colouration (‘Discovery’ and ‘Red Windsor’), or there was no apparent change in peel colour (‘Egremont Russet’) as fruits ripened. Whilst fruits were expected to exhibit the typical sigmoidal growth, further increase in size were recorded even when the fruits were already ripening.

Second, the three cultivars have medium-sized fruits. Maximum fruit diameter of ‘Discovery’ was 8.25 cm. In the 2019 scale, this would be both equivalent to BBCH 74 (fruit size is ~40 mm) and BBCH 75 (fruit is 50% of the final size). This codification issue would be more prominent in cultivars with smaller/narrower fruits.

Considering these, macrostages 7 and 8 were aggrouped as macrostage 7. Instead of using the actual fruit sizes from BBCH 71-74 as basis for determining BBCH scores, the phenological scores were expressed rather as percentage of the maximum fruit size like in BBCH 75-79 of the original identification keys. Extent of change in surface peel colouration was not used as index for phenological scoring.

**Keywords:** apple, phenology, BBCH scale

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Meier U, Graf H, Hack H, Hess M, Kennel W, Klose R, Mappes D, Seipp D, Stauss R, Streif J, Van Den Boom T. 1994. Phänologische Entwick-lungsstadien des Kernobstes (*Malus domestica* Borkh. und *Pyrus communis* L.), des Steinobstes (*Prunus*-Arten), der Johannisbeere (*Ribes*-Arten) und der Erdbeere (*Fragaria* x *ananassa* Duch.). Nachrichtenblatt Deutschen Pflanzenschutzdienstes 46, 141-153.

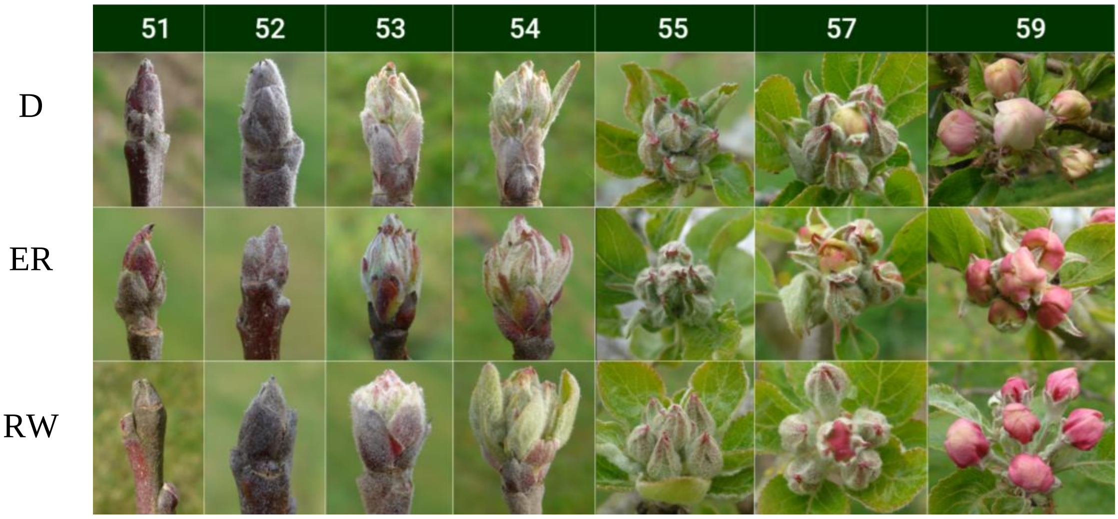


Figure 1. Morpho-developmental changes in three dessert apple cultivars during inflorescence emergence (macrostage 5) based on the 2019 BBCH scale, 3rd week of February to 3rd week of April 2019. D = 'Discovery'; ER = 'Egremont Russet'; RW = 'Red Windsor'. Number on top corresponds to the BBCH stage.


Figure 2. Morpho-developmental changes in three dessert apple cultivars during flowering (macrostage 6) based on the 2019 BBCH scale, 4th week of April to 1st week of May 2019. D = 'Discovery'; ER = 'Egremont Russet'; RW = 'Red Windsor'. Number on top corresponds to the BBCH stage.




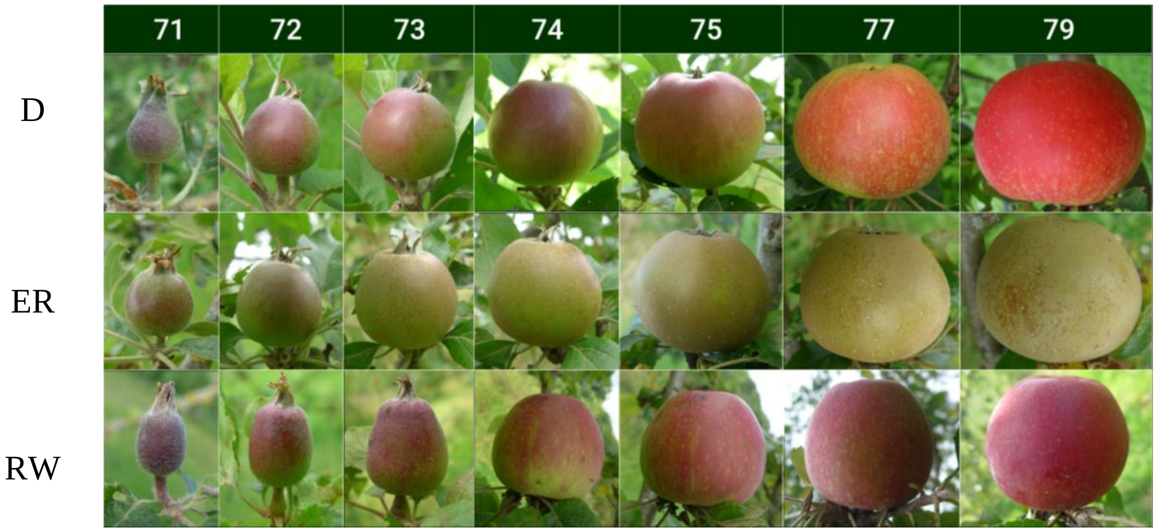


Figure 3. Morpho-developmental changes in three dessert apple cultivars during fruit development and maturation (macrostage 7) based on the modified BBCH scale, 2nd week of May to September/October 2019. D = 'Discovery'; ER = 'Egremont Russet'; RW = 'Red Windsor'. Number on top corresponds to the BBCH stage.




## S2.P2 – How to study crop and herbaceous vegetation phenology in an agroforestry system?

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**Abstract**

Alley cropping systems offer several ecosystem services such as increasing C storage and have been put forward as potential candidates for the development of low input agriculture. These systems are composed of tree rows and their associated understory vegetation which are regularly spaced within a cropped field. In the context of climate change, and particularly in the Mediterranean area in which episodes of water and heat stresses are frequent and intense, monitoring plant phenology in such heterogeneous systems is essential.

The DIAMS trial, “Experimental site in Mediterranean Agroforestry under water Stress” is an alley cropping system set up in 2017 at 10 km South East of Montpellier (Mauguio, 43.612°N,3.976°E; INRAE DIASCOPE unit). Research conducted on DIAMS aims to understand aboveground functioning, belowground plant-soil interactions and the balance of Carbon, Nitrogen and Phosphorus in Mediterranean agroforestry. The trial is a 5-ha complete block design (3 blocks) on which three land uses are compared: forestry i.e. trees planted at high density (1925 trees.ha-1), crop (without trees) and alley cropping (327 trees.ha-1). Trees in forestry and alley cropping are Black Locusts (*Robinia pseudoacacia*), a N fixing species. In alley cropping, trees were planted from East to West every 2 m, in 2 m wide rows covered with herbaceous vegetation, and spaced with 15 m wide crop alleys. Crops and alley crops are rotations of cereals and legumes (wheat/barley/pea).

Our aim is to determine the impact of the trees on the agronomic and environmental performance of the agroforestry system, by comparing it to crop and forestry systems. For this, the phenology of trees, crops, vegetation under trees (grass strips and undergrowth) as well as the phenology of arthropods on the soil surface have been monitored since early 2021. The aboveground phenological observations are completed by belowground monitoring (root traits). In this poster, we will present our protocol to study crop and tree understory vegetation strip phenology.

**Keywords:** agroforestry, crop phenology, understory vegetation strips, tree phenology, Mediterranean climate.




## S2.P3 – Towards the homogeneization of leaf senescence observations through reference coulour charts based on MUNSELL® colours and physiological measurements

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### Abstract

The vegetative season length plays an important role in the annual carbon production of plants. It is determined by both the bud burst date and the leaf senescence date. Whereas the budburst is an event easily observable (a binary observation indicating if the bud is burst or not), the leaf decolouration is more subjective due to the progressive and long aspect of the process. The observation of the beginning of colour changing can be more or less late (from light green to yellow) according to the observers that could lead to a false shift of observations among the observers (Liu et al, 2021). Our objective is to develop tools to homogenise these observations.

In the working group of the TEMPO network (https://tempo.pheno.fr/soere-tempo_eng/) on the leaf senescence, during two vegetative seasons (from the end of leaf expansion to the end of leaf fall), leaves were collected monthly in summer and weekly or biweekly during autumn in shaded and sunned canopy positions, on different tree species including forest (Fagus sylvatica, Quercus robur, Quercus petraea, Carpinus betulus and poplar hybrid (Populus deltoides × Populus nigra)) and fruit (Malus domestica and Prunus avium) species and in different locations in France for some species. The colour of theses leaves was immediately measured thanks to a PANTONE CAPSURE™ including the complete Munsell® colour chart. The leaf chlorophyll content was also estimated with a chlorophyll meter on the same leaves.

From the combination of the colour measurements in the different locations or years, a reference colours chart has been identified for each species. This chart combines i) the main summer reference colours which could be different among trees within a same species according to the growing conditions of trees; ii) the colour when leaf senescence starts that we

have defined as the colour from which leaves have lost 50% of their chlorophyll content and iii) the main colours during the leaf senescence.

The perspective of the project is to extend this approach for a large number of species to build a standard tool to measure the leaf senescence in trees and even beyond in all perennial plants in various ecological context. For example, the development of these reference colour charts could help to homogenise the leaf senescence observations in professional networks (ex: RENECOFOR for forest species in France) or in citizen sciences projects (ex: observatoire des saisons).

**Keywords:** leaf senescence, reference colour chart, standardised protocols, tree.

Liu G, Chuine I, Denéchère R, Jean F, Dufrêne E, Vincent G, Berveiller D, Delpierre N (2021) Higher sample sizes and observer inter-calibration are needed for reliable scoring of leaf phenology in trees. J Ecol, 109: 2461-2474.




## S2.P4 - Analysis of birch aerobiological data for phenological research: a case study from Latvia

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### Abstract

Comparison of aerobiological and phenological data can reveal the impact of non-local processes in a specific region. Phenological data are of essentially point character, whereas the aerobiological observations are affected by atmospheric transport. A complexity, however, originates from the very high uncertainty in the phenological observations (Siljamo et al., 2008). Combining data from different monitoring types might also allow one to re-construct missing values and get more extended time series for scientific studies. The current study shows the relationship between aerobiological and phenological data from 1980 to 2018 using birch flowering season for Latvia as an example.

Phenological data were taken from the free-access database (Kalvāne, 2020). The first flowering day (expressed as a day from the 1st of January) was calculated for each year. Pollen data were taken from the local aerobiological monitoring site for the years 2003-2021. Missed pollen data were re-constructed by re-analysis using SILAM(Sofiev et al., 2012). Statistical analysis was performed to find a relationship between phenological and aerobiological data and reveal possible systematic differences.

The results allowed to roughly quantify the difference in the season start determined from phenological and aerobiological data, estimate the trends and compare their strengths. Over forty years of changing climate resulted in a noticeable shift in the flowering dates. Aerobiological data revealed the trends of timing of the peak of flowering, end of the season, and the season strength.

**Keywords:** birch pollen, Latvia, aerobiology, re-analysis, forecasting.

Kalvāne G., Kalvāns A., Ģērmanis A., Long term phenological data set of multi-taxonomic groups and agrarian activities, abiotical parameters from Northern Europa, Latvia. Earth System Science Data

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# SESSION 3




## S3.P1 - The timing of leaf senescence relates to flowering phenology and functional traits in 17 herbaceous species along elevational gradients

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### Abstract

Leaf senescence is a major event in a plant's life history as autumn marks the end of the growing season. The optimal timing of leaf senescence is crucial to both minimize risks of low temperature events and maximize carbon gain during the growing season. As abiotic conditions are currently changing, it is important to study how leaf senescence is responding to these changes in order to forecast future growing season length and carbon sequestration potentials. In contrast to flowering phenology, data on autumn events is scarce and even more so for herbaceous than for woody plants.

Thus, we studied leaf senescence in 632 populations from 17 herbaceous species located along elevational gradients. We focussed on the beginning (5% of the population senesce, $LS_5$) and peak (50% senesce, $LS_{50}$) of leaf senescence (Bucher and Römermann 2021). To see whether we can predict species-specific changes, we studied the link between $LS_5$ and $LS_{50}$ and flowering phenology as well as leaf functional traits related to plant performance. We looked at first and last flowering day and flowering duration as well as the traits specific leaf area, leaf dry matter content, area based leaf nitrogen and carbon content, carbon isotope discrimination ($\Delta^{13}C$), and the stomatal pore area index.

We found species-specific changes of the beginning of leaf senescence along the elevational gradient. The peak of leaf senescence was uniformly delayed with increasing elevation across all species. Flowering phenology as well as leaf functional traits had a close relationship with leaf senescence and thus can be used to forecast species-specific responses to changes in abiotic conditions. High SLA and high leaf nitrogen were related to earlier senescence while high LDMC, high $\Delta^{13}C$ and high SPI to later senescence.

The link between senescence, flowering phenology and plant functional traits will help to fine-tune predictions of future growing season length and ecosystem function.

**Keywords:** European Alps, global change ecology, leaf colouring, leaf traits, plant–climate interactions

Bucher, S. F., and C. Römermann. 2021. The timing of leaf senescence relates to flowering phenology and functional traits in 17 herbaceous species along elevational gradients. Journal of Ecology **109**:1537-1548.




## S3.P2 - Phenological changes between the two climate normal periods 1961-1990 and 1991-2020 in Switzerland

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### Abstract

The climate of a region is described with 30-year average periods, also known as climate normals. Currently, the WMO recommends the use of the 1991-2020 period. The 1961-1990 period has been retained as a standard reference for long-term climate change assessments. These two normal periods can be used to describe the long term “phenology climate”. We aim to provide climatological values for different phenological phases for the two normal periods in Switzerland and to quantify their differences. Linear regression with temperatures based on inter-annual variations provide information about the phenological response to temperature change.

Observations of 26 phenological phases of the Swiss Phenology Network and stations with at least 25 years of data have been selected for this study. The data was quality controlled and outliers were removed. Yearly average phenology dates for whole Switzerland and for altitudinal layers (≤ 800 m, > 800 m) were calculated with a linear mixed effect model. Correlations and linear regressions of mean onset dates with mean monthly temperatures were analysed.

The increase in yearly Swiss mean temperature between these two normal periods was 1.2 °C, with higher increases in spring (+1.6 °C) and summer months (+1.7 °C) and lower for autumn (+0.7 °C) and winter months (+0.9 °C). In whole Switzerland vegetation development in early spring advanced by 8.4 days (3 phases), in spring by 7.4 days (14 phases) and in summer by 11.8 days (3 phases). In spring, leaf unfolding phases advanced less (5.2 days) than flowering phases (8.6 days). Mean dates for beech leaf colouring and leaf fall did not change significantly. Locations above 800 m a.s.l. generally showed stronger advances and even autumn phases advanced by 3.2 days.

The phenological response to temperature warming of the two or three months before the onset dates is for early spring phases –6.0 days/°C, for spring phases –4.9 days/°C and for early summer phases –6.5 days/°C. The sensitivity of beech leaf coloration in relation to September temperatures is +1.9 days/°C.

The application of the climatological method of normal periods for phenology allows to adequately describe the current and past phenological climate and confirms the trend of advanced vegetation development during the last 60 years. The normal period 1991-2020 is currently used in Switzerland as baseline for indicating yearly deviations of the vegetation development.

**Keywords:** climate normals, climate change, flowering, leaf unfolding, leaf colouring.




## S3.P3 - Changes in the beginning of flowering of common snowdrop in the czech republic during 1924-2021

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### Abstract

Phenology, a study about the seasonal timing of recurring biological events, is commonly known as an indicator of climate change (e.g. Beard et al., 2019). Standard phenological assessments are usually based on the calendar dates when specific changes of phases are seen in nature (Meier et al. 2009). The long-term series are very important in the phenological research.

The main goal of this study was to process and evaluate the phenological data of the common snowdrop (*Galanthus nivalis*) using so far unpublished and long-term data (for 97 years) from Hodonín station in central Europe. Station is situated in the warm region according to Quitt's classification (48.8526131 N; 17.0910511 E; 162 m a.s.l.). The phenological in-situ observations were performed from 1924 through 2021.

The analysis was done with Man-Kendall test and Microsoft Excel tools. The beginning of flowering of common snowdrop has advanced to the earlier time substantially (by -16.7 days per the whole period 1924–2021). In addition, the beginning of flowering was very variable in individual years and the earliest mean date of the beginning of flowering was on 21st February in the last decade (2011–2020).

The results indicate possible changes in ecosystems due to ongoing climate changes. It is important to process as many long-term phenological series as possible in different climatic conditions.

**Keywords:** long-term series – Man-Kendall test – phenophase – *Galanthus nivalis*.

## S3.P4 - Creating an Australian Plant Phenological index – one State at a time

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### Abstract

Australia lacks extensive phenological data, however, more data are slowly being uncovered from historical records and citizen scientists. These are studies at single locations which can be used to assess impacts of climate on plant and animal communities at a local scale, however, such data are inadequate to inform regional, state, and national assessments.

Fortunately, methods exist to combine such 'messy' data - a phenological index, which combines records of the phenological phase of interest, into an integrated time series. These have been developed for several regions and countries (e.g. south-west Finland, eastern China, England and the United States). In doing so an overall dataset can be built that is more powerful and can be used to inform assessments on biodiversity.

Here we present the very beginnings of an Australian plant phenological index using first flowering dates from the State of Victoria collected from newspaper records, government records and citizen scientists covering the period 1940-2021. The index highlights years of early flowering (e.g. 2006) which seem to align with particularly low rainfall, minimum temperature and maximum relative humidity. Future work will add additional species and State. We will also investigate the relationship between the index as well as contemporaneous and lagged multiple climate variables.

**Keywords:** Australia, Index, First flowering day




# S3.P5 - Indicators of the effect of climate change on plants support the Swedish environmental objective Reduced Climate Impact

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## Abstract

Sweden's environmental goals are guiding lights in Swedish environmental work and define which environment Swedish policy should steer towards in the implementation of the urgent transition to a sustainable society (Swedish Environmental Protection Agency, 2022). To support the evaluation of the degree of achievement of the goals, certain indicators have been defined.

The Swedish National Phenology Network was established in 2008 by the support from several universities and governmental agencies in Sweden. A monitoring program started the same year, with the help of the general public. In 2011, people were recruited to be "Phenology watchers" who follow a defined protocol for their observations, to guarantee a certain quality of the data collected. They were encouraged to make observations on a subset of plants and phenology phases that could be compared to a historical dataset, collected between 1873 and 1951 (Langvall and Dahl, 2019). In 2015, a framework to produce estimates of two indicators for the environmental objective Reduced Climate Impact based on the Phenology watchers observations, was set up. The indicator ***Growing season*** was produced from the budburst and autumn-coloured leaves of birch (B*etula sp.* L.), trembling aspen (*Populus tremula* L.) and bird cherry (*Prunus padus* L.), while the indicator ***Spring signs*** was produced from the budburst of birch and the flowering of bird cherry, goat willow (*Salix caprea* L.), coltsfoot (*Tussilago farfara* L.) and wood anemone (A*nemone nemorosa* L.). Baseline functions for the indicators were produced using corresponding species/phase-combination observations in the historical dataset, based on the environmental factors latitude, altitude and distance from big water bodies.

Data from 2011-2021 was compared with the baseline functions. On national level the ***Growing season*** has on average increased in length by 6 days, compared to the baseline period. Only two of these years had a shorter ***Growing season***. The main reason for the increased ***Growing season*** was due to an earlier spring, on average 12 days earlier than the baseline period. However, on regional scale, the ***Growing season*** length varied between different parts of Sweden, so that it could be shorter in some parts and longer in other parts during the same year. The inter-annual variation of the indicators was rather high, meaning that observations need to be run for a significantly longer time, to be able to establish a climate change-induced shift in the ***Growing season*** length and start of the ***Spring signs***.




**Keywords:** Phenology, Climate change, Environmental objectives, Citizen Science, Growing season, Spring signs.

Langvall, O and Dahl, Å. 2019. Swedish historical phenology dataset, DOI:10.5878/sa66-2586

Swedish Environmental Protection Agency, 2022. Environmental objectives. (https://www.naturvardsverket.se/en/environmental-work/environmental-objectives)




## S3.P6 - Vårkollen – A yearly snapshot of the spring in Sweden reveals climate change

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**Abstract**

Recent climate change may have caused plants to start flowering and flush earlier in the spring than ever known in modern times. To reveal if and how much, citizen scientists can perform geographically distributed observations over a vast area. Carrying out a certain event on the same dates every year facilitates the engagement from the public to participate and gives far better response and thus produce much more data than is common in citizen science projects over time. Such event also gets high attention from media, which promote the event even more. When recurring over a longer period, annual variations can be overcome and can be compared to historical records.

A citizen science event called "Vårkollen" (i.e. "Spring check") has been run for eight years, where observations of six species (flowering of, and budburst of) has been collected from all Sweden during two days in the turning of April to May. Observers could report "Not flowering yet", "Flowering", "Flowering ended" or "Not observed" on Liverleaf (*Hepatica nobilis* Schreb.), Colt´s-foot (*Tussilago farfara* L.), Wood Anemone (*Anemone nemorosa* L.), Goat Willow (*Salix caprea* L.), Bird Cherry (*Prunus padus* L.), and "Not flushing yet", "Flushing" "Flushing ended" or "Not observed" on Birches (*Betula* L.). Thus, anybody could report on all species at their site independent on the phenological phase occurred or not, given the species were present. Current observations were compared with historical records collected in a network between 1873 and 1951 (Langvall and Dahl, 2021).

Approximately 10 000 observations from 2 000 locations per year showed annual snapshots of how far north the spring, in terms of flowering and budburst of the plants, had reached on May 1st. It was revealed that spring has reached ca 600 km further north, for most species, compared to 100 years ago. Plants that historically had not started flowering or flushing yet, now often flowers and flushes in southern Sweden. It was also clear that flowering and flushing was delayed in the north-western parts of Sweden, due to snow coverage, making the difference to the historical records less pronounced.

In conclusion, this event-based citizen science project has given a different way of revealing how climate change has affected plants to an earlier behaviour during spring. The call and the results were easy to communicate to the public and the engagement to observe and report has therefore been better than is common in citizen science projects.

**Keywords:** phenology, spring flowering, budburst, climate change, citizen science.

Langvall, O and Dahl, Å. 2019. Swedish historical phenology dataset, DOI:10.5878/sa66-2586

## S3.P7 - The use of ecoclimatic indicators as a strategy to take into account the effects of repeated heat waves in crop performance predictions


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### Abstract

Modelling is an obligate approach to predict crop yield under a wide range of environmental conditions. Simulations under different climatic scenarios can provide useful information to adapt management practices in order to maintain, or even improve, crop performances under changing environments. Based on the last Intergovernmental Panel on Climate Change (IPCC) report, heat waves are expected to become more frequent, to last longer and to increase in intensity during the plant's reproductive phase, thus impacting the yield and quality of economically important crops such as oilseed rape (Magno et al., 2021). In our work, we aim to improve crop predictions by considering the effects of repeated heat waves into ecoclimatic indicators that can be used in statistical models. Our underlying hypothesis was that crops response to a stressing event might be modified due to a previous exposition to similar stresses.

Based on large datasets in oilseed rape (Corlouer et al., 2019), we developed statistical models to look for correlations between ecoclimatic indicators and the plant final performance variables (i.e. yield, oil and protein content). For this purpose, (i) the plant cycle was divided into four intervals after flowering, according to the physiological stages of development in oilseed rape; (ii) the number of warm days (i.e. above 25°C and 30°C) was scored in each interval for 26 combinations of location x year in France; (iii) several models that differed from the combination of ecoclimatic indicators were tested; and (iv) the best fit predictive models of the final performance-related variables were selected based on the Akaike Information Criterion (AIC), as performed in Akmouche et al. (2019).

With this approach, we first observed that contrasting final performances were tightly related to the timing, frequency and intensity of high temperature events after flowering. In addition, specific combinations of these ecoclimatic indicators seems to be much more predictive of the final crop performances than a single cumulative indicator which reflects the sum of all stresses in the same period. These results support our prior assumption that the outcome of several successive stressful events is not equal to the sum of each individual effect.



**Keywords:** oilseed rape, heat stress, stress memory, crop modelling, indicators.



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# S3.P8 - Understanding phenological changes using FLUXNET observations


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## Abstract

Phenological responses of vegetation to climate change can significantly affect the energy, water, and carbon exchanges between the land surface and the atmosphere. Recent studies (Piao et al., 2019; Schwartz et al., 2006) indicate an advanced onset and increased productivity at the beginning of the growing season. However, the impacts of phenological shifts on the biophysical properties such as albedo, evapotranspiration, surface air temperature, and surface energy balance are still unclear. In this research, we use eddy covariance data from multiple eddy covariance sites (Baldocchi, 2020), primarily to quantify the metrics that assess phenological changes and to understand how they are related to anomalies in water, energy, and carbon fluxes.

The overarching goal of this research is to identify and understand the biophysical feedbacks associated with changing phenology of the climate system. First, we analyze phenological transition periods including the onset and the end of the growing season, amplitude, bi-modality and seasonality, and the speed of re-greening or of senescence. The extraction of these metrics is based on previous studies by Migliavacca et al., 2011 and Wutzler et al., 2018, that is further developed for different biomes (grassland vs forests; evergreen vs deciduous), climate zones (boreal, temperate, and tropical) and for different ecosystem characteristics available at eddy covariance sites (leaf area index, stand age and foliar nutrients). For this, we use data for Gross Primary Production (GPP) and NEE (Net ecosystem exchange). Drawing on these analyses, we additionally discuss if the advanced onset of the growing season leads to drought conditions later in the growing season. In this scenario, one can expect reduced evapotranspiration, increased surface temperature, and lower fuel moisture content. But in absence of late-season drought, the land surface albedo tends to decrease leading to higher evapotranspiration. In this case, the changes in radiative forcing might compensate for the effects of increased carbon uptake due to the early onset of the spring season.



**Keywords:** Gross Primary Productivity, Eddy Covariance, Growing season




## S3.P9 - Onwards shift in flowering phenology in response to climate change in the mediterranean.

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### Abstract

Plants in the northern hemisphere are advancing their flowering phenology in response to global warming [1]. Mediterranean region's biodiversity is especially vulnerable to climate change due to the high rising of temperatures and the increasingly frequent droughts [2]. Several studies have documented earlier records of first flowering date for well-studied species in the Mediterranean region. However, considering entire flowering periods and community context is relevant because reproductive success of a given plant species depends on its entire flowering period and is influenced by competition with its co-flowering neighbour species.

The aim of this study is to assess if the flowering period of plant species is shifting in response to climate change in the Mediterranean region and if the same trend can be found across species in an ecological community context

To assess these questions, we selected a Mediterranean community at southwest Spain and carried weekly flower counts on 12-15 individuals of the 50 most important woody and shrub species in 1986 and in 2021 throughout both years. Then we calculated the change in flowering starting, peak and end dates and in flowering period duration and synchrony for each species.
Over 90% of species showed an advance of both their flowering starting date (up to 114 days), peak date (up to 58 days) and their end date (up to 43 days), while changes in flowering period duration and synchrony showed mixed results. The direction and magnitude of the shifts were unevenly distributed throughout the year, with winter flowering species suffering the biggest advance and late summer species suffering little advance or even a delay in these phenological parameters, leading to new combinations of co-flowering species in 2021 with respect to 1986.

We concluded that plant species are shifting their flowering phenology onwards in the Mediterranean, but the shifts are highly variable across species and seasons. We suggest that there will be consequences for plant reproduction through changes in flowering synchrony, competence among plant species, mismatches with pollinators phenology [3] and production of seeds in suboptimal environmental conditions.

**Keywords:** Flowering phenology, Climate change, Mediterranean ecosystems.

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## S3.P10 - Pollen emission and climate change

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**Abstract**

According to the World Health Organization (WHO), allergy is the fourth chronic disease in the world and respiratory allergies rank first among infant chronic diseases. The environment is the major source of the allergens, with allergenic pollen representing outdoor the main trigger for allergic reactions in sensitized individuals. In France, more than 20 % of the population is affected by a pollen allergy called pollinosis, with seasonal rhinitis, conjunctivitis and asthma being the most common symptoms. As part of the prevention of allergies, the National Aerobiological Surveillance Network (RNSA) informs physicians, health authorities and allergy sufferers about the health risk associated with exposure to pollen. To do so, in addition to the sampling of airborne pollen grains, in order to count and identify them, the RNSA regularly uses phenological data from the plant species that cause the main allergic manifestations. The most commonly used phenophase (stage 6) is flowering, defined by a start and an end point. The analysis of several decades of flowering dates has made it possible, for example, to estimate the long-term trends in birch pollination in France, and to propose an explanation involving the two successive phases of “chilling” and “forcing”. The chronology of the pollen season has also been used to follow the evolution for other species, in particular grasses, over a period of 30 years (1). Moreover, the RNSA has created for the ONERC (Observatoire National sur les Effects du Réchauffement Climatique) a health indicator comparing the quantities of birch pollen emitted and temperature trends along the last 30 years.

Finally, phenological studies allow one to follow pollen release from the sources at species level by determining the flowering interval and peak for each species, and to attribute the responsibility for allergic symptoms to a particular species. Moreover, the monitoring of the flowering dates makes it possible to determine the influence of climate change on the start date, peak date, end date, and duration of the pollen season of the main species of interest.

**Keywords:** pollen, climate change, phenology,

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# SESSION 4




## S4.P1 - Disentangling phenological and oenological syndromes in 8 varieties of vitis vinifera in the iberian peninsula

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### Abstract

Climate change is affecting agriculture through phenological shifts that may alter when and how crops ripen. Grapevine (*Vitis vinifera* subsp. *vinifera)* is amongst the most sensitive crops to climate. Its great varietal diversity is seen as a promising option to adapt viticulture to climate change, because different varieties differ in key traits mediating their responses to climate stressors. However, we still lack quantitative knowledge on the existing diversity in relevant traits such as phenology and oenology, on how they interrelate or on how they have responded jointly to climate. Thus, the aim of this work was to analyze how the phenology and oenology of 8 different varieties from the Iberian Peninsula covaried in response to climate over the last decades and to test for the existence of syndromes among traits. We assembled data from 3 different agronomical research stations (IMIDRA and IFAPA in Spain and INIAV in Portugal) including observations ranging from 1957 to 2019. The data included oenological traits (sugar and acidic content), key phenological events (budbreak, flowering, veraison and ripening) and agronomical data (growth and crop yield). We extracted climate data from published datasets and examined the existence of statistical relationships between oenological and phenological traits with temperatures and rainfall through linear models. We also tested the existence of temporal trends in these traits. Ripening was the only phenophase showing a significant phenological advance over the last decades across varieties and using aggregate data. While other phenophases have not shown consistent temporal patterns of advancements or delays, dates of budbreak and, to a lesser extent, of flowering, show strong relationships with experienced climate. On the other hand, there was a significant increase of sugar accumulation and decrease of acidic content in the berries in years where the veraison and ripening dates were earlier, as well as in the years when the ripening period had higher temperatures, although no clear relationships were found between the traits and the length of the ripening period. Altogether, our results contribute to enlarge the existing knowledge on winegrape diversity, and on the relationships among relevant dimensions to such diversity. Nevertheless, further research is needed to assemble data from additional locations and varieties to build more robust datasets.

**Keywords:** grapevine, phenological advancement, oenology, climate change, diversity




## S4.P2 - enhanced vegetative growth at warmer temperatures brings about fewer but bigger fruits in 'red windsor' apple (malus x domestica borkh.)

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### Abstract

With climate warming, the general trend in temperate trees has been an earlier onset of flowering and leafing-out during spring, and a delay in leaf fall in autumn. Whilst there is substantial evidence of how this developmental phenomenon proceeds in temperate forest trees, less is known about its impact on fruit formation and development in temperate fruit trees with economic importance like apple. Hence, our research aimed to characterise how the influences of warming temperatures on phenology and growth would affect the fruit productivity of apple trees. In this study, three-year-old potted trees of grafted 'Red Windsor' apple were kept inside growth chambers with varying temperatures (ambient [AT], AT + 2°C, AT + 4°C, and AT - 4°C) from February to October 2020. Phenology, growth, and yield components were monitored on a weekly basis. At least ten floral buds per tree were tagged and scored individually using the BBCH scale to account for the timing, pacing and duration of phenophases of floral buds, flowers, and fruits. Weekly increment in shoot length, stem diameter, fruit size, and fruit number were also taken until the growth increment levelled off. Season-long results showed that temperature was positively correlated with phenological and growth and developmental events. As expected, warmer temperatures were associated with earlier shifts to the next phenophase and a faster completion of each phenophase. The number of days to reach full bloom, fruit set, and fruit maturity were reached earlier at warmer temperatures and the phenophase duration increased progressively as the temperature decreased. These changes were reflected in the amount of heat units (expressed in growing-degree days, GDD) needed to complete a certain phenophase. Higher temperatures also resulted in faster and higher magnitude of vegetative organ growth (shoot, leaves, and stem), while the coldest temperature had the highest fruit set. Primary flowering occurred in April or May across temperature treatments, but several re-flowering events were observed, especially in the warmer chambers, although these translated to very low fruit set. The final number of fruits was fewer, yet fruit size was bigger at warmer temperatures, suggesting that enhanced vegetative growth and prolonged leaf duration at higher temperatures alter fruit yield characteristics, and perhaps fruit quality.

**Keywords:** apple, temperature, phenology, growth, development

## S4.P3 - Classification of a wide range of varieties according to their phenological behaviour


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### Abstract

In order to study the impact of climate change on Bordeaux grape varieties and to assess the adaptation capacities of candidates to the grape varieties of this wine region to the new climatic conditions, an experimental vineyard composed of 52 grape varieties planted in a randomized block design was established in 2009 at the INRAE Bordeaux Aquitaine. Among many parameters, the three main phenological stages of budburst, flowering and véraison were closely monitored each year from 2012 to 2021 with each observation carried out on four independent replicate blocks. Precocity indices were calculated each year for all varieties using the method of Barbeau et al. (1998) and then evaluated using heat maps. Six groups of varieties were identified based on their phenological behaviour, including the timing of the subsequent developmental stages, the overall precocity of the cycle, and the total length of the cycle between budburst and véraison.



**Keywords:** phenology, classification, climate change, precocity indices.




## S4.P4 - can phenology and chlorophyll be used for indicating the susceptibility of common ash to ash dieback?

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### Abstract

Ash dieback, caused by the fungus *Hymenoscyphus fraxineus*, is severely affecting forest ecosystems. Even trees that are visually regarded as vital and healthy can show substantial symptoms of ash dieback in the following year. In this study, we examined whether leaf phenology and chlorophyll content of leaves can be used as indicators for assessing the susceptibility of common ash (*Fraxinus excelsior* L.) to ash dieback.

Flushing and leaf fall of 50 ashes were observed in 2021 at three study sites in Bavaria, Germany, at a regular basis using an extended BBCH scale. In addition, we measured the chlorophyll content of leaves of 30 ashes during six days within the vegetation period using the chlorophyll meter SPAD 502Plus (Konica Minolta). We applied Kruskal-Wallis test to check for differences between healthy and affected ashes and their respective phenological patterns and physiological characteristics. Correlation analyses were used to conclude on relationships between phenology and chlorophyll.

We found significant differences for leaf phenology in spring 2021, but only at one particular study site. Here, the timing of bud burst and mouse-ear stage (BBCH 7 and 10) were 4.1 and 3 days earlier for healthy compared to damaged trees. Damaged ash trees were associated to a significantly earlier end of leaf fall (mean: -6.4 days) and to a shorter vegetation period (average: -9.7 days). The temporal analyses of chlorophyll indicated the expected increase until the end of summer, with the maximum (mean: 38.1 SPAD value) measured on 03.09.2021. In most of the cases spring phenology was negatively and autumn phenology was positively related to chlorophyll readings.

Phenology is a highly hereditable trait and can be used as a monitoring tool to derive information on vital ash trees. Since the assessment of autumn leaf phenology is also influenced by symptoms of ash dieback, we suggest to solely focusing on the date on which all leaves are fallen. Spring phenological patterns were not that clear at all study sites; however, in most cases the early flushing species might present genotypes that are more suitable to cope with the disease.

**Keywords:** leaf phenology, chlorophyll, ash dieback, *Fraxinus excelsior*.




## S4.P5 - Effect of the planting system on phenology of a young black locust-based agroforestry site under Mediterranean climate

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### Abstract

Agroforestry systems (AFS) can provide many services, among which sequestering atmospheric carbon (C) dioxide ($CO_2$) into both tree biomass and soil organic matter for mitigating climate warming. But atmospheric $CO_2$ uptake is depending on vegetation functioning and phenology can dramatically impact annual primary productivity. Assessing the feedback interactions between climate change and AFS functioning requires monitoring phenology and understanding its determinism. This study aims at providing the first main phenological stages of a black locust (*Robinia pseudoacacia* L.)-based agroforestry site (DIAMS) in Mauguio (43.612°N, 3.976°E; INRAE DIASCOPE unit), Southern France. Research conducted on DIAMS aims to understand aboveground functioning, belowground plant-soil interactions and the balance of Carbon, Nitrogen and Phosphorus in Mediterranean agroforestry. The experimental site is a 5-ha complete block design (3 blocks) on which three planting systems are compared: forestry (F) *i.e.* trees planted at high density (1925 trees $ha^{-1}$), crop (without trees) and agroforestry (AF, 327 trees $ha^{-1}$). The observations of the main phenological stages were performed on 44 individuals in each block and each planting system (AF or F), except for one plot were 64 individuals were considered. The current stages comprised latent buds, beginning of budbreak, first leaf visible, leaf yellowing and fall. The planting systems will be compared in order to provide different hypotheses in the determinism of the observed phenological patterns. Future observations will cover the inflorescence and fruit development, which can represent an important C sink, despite the young age of this agroforestry site, as well the cambial phenology.

**Keywords:** Agroforestry, Black Locust, Mediterranean Climate, Leaf Development, Tree Phenology

# SESSION 5




## S5.P1 - Genetic determinism of grapevine development stages as a tool for the adaptation to climate change

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### Abstract

A major aim in modern grapevine (*Vitis vinifera* L.) breeding programs is the introgression of resistance genes along with desired traits for better adaptation to climate change. Developmental stages may affect many physiological processes in grapevine like fruitfulness and berry quality. The shifts of phenological stages observed in the context of climate change increased the impact of these traits on the selection of new varieties. In this study, we studied the genetic determinism of phenological stages in the progeny of a cross between two grapevine hybrids carrying each several quantitative trait loci (QTL) of resistance to downy and powdery mildew. The dates of three phenological stages, budbreak, flowering and veraison, were recorded during three successive years for 209 genotypes in the vineyard. The phenotypic data analysed were the duration of three periods expressed in thermal time (degree-days): 15 February to budbreak, budbreak to flowering and flowering to veraison. High density parental and consensus genetic maps were built using on 239 individuals. Several QTL were detected for each period. Four new QTL detected for the period between 15 February and budbreak on chromosomes 5, 6, 9 and 17 explained 50% of the phenotypic variance. One new QTL for the period between budbreak and flowering time with minor effect were detected on chromosome 8. Using the available grapevine whole-genome sequences, possible candidate genes underlying the QTL of budbreak on chromosomes 5 and 6 were identified. These results confirm the possibility of creating late grapevine varieties resistant to fungal diseases.

**Keywords:** Grapevine, climate change, phenology, QTL, plant breeding.

## S5.P2 - Phenology of tropical tree species – environmental cues, molecular mechanisms, and consequences for plant-animal interactions

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### Abstract

The timing of phenological transitions - including flowering, fruiting, bud burst, and leaf senescence - is vital for fitness of trees in their local habitats. For temperate regions, there is already a good base of knowledge on the environmental cues used to time these transitions, as well as on the molecular basis and the importance of phenology for structuring plant-animal interactions. In contrast, such knowledge is still scarce for tropical regions where many tree populations also exhibit regular and synchronized phenological transitions even the absence of clear seasonal differences in climatic conditions. As a consequence, there is uncertainty about the environmental cues used by the trees to time transitions and we know virtually nothing about the underlying regulation of genes, or the effects of phenological transitions on tree growth and plant-animal interactions. In the framework of our project, we will investigate tropical tree phenology in the evergreen montane and the seasonally dry tropical forests of Southern Ecuador. To obtain time-series data on phenological transitions in the canopy, we will install PhenoCam on existing canopy towers. The image data will be jointly analyzed with data of climatic parameters, carbon flux and tree growth which are currently collected in the framework of the research unit RESPONSE (FOR2730). Further, focusing on four target tree species, we will collect data on phenological transitions at the individual level. For these trees, we will monitor the expression of important phenology genes to characterize the molecular phenology of the trees, and we will study the interactions of trees with pollinators and herbivores in the light of phenological transitions and with special attention on the degree of synchrony within plant populations and its effects on the degree of leaf loss and pollination success. The projects main objectives and work plan will be presented on the conference poster.

**Keywords:** tropical trees, molecular phenology, tree growth, herbivory, pollination

# S5.P3 - Variation in phenology of beech and spruce populations in Germany

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## Abstract

Climate change will probably be associated with a further change of stability and vitality of forest stands. E.g., disturbances such as late frosts may especially affect trees with early phenological onset dates and have an impact on reproductive success. This may lead to adaptational processes and, consequently, to a change in population genetic structures or, in the case of low effective population sizes, to a loss of genetic diversity. In order to assess possible climate change impacts, we investigated leaf/needle phenology for two important forest species, beech (*Fagus sylvatica*) and spruce (*Picea abies*), along with characteristics of flowering and fructification intensity.

Phenological observations (2017-2020) were conducted in 24 forest stands for beech/spruce (14/10) across Germany. In each stand, we selected 20 adult trees and 200 individuals of the natural regeneration and assessed the timing and duration of leaf/needle development along with the visually rated intensity of flowering and fructification. Kruskal-Wallis test was used to compare phenological differences between adult trees and the natural regeneration. We checked for the influence of late frost, differences in specific phenological patterns (early *vs.* late) across the study years and assessed the synchrony of flower/seed masting. Correlation/regression analyses were used to characterize relationships to temperature and to assess future climate warming related changes.

In most of the stands, especially for beech, the natural regeneration significantly leaved out earlier compared to adult trees (mean: beech 2.2 days; spruce 0.3 days). The duration from bud break to the end of flushing was usually longer for younger trees, but mostly not statistically significant (mean: beech 3.2 days; spruce 6.4 days). Only some trees that flushed very early/late were associated with the same pattern constantly over the 3-year period. Flowering intensity seemed to be synchronized across Germany but seed development was also influenced by local environmental conditions. Higher spring temperatures were related to an earlier flushing of adult trees (beech $r_s$=-0.757; spruce $r_s$=-0.916) and to a shorter duration of leaf unfolding ($r_s$=-

0.674, only for beech). Phenological response rates to temperature were quite similar for adult trees and the natural regeneration of beech (both -2.5 days/°C) but more pronounced for young (-4.6 days/°C) compared to adult spruce (-2.7 days/°C).

Besides flushing being regarded a highly heritable trait, our study confirmed a plastic phenotypic response which might be advantageous for forest trees under changing environmental (climate warming) conditions.

**Keywords:** *Picea abies*, *Fagus sylvatica*, flushing, flowering/fructification intensity.




# S5.P4 - Sweet cherry spurs under forcing conditions: a different view of bud dormancy

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## Abstract

Winter dormancy is a key step of the tree life cycle, preventing growth under unfavorable conditions and allowing the survival of perennial species. Bud dormancy can be split into three stages (Lang et al, 1987): 1) paradormancy or apical dominance where growth of lateral buds is repressed by surrounding organs, 2) endodormancy, which is a deep dormancy, triggered by low temperatures, short photoperiod and endogenous inhibitors, when buds cannot grow until a certain amount of cold is accumulated (chill requirements), 3) ecodormancy, or quiescence, when plant growth can restart if growth conditions are fulfilled (heat requirements). Bud dormancy is therefore regulated by a complex combination of cold and heat accumulation and increasing temperatures due to the climate change can lead to early flowering and a higher risk of frost damages, with major economic impacts. In particular, sweet cherry is very sensitive to temperatures and therefore, improving the knowledge on sweet cherry dormancy is necessary to propose solutions for better adapted cultivars facing climate change.

Even though fruit tree dormancy has been extensively studied, monitoring sweet cherry dormancy remains challenging. This is especially true for paradormancy and endodormancy onset, which are still difficult to phenotype. Here, we aimed to fill this gap and accurately characterize dormancy advancement. The experiment design combines two different forcing methods: on twigs and on spurs where only one flower bud was left. Bud burst under forcing conditions was monitored from floral initiation to flowering every two weeks on four sweet cherry cultivars, characterized by their contrasted phenology. Results show that the bud burst percentage of the spurs under forcing conditions increases earlier in the winter compare to the twigs under forcing conditions, suggesting significant different responses to growth conditions, given the same cold accumulation.

This original study highlights effects of apical dominance and endogenous inhibitors that could occur to regulate dormancy progression. Moreover, our results show that the studied cultivars have very different behaviour during dormancy onset.

These observations combined with physiological analyses such as transport capacity, phytohormones levels and oxidative stress studies could decipher how dormancy is regulated in sweet cherry buds.

**Keywords:** bud dormancy, sweet cherry, forcing, dormancy onset, climate change.




## S5.P5 - Testing the effect of cold soil and warm air on the phenology and physiology of young Douglas-fir saplings

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### Abstract

Conifers in low mountain areas (700-1000m above sea level) are exposed to large variations in environmental conditions in late winter (large thermal amplitude and sudden changes in light intensity) that can influence their physiological state. Late winter anticyclonic periods, characterized by freeze during night, create harsh conditions for young trees when the soil temperature is cold while the midday air temperature can be relatively warm (>15°C). On the one hand, cold soil temperatures limit water uptake by the root system, subsequently inducing a pressure drop in the needles and stomatal closure. Such increased hydraulic resistance could represent a growth limiting factor. On the other hand, high light irradiance and warm air temperature promote growth resumption. We hypothesized that low soil temperature combined with high air temperature and high light intensity would have antagonistic effects on tree growth resumption and bud break. We expected that the increased growth due to irradiance and mild temperature would be outwheighed by limited water uptake by the roots.

To test this hypothesis, 4-years-old dormant Douglas-fir saplings were exposed to cold soil (≈ 3°C) and warm air (>18°C) in greenhouse and compared to trees with warm soil. A subset was exposed to high light intensity (2000 µmol/s/m² for 7 hours per day) to saturate the photosystems. Relevant physiological parameters were measured: stomatal closure, chlorophyll fluorescence, relative water content, soluble carbohydrates, shoot phenology and water potential. Furthermore, dendrometers continuously measured microvariations of tree diameter to detect the resumption of cambial growth.

Low soil temperature induced limited root water uptake that affected leaf water potential and triggered stomatal closure. However, high thermal amplitudes between below-and above-ground parts, even combined with high light fluence did not induce hydraulic failure but significant growth delay. Tree growth resumption began with cambial growth before bud break. Spring phenology was significantly delayed for Douglas-fir under low soil temperature despite warm air temperature. However, high light intensity apparently restored the growth ability of Douglas-fir despite low soil temperature stress.

**Keywords:** Douglas-fir, low soil temperature, growth resumption, cambial growth, budbreak.

# SESSION 6




# S6.P1 - Grassland phenology: a methodology to detect start, peak and end of growing season via satellite

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**Abstract**

Phenology, defined as the timing and causes of repeated biological events (Lieth, 1974), represents a key element for the understanding of natural ecosystems. In this context, the use of remote sensing technology (e.g. satellites) proved its potential in analysing environmental variations on a large scale (Tian et al., 2021), but still some uncertainties exist in the identification of grassland phenological changes during the growing season.

On these premises, the aim of this work was to evaluate the reliability of satellite-derived vegetation indices (VIs) to identify the start (SOS), peak (POS) and end (EOS) of grassland growing season (GSS) as detected using observed data, i.e. the seasonal course of Gross Primary Production (GPP) measured from eddy covariance towers.

Accordingly, SOS, POS and EOS extracted from GPP of 9 grasslands sites (FLUXNET and ICOS networks) and from the relevant VIs courses as obtained from MODIS satellite imageries in the period 2001-2020, were compared using a multivariate approach. Specifically, GPP datasets and the corresponding VIs, namely *NDVI*, *EVI* and *kNDVI*, were fitted to four different models based on a double logistic curve: *Gu*, *Elmore*, *Klosterman*, *Beck*. These functions were applied to facilitate the extraction of SOS, POS and EOS with four different approaches: three working on inflection points of the derivatives (*Klosterman*, *Gu*, *Derivatives*), one that identifies the dates when a fixed threshold of the seasonal amplitude is reached (*Thresholds*) (Filippa et al., 2016). The accuracy of each combination *fitting model*extraction approach* was evaluated comparing SOS, POS and EOS extracted from GPP (observed values) and VIs dataset (simulated values), using determination coefficient (r), Mean Absolute Error (MAE) and AiKike Information Criterion (AIC) as goodness of fit indicators.

The best results in the detection of SOS and POS from satellite were obtained using *kNDVI* as vegetation index, whereas EOS was difficult to identify with all VIs. The combinations of fitting function and extraction method that provided best results were *Elmore*Thresholds*, *Gu*Thresholds*, *Beck*Thresholds* for SOS and *Elmore*Gu* for POS, respectively.

In conclusion, the results indicate a good ability of the aforementioned methodology in identifying SOS and POS of grasslands from satellites, while EOS proved to be more complicated to detect. Accordingly, the information obtained from the elaborated VIs could represent a reliable option to observe and understand phenological changes in the growing season of grasslands.

**Keywords**: grassland, phenology, MODIS, kNDVI, GPP

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## S6.P2 - Phenology monitoring in European beech (Fagus sylvatica) in the Carpathian Mountains using UAVs sensor

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**Abstract**

A better understanding of how European beech (*Fagus sylvatica*) phenology is responding to predicted climate change effects is essential for forest management, due to the great ecological and economic potential of this forest tree species in Europe. Observing phenology using remote sensing devices, such as UAVs, is a promising technique, offering fast, accurate and unbiased results. We carried out phenological observations on European beech in the Carpathian Mountains, in a study area situated at an elevation between 1000 - 1150 m. Phenological observations were performed during spring and autumn 2021, twice per week, and they were based on a scale that includes 4 stages of bud's development (dormant winter bud, bud-swollen, bud-burst and at least one leaf unfolding) and for the autumn's one it was applied a formula that has as variables the percentages of yellowed and fallen leaves. The phenology observations were also carried out using a DJI Phantom 4 Pro v2.0 drone, carrying a 20 megapixels RGB sensor. The unprocessed phenological images for the remote sensing process was obtained from overflights using DroneDeploy software. The collected photo mosaics were processed into ortophoto – maps using open-source software (Open Drone Map) A first comparison has been done directly based on gross and unprocessed images. Various vegetation indices were tested based on the RGB bands. Out of these, we used a formula for the RGVBI index for further phenology analyses. The vegetation index was calculated using the raster calculator function of the QGIS platform. The changes of the tree's phenology were observed by differences between each pixel value on the temporal scale of RGVBI orthophoto-maps. In this way, we obtained a new product that highlights, for each pixel, the difference of the vegetation index during two points in time. The two processes have to be performed simultaneously to obtain valid data sets and, further, to associate them. It is essential that the topography of the terrain allows overflights in optimal conditions, without fluctuations of altitude of the device during the movement but also the overflight environmental conditions at that moment (no precipitation, wind, fog). The UAVs' resulting observations were compared to the phenological observations on the ground. A correlation index of 0.7424 was obtained between predicting phenology classes based on the two methods. Our study shows the potential of remote observation based on UAVs sensors. However, further analyses can be improved by calibration of machine learning in order to estimate phenology.

**Keywords:** European beech, phenology, field observations, remote sensing, UAVs.




## S6.P3 - Remotely sensed land surface phenology to analyze the timing of curlew migrations

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**Abstract**

Remote sensing has often been used to estimate the ecosystem green-up date, its spatial gradients and its interannual variations driven by the climatic variability. It is often related to vegetation photosynthetic material phenology, and more secondarily to the flower phenology. Among other usages, it has also been used as a contextual factor for animal phenology. This is the case in this study, which aims at analyzing the timing of bird long-range migrations. Eurasian curlews (*Numenius arquata*) migrate from their wintering site located on the French Atlantic coast to their breeding sites in Eastern Europe (Amelineau *et al.* 2021). Although the breeding sites remain the same from one year to the other for each individual, the timing of the departure change from one year to the other. Here, we test the hypothesis that curlews consider the environment conditions at the breeding site of the previous year to adjust their spring departure timing. To this end, we used tracking data of Eurasian curlews from different locations and combined movement data with satellite-extracted green-up dates at their breeding site (Delbart et al. 2005). The date of spring departure from the wintering site was better explained by green-up date of the previous year, while arrival date at the breeding site was better explained by latitude and longitude of the breeding site, suggesting that other factors impacted migration timing *en route*. On a broader temporal scale, our results suggest that long distance migrants may be able to adjust their migration timing to advancing spring dates in the context of climate change.

**Keywords:** remote sensing, land surface phenology, bird, migration timing

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## S6.P4 - Intercontinental analysis (USA and Europe) of the within-community variability of budburst in temperate forests

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### Abstract

The seasonality of development (phenology) of vegetation is sensitive to temperature. It is one of the most visible biological markers of current global warming. The budburst period is of particular interest because the budburst date is decisive for the development and survival of deciduous hardwoods. It reflects a trade-off between the need to maximize the growth period and the risks associated with late frost. Our study analyses the intra-community variability (ICV) of budburst dates using phenological cameras acquired over 107 site-years in temperate forests located in the USA (67 site-years) and Europe (40 site-years). We hypothesized that the VIC of budburst dates depends on climate conditions during the budburst period. We evidenced that the VIC of budburst is linked to several climatic parameters, and this during several periods of time. With mainly a decrease in the VIC with the average date of budburst and the increase in spring temperatures. Our study also reveals that the effects of climatic parameters differ between the American and European communities. With a greater influence of temperatures (spring and autumn) in Europe, and the photoperiod and average solar radiation in the United States.

**Keywords:** Phenology, Temperate forests, Bud break, Intra-community variability, Phenological cameras




## S6.P5 - Feasibility of camera-based phenology in Switzerland

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### Abstract

The Swiss Phenology Network, founded in 1951 and operated by MeteoSwiss, is a traditional observation network of currently 155 stations. Expanding or even just maintaining such a network is only possible with strong involvement from volunteer observers. Automating phenological observations using cameras and image analysis algorithms could potentially reduce some of the maintenance effort, increase the spatial and temporal resolution of observations and enable new applications.

The MeteoSwiss camera network, which is primarily used for weather observations, is currently undergoing a technology upgrade. The new cameras have greatly improved image resolution and dynamic range, sufficient to recognize tree species and their phenophases. They also support taking additional images that are intended for automated analysis, with minimal post-processing (retaining as much of the physical signal as possible) and maximal downwards tilting (reducing the risk of over-saturating the sensor). In addition to our own network, more than 300 similar third party webcams are available to us through a sharing agreement with our industry partner. Although these partner cameras produce panoramic pictures rather than analysis images, they greatly increase the coverage of Switzerland, and sometimes already provide multi-year archives of past images.

We plan to use the large number of available cameras for producing automatic phenological observations. For this reason, we have assessed the suitability of all camera sites for phenological observations. On-location plant determinations have been carried out for each MeteoSwiss site, while, given their number, this process was performed online for each partner camera. This assessment shows that 21 MeteoSwiss cameras and 90 partner cameras are suitable for phenological observations. Currently, we are manually segmenting the plants of interest in a reference image for every camera. Additionally, we are developing a suitable labelling scheme for the different phenophases for all target species.

All this preliminary work is a solid basis for a future project to use modern image analysis methods, such as deep learning, to identify the different phenophases of target species. In the long term, MeteoSwiss intends to build an automated camera-based phenology network, which will supplement the current Swiss Phenology Network. Furthermore, new phenological applications are envisioned by using the same infrastructure, such as investigating the damages caused by global warming on vegetation, or tagging the vegetation zones harbouring pest symptoms.

**Keywords:** phenocamera, phenology network, webcams, deep learning, automated phenology observations.

# S6.P6 - Crop-specific phenology from sentinel-1 & 2 and disaggregated proba-v data

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## Abstract

Remotely-sensed crop phenology is a key variable for the assessment of ecosystems functioning. In this study, we evaluate the potential of the data from three sensors to retrieve several winter wheat phenological event dates in 2018-2019, over seven areas of interest delimited from Sentinel-2 tiles (100 x 100 km) and distributed throughout France. For this purpose, we used 1/ Sentinel-2 10 m (NDVI) which offers excellent spatio-temporal resolution with a revisit period of 5 days from 2017 onwards in cloud-free conditions to detect changes in photosynthetic activities; 2/ Sentinel-1 20 m (VV and VH polarizations) which is not cloud-sensitive and can be used to complement optical data, even if not directly related to the photosynthetic activity and 3/ PROBA-V 300 m (NDVI) which offers daily observations thus increasing the probability for cloud-free data. However, because of the lower spatial resolution, we have implemented a linear spatial disaggregation approach, which estimates crop-specific NDVI based on the crop fraction within a mixel (Rivas et al. 2021).

From each index, four specific phenological stages (i.e. end tillering, heading, development of fruit and senescence) were extracted either at field scale (Sentinel-1 and 2) or at the sub-mixel scale (PROBA-V). These remotely sensed phenological dates were aggregated at the communal level in order to be compared with ground data provided by the French phenology observation network - TEMPO database.

At the field scale, remote sensing phenological stages dates differed from the TEMPO observations by only 6.5 days on average. The end tillering and heading are detected more accurately by Sentinel-1 while development of fruit and senescence by Sentinel-2, demonstrating their complementarity. Moreover, disaggregated PROBA-V increased the number of NDVI valid observations when 5-day Sentinel-2 revisit was insufficient with regards to the cloud conditions, showing a strong potential to improve the detection of the end tillering and heading from NDVI. In addition, spatial disaggregation could be easily computed at the scale of France without the need for powerful computer resources. This would facilitate the operability of crop monitoring and paves the way for monitoring crop-specific phenology over fragmented landscapes, with medium resolution sensors such as SPOT-VEGETATION, even in the past as long as a land use map is available.

Our results suggest that crop-specific phenology monitoring benefits from using several sources of remote sensing data that could be used to build a large-scale and long-term phenological database for climate or food security applications.

**Keywords:** Crop phenology mapping, Phenometrics, Spatial disaggregation.




## S6.P8 - Variation in phenocam-derived observations of leaf phenology within and among hemiboreal tree species

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**Abstract**

Hemiboreal forest encompasses the shifting optimal distribution limits of both boreal and temperate forest types, providing an opportunity to develop insights for the potential effects of global change on each forest type. This study seeks to better understand how leaf phenology varies within and among tree species in order to develop insights for the potential effects of global change on the hemiboreal forest.

We established a network of 33 leaf phenocam stations across Maritime Canada encompassing a range of 3° latitude and 2 °C in annual average temperatures throughout the 2019, 2020, and 2021 growing seasons. Our phenocam stations consist of a solar-powered consumer grade cellular time-lapse camera and colour reference panel. The most common broadleaf species observed were red maple (*Acer rubrum*) and paper birch (*Betula papyrifera*), while the most common needleleaf species we observed were red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*). We dissected image field of views into regions of interest corresponding to discernable individuals and used green chromatic coordinate curve fitting and thresholds to extract leaf phenology transition dates. To evaluate how leaf phenology varies within and among hemiboreal tree species, we compared median values and absolute ranges in phenology dates for individuals at a given site and across sites.

We found that most species had a high degree of plasticity in phenological response to varying site conditions, though some had a relatively conserved response to varying site conditions.

This suggests that climate change may have differential effects on hemiboreal tree species due to the differing degrees of variation in phenology observed within species. This work demonstrates the complexity of environmental and genetic influence upon leaf phenology, as well as the utility of phenocams in monitoring leaf phenology in remote regions of Maritime Canada.

**Keywords:** leaf phenology, hemiboreal forest, phenocam, phenological response, environmental influence.

# SESSION 7




## S7.P1 - Uncertainty of the future bud-break occurrence of grapevine (vitis vinifera l.) in europe

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### Abstract

The budbreak stage plays a relevant role in the grapevine seasonal cycle by representing the beginning of vegetation growth and the starting point for vegetative biomass accumulation in many simulation models. Budbreak is mainly affected by temperature and corresponds to the bud dormancy release driven by endogenous and exogenous factors. Currently, the budbreak date is estimated using two main phenological model categories: forcing and chilling-forcing models. The first set of models estimates budbreak based on forcing units accumulation, assuming that chilling requirement has already been satisfied while the second accounts for both the chilling demand and forcing unit's accumulation (Chuine, 2000). Despite most of these models being able to estimate budbreak date under current temperatures conditions, the contribution of these models to the overall uncertainty on the estimation of the onset of the growing season under projected climate change conditions is still poorly investigated. With this regard, this study aims to explore the different sources of uncertainty as a result of climate and phenological models on budbreak date estimations for eight grapevine varieties across Europe. To this, budbreak is simulated by six phenological models (three forcing models and three chilling-forcing models previously calibrated, Leolini et al., 2020) in near/medium future scenarios (the combination of ten Global and Regional Circulation Models, GCMs-RCMs and two Representative Concentration Pathways-RCPs 2.6 and 4.5, in the period 2026-2055), bias-corrected (Lange et al., 2021) according to historical weather observations (E-OBS, https://www.ecad.eu). The source of the uncertainty on the estimation of the onset of the growing season in the future has been assessed by applying the analysis of variance (ANOVA), in which the estimated budbreak date has been correlated with the phenological models, the GCMs-RCMs and the RCPs by location and variety, and classifying the European regions. The results focus on the spatial variability assessment related to the sources of uncertainty of budbreak estimations, showing a different response of the predictive variables along to the latitudinal gradient in Europe.

**Keywords:** ANOVA, Budbreak, Climate models, Grapevine, Phenological models.




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## S7.P2 - Lessons from long term monitoring of budburst and leaf fall at the southern margin

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**Abstract**

We compare simulations and measurements of leaf phenology observations on two forest tree species, European beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) carried out over 14 consecutive years, along two altitudinal gradients located on Mount Ventoux in France at the southern margin of the distribution areas of both species. We observed and simulated an increasingly late budburst trend for Abies alba ($\beta_{meas}$ = +1.382) and Fagus sylvatica ($\beta_{meas}$ = +0.443) and an increasingly early senescence trend for Fagus ($\beta_{meas}$= -0.9841). Phenological models correctly reproduce interannual variations, but fail to predict late fir budburst and early leaf fall at low elevation site as compared with the high elevation site. This discrepancy between models and measurements is probably due to the effects of drought and dieback of both species at low altitude. On the other hand, we observe a significative effect of early droughts on the earliness of leaf fall. We discuss the implication of these results on the effect of drought on the extension of vegetation duration in the future.

## S7.P3 - Phenological and aerobiological evaluation of the birch pollen season in the czech republic

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**Abstract**

Over the past 30 years, the prevalence of pollen allergy and asthma in Europe has increased fourfold, now affecting between 15 and 40% of the population (Clot et al. 2020). This study was focused on the phenological, aerobiological and meteorological data evaluation in period 2015–2019, and the shifts in the birch flowering during 1991–2021 in the Czech Republic.

Phenological and meteorological data were exported from the CHMI database and aerobiological data from the database of the Institute of Public Health. The analysis was performed with Man-Kendall test, Geographic information methods and Microsoft Excel tools.

The results of start and end of pollen season were between April 1$^{st}$ and April 15$^{th}$ and between April 16$^{th}$ and May 8$^{th}$. Duration of the birch flowering oscillated from 12 to 29 days. The highest Pearson's correlation coefficient (0.854) was found between the amount of pollen grains and maximum air temperature. The shifts to an earlier date were found in both investigated phenological phases.

The study found out the most suitable meteorological inputs to the birch forecast model, and as well it confirmed the importance of phenological observations in connection with the aerobiological data.

**Keywords:** meteorological variables – flowering – Fenodata – correlation – phenophase.




## S7.P4 - Ecophysiological modelling of wood formation phenology in temperate and boreal forest trees

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**Abstract**

Wood phenology is an important indicator of ecosystem response to climate change. However, compared to leaf phenology, the understanding of wood phenology is still in its infancy. In this project, we aim at constructing phenological models of the wood formation process. For this, we use the GLOBOXYLO database documenting the occurrence of phenological stages in wood formation, which encompasses 220 site-years of data collected over Europe and Canada. In this data base, four major Northern Hemisphere conifer species (*Larix decidua*, *Pinus sylvestris*, *Picea abies* and *Picea mariana*) present enough data to develop such models. A combination of environmental and internal factors controls wood formation phenology. Temperature is one of the main factors. However, the role of temperature is ambivalent. For instance, the cessation of cambial divisions takes place at temperatures much higher than those promoting the onset of spring activity (Delpierre *et al.*, 2019). This suggests that other environmental factors may influence the process of wood formation, such as soil water availability (Cabon *et al.*, 2020). To date, our understanding of the impact of environmental factors on the seasonality of wood formation remains limited and there is no process-based model describing the entire cycle of wood formation phenology from spring to fall.

Our project aims at improving the knowledge of the role of environmental and ontogenetic factors controlling wood formation phenology in temperate and boreal zones and how wood phenology changes under climate warming affects carbon sequestration in terrestrial ecosystem.

**Keywords:** wood phenology, conifers species, phenological model, temperature, water availability.

Cabon, A., Peters, R. L., Fonti, P., Martinez-Vilalta, J. & De Caceres, M. (2020). *New Phytol* **226**, 1325-1340.
Delpierre, N., Lireux, S., Hartig, F., Camarero, J. J., Cheaib, A., Cufar, K., Cuny, H., Deslauriers, A., Fonti, P., Gricar, J., Huang, J. G., Krause, C., Liu, G., de Luis, M., Makinen, H., Del Castillo, E. M., Morin, H., Nojd, P., Oberhuber, W., Prislan, P., Rossi, S., Saderi, S. M., Treml, V., Vavrick, H. & Rathgeber, C. B. K. (2019). *Glob Chang Biol* **25**, 1089-1105.

# S7.P5 - Data-driven modelling of canopy greenness dynamics reveals short- and long-term meteorological effects on phenology


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## Abstract

Vegetation phenology, measured as the seasonal canopy greenness signal, is highly sensitive to present as well as past meteorological conditions. However, how these meteorological conditions affect canopy greenness on the short-term and the long-term (memory effects from previous climatic conditions) is still unclear, and modeling these effects on vegetation phenology in particular is a major challenge. In this study, we develop data-driven models to identify the influence of short- and long-term memory effects of temperature, radiation and water availability on the canopy greenness using data-adaptive approaches, such as random forest regression (RF) models and Long Short-Term Memory (LSTM) setups. We use the Green Chromatic Coordinate (GCC) from the PhenoCam network as a proxy for canopy greenness and meteorological observations from the DayMet dataset. We find that the importance of these short-term vs. long-term memory effects on canopy greenness differs across the plant functional types. For deciduous forest, roughly the last 10 days of minimum temperature and the photoperiod are identified to be the key drivers of canopy greenness, while in grasslands also the water availability and its long-term memory are important factors in controlling the seasonal course of canopy greenness. Additionally, our results show that an LSTM approach with embedded predictor memory effects outperforms a model without the memory effect (such as RF) in simulating the canopy greenness, and captured memory length varies across meteorological predictors with short temperature and radiation memory and long water memory. Our findings highlight the importance of memory effects of environmental conditions throughout the season across different time scales for canopy greenness and the fundamental role of water availability, often neglected in phenological models. Accounting for these effects in such data-driven approaches opens up new avenues for improving the representation of phenological processes in models, such as Earth system models.



**Keywords:** phenology, machine learning, memory effect, phenological model.




# S7.P6 - Combining simple cultivar phenotyping and photothermal algorithm to explore the present and future suitability of soybean crop in France

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## Abstract

To develop new cropping strategies for soybean (including early sowings for drought escape or late sowings as a double crop after a cereal), a good prediction of phenology under different photo-thermal conditions is required. For that purpose, a simple phenology algorithm (SPA) was developed and calibrated in controlled conditions then evaluated at field level (Schoving et al., 2020). The objective of this study is the evaluation of soybean crop suitability in France according to maturity groups and contrasting sowing dates.

SPA was described in Schoving et al. (2020). It simulates the duration of the main phenophases between VC and R7 stages as a function of temperature and photoperiod. It was calibrated for 10 cultivars (from MG 000 to II) using a simple phenotyping method to determine genotypic parameters. Historical series of daily temperature were retrieved from the SAFRAN historical reanalysis which covers France at 8 × 8 km resolution (Vidal et al., 2010). The SPA model was applied on each of the 8602 grid cells on the 1997-2017 period. The crop duration (from sowing to harvest) was simulated for the 10 varieties sown (i) as soon as possible from March 15 (early sowing, flexible date); (ii) on 5th May (conventional, fixed date) and (iii) on 1st July (double cropping). The flexible date for early sowing was established when air temperature was greater than 10 °C for 5 consecutive days. We considered that soybean should be harvested before October 15th at least 8 years out of 10 to be suitably grown in a given region. Climatic projections from 2020 to 2100 under the different RCP scenarios were downloaded from the DRIAS website (http://www.drias-climat.fr/).

The parameterized algorithm resulted in a RMSE value of less than 6 days for the prediction of crop cycle duration in the field trials. This performance was acceptable to attempt simulations of crop suitability at France level. Maps were generated for each of the 10 cultivars and the 3 sowing dates (early, conventional, double crop). Climate change is leading to the expansion of the soybean growing area. When choosing adapted cultivars, it is theoretically possible to grow soybean on a large proportion of the French territory when considering only photothermal requirements and realistic conditions for sowing (temperature) and harvesting (date). The simple phenology algorithm is currently being calibrated and evaluated for the prediction of other grain legumes phenology (ECODIV project) to design more diversified and agroecological cropping systems.

**Keywords:** Agroecology, Grain legumes, Maturity group, Phenotyping, Photoperiod sensitivity

Schoving C. et al. (2020). Front. Plant Sci. 10, 1755
Vidal J.P. et al. (2010). Int. J. Climatol. 30: 1627-1644




# S7.P7 - Predicting spatio-temporal occurrence of crop pests: a review of models with Mediterranean Brassica pests as a case study

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**Abstract**

Global warming is increasing herbivory in agroecosystems, resulting in yield losses worldwide. Pest incidence and damage on crops is predicted to increase in the following decades, thus urging predictions of where and when they will occur. Being ectotherms, arthropod pest development is mainly influenced by temperature. For decades, thermal requirements of these arthropod pests have been studied mostly using degree-day accumulation over a threshold temperature. These requirements often arise from development linear models fitted to physiological data obtained under laboratory conditions. More sophisticated models (i.e. including nonlinearities of thermal performance curves) have been suggested recently, but they are still limited regarding their ecological basis. Identifying and characterising these limitations while suggesting possible avenues to overcome them may help obtain more realistic spatiotemporal predictions of pest emergence, usually inferred from development models. Here we review temperature-development models of arthropod pest phenology, with the focus on Mediterranean Brassica pests as a case study. Our findings reveal several gaps in the pest modelling literature and some potential avenues to fill them. First, most models would benefit from widening their underlying ecological basis. Doing so would involve incorporating both abiotic (fluctuating temperatures, precipitation and microthermal environment) and biotic (demography through life history traits involving seasonal diapauses or migrations, host plant features such as their identity, phenology or abundance and multi-trophic phenological synchrony shifts) factors to the models. Accordingly, we illustrate with a simplified example for Brassica pests how we could incorporate phenology synchrony shifts into spatio-temporal predictive models. Second, more field data at large scales would be required for validation and transferability of development models. For our case study, we compare phenological trends predicted by linear degree day models with long-term published phenological data to illustrate this. Last, we identify and suggest some classification criteria to help guide future arthropod phenological modelling based on four categories: (i) model selection, (ii) model validation, (iii) science openness and reproducibility and (iv) practical applications for pest occurrence forecasting. In sum, integrating ecological theory, emerging methodologies and communityscience collected data into future modelling approaches will improve our ability to predict crop pest spatio-temporal incidence in a challenging climate change context.

**Keywords:** *phenology, thermal performance modelling, degree-days, crop pest, synchrony.*

# S7.P8 - A first guess late frost damage model for apple in Austria

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## Abstract

The frost damage model for apple is intended to support the insurance industry assessing the damage immediately after a late frost event. The model provides a first idea of the extension of the damaged areas and the intensity of the damage. Secondly the model has the ability to forecast potential frost damage events for the next 48 hours.

The phenological model is based on the Austrian 1 km SPARTACUS datasets, which provided daily minimum and maximum temperatures over Austria in near real time. The 48 hour forecast temperature fields are supplied by the INCA analysis and nowcasting system of the Austrian weather service. Near real time phenological observations originate from Austria's phenological observation network. For the derivation of phenological temperature sum models historical phenological observations going back to 1946 are at hand. Experimental frost damage data for apple Red delicious could be downloaded from the Wisconsin State University's home page, these are the LT10 and LT90 (10% and 90% damage at 30 min exposure) temperatures for 9 phenological stages.

The frost damage function operates on a daily basis and requires two parameters as input:

- The current phenological stage as percentage of the temperature sum required to reach beginning of flowering. On an empirical basis the percentage numbers for the four observed phases are 43% for bud break, 88% for beginning of flowering, 105% for full flowering and 130% for end of flowering. The temperature sum model is on average too late. Near real time phenological observations from Citizen Scientist are ingested into the model as residual distribution (observations – model) to move the modelled entry dates towards observations.
- The second input is the daily temperature variation in half hourly resolution.

From this input the percentage of damaged buds/flowers is calculated for the fraction left intact from the previous time step and added up to the total damage of the flowering season.
The seasonal frost damage was calculated for the last 12 years, from 2010 to 2021, and as a first validation, subjectively compared with the frost damage numbers published by the insurance company (Österreichische Hagelversicherung). The coincidence between the late frost damage calculated by the model and reported by the insurance company (in Euro) appears quite good.

**Keywords:** phenology, late frost, late frost damage, apple

# S7.P9 - Exploring the ABA signaling pathway for molecular-based phenological modelling of sweet cherry bud dormancy

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**Abstract**

Bud dormancy is a crucial stage in perennial trees and allows survival over winter and optimal subsequent flowering and fruit production. Environmental conditions, and in particular temperature, have been shown to influence bud dormancy In the current context of climate change, it is therefore essential to better understand and predict dormancy behaviour in order to anticipate upcoming changes and identify the genotypes best adapted to the future conditions.

We combined physiological, transcriptional analyses and phytohormone quantification to further elucidate how key signaling pathways control dormancy progression in the flower buds of sweet cherry (*Prunus avium* L.) cultivars characterized by their contrasted dates of dormancy release. In particular, we found that genes related to abscisic acid (ABA) metabolism were up-regulated during dormancy, associated with high ABA levels. Based on these results, we hypothesized that ABA concentrations were correlated with dormancy depth, and that they triggered dormancy release when they fell below a threshold. Subsequently, we successfully modelled ABA content and dormancy behavior based on the expression of a small set of genes regulating ABA levels. Such integrative approaches are extremely useful for a better comprehension of how complex processes control phenology in other perennial species and open up new perspectives for the development of future molecular-based phenology models.

**Keywords:** Abscisic acid, bud dormancy, hormones, modelling, *Prunus avium* L.




# S7.P10 - On the use of data-driven approaches to model spring onset from volunteered phenological observations

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## Abstract

Several national and international phenological networks were established or revitalized over the past years. These networks mostly rely on volunteers (citizen scientists) to collect data widely and over the long term. In parallel to the establishment of these networks, changes in data policies and sensor technologies have resulted in large amounts of open environmental data that can be used in phenological studies. On top of this, advancements in machine learning and computational solutions have given birth to a third scientific paradigm based on (big) data-driven approaches. Here we propose a novel approach to model spring phenology by capitalizing on these three developments. We start by collecting and exploring volunteered phenological observations from a few indicator plant species such as lilac (*Syringa vulgaris*) and from multiple networks (USA, PEP725, TEMPO, etc.). Then, we define and extract many likely explanatory variables from various weather and remotely sensed products (e.g., short- and long-term temperature accumulations and various vegetation indices). Finally, we illustrate and evaluate multiple data-driven approaches to model spring phenology. In particular, we focus on using mixed effects machine learning models because they can both deal with "clustered" longitudinal data and accommodate spatial variability in the way phenological events, e.g., leafing or blooming, react to (changes in) environmental conditions. To evaluate the merits of the proposed data-driven models, our results are compared against those obtained with classical phenological models based on thermal time.

**Keywords:** spring onset, phenological models, machine learning.

# SESSION 8

## S8.P1 - Characterization of spring phenology of plants, moth abundance and birds breeding activity in central European beech forest at three different elevations

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**Abstract**

In the temperate zone, food webs are exposed to strong seasonal dynamics. In fact, the phenology of the involved organisms shapes trophic interactions, which ultimately also affect the fitness of individuals and populations. However, species differ regarding temperature and photoperiod sensing mechanisms that induce specific life cycle events. Thus, increasing spring temperature is likely to cause considerable differences in phenological shifts among interacting species (phenological mismatch).

Central European beech forest ecosystems for instance are susceptible to such phenological mismatches since European beech (*Fagus sylvatica*) is expected to show a more conservative shift due to photoperiodic limitation, whereas insects may be more adaptive to temperature changes. Further, we expect also bird to be less responsive to warmer spring temperatures compared to insects, which could be a thread for birds when they rear their offspring after the peak in prey biomass availability.

The aim of this preliminary study is to characterize the spring phenology of plants, moths and birds at three beech forest sites along an elevational gradient of 700 meters. This includes weekly monitoring of focal plants, light-trapping of moths and monitoring of the breeding activity of a widespread insectivorous bird species, the great tit, using ten installed nest boxes at each site. Key phenological events such as budburst, peak species abundance or egg laying and hatching dates will then be compared among the sites, while the downward shift in elevation simulates climate warming scenarios.

This study aims at i) assessing the thread for phenological mismatch between trophic levels in beech forest ecosystems and ii) to discuss about possible fitness effects of the predicted shifts on taxa of the investigated community.

**Keywords:** beech forests, birds, phenological mismatches, trophic interactions




## S8.P2 - The early bud gets the cold: spring phenology drives exposure to late frost

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### Abstract

Under climate change, the increasing occurrence of late frost, combined with earlier growth reactivation linked to warmer spring temperatures, could increase the risk of frost damages on developing buds and leaves with negative consequences on tree growth and forest productivity. Species with large distribution areas can exhibit large intra-specific variability in bud phenology, resulting in a different susceptibility to frost damages. This study analysed the effects of frost damages in a common garden of black spruce (*Picea mariana (Mill.) BSP*) in Simoncouche (48°12'N; 71°14'W), QC, Canada. We tested the hypothesis that phenology drives the exposure of vulnerable tissues to frost and explains observed differences in damage.

We measured 371 trees, planted in 2014 and originating from five different provenances located along a temperature gradient between 48 and 53° N. Phenological measurements of bud break for the apical bud were performed from 2015 to 2021, including the time of frost occurrence in 2021. Frost damages were measured by counting the proportion of damaged (brown and desiccated) buds on each tree. Phenological phases and frost damage levels were analysed by ordinal regressions.

After an early and warm spring, temperatures <0°C occurred between 28 and 30 May 2021, reaching a minimum of -1.9°C. Field measurements indicated that, at the time of frost occurrence, the buds of trees from the southern provenances were still dormant or at the first phases of development, while trees from the northern provenances had more exposed shoots. The percentage of damaged trees ranged between 60% and 100% for the southernmost and northernmost provenance, respectively. The provenances originating from the colder climates (i.e. higher latitudes or altitudes) also showed more severe damages. We found a significant correlation between the progression in bud break and severity in frost damage, with a higher probability of observing more severe frost damages for the provenances from colder sites, i.e. those with the earliest phenology.

Our study provides evidence that phenological differences between provenances influence the risk of frost damage. When compared under the same conditions, northern provenances reactivate earlier than southern provenances and have higher risks of late frost damage. Our findings highlight the importance of provenance selection in forest management under climate change.

**Keywords:** Frost hardiness, Picea mariana, provenance trial, common garden, bud break.




# S8.P3 - Impact of plant-pest synchrony on the success of the corn borer of the maize

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**Abstract**

The success of a pest depends on its ability to encounter and colonize its host. Both components of the pest success depends on the match or mismatch between the phenology of the pest and the host. Hence, to limit the use of phytosanitary products, the role of phenology in plant-pest interactions can be explored in order to propose innovative pest management strategies. The impact of the match/mismatch between plant and pest phenologies was investigated for the European Corn Borer (ECB, *Ostrinia nubilalis*, Lepidoptera: Pyralidae), a major pest of maize in Europe. A field experiment on 23 maize inbred lines was performed on the Saclay plateau. The plant material includes 19 inbred lines from a public published panel representing the genetic diversity of maize as well as 4 sister-inbred lines with contrasted flowering time but descending from the same ancestor. In order to expose different maize phenological stages to ECB natural infestation, each line was sowed at three different dates. For each line and each sowing date, 6 plots of 25 plants were sowed. Plant development and the dynamics of natural pest infestation were documented throughout the season.

For the 2021 season, two generations of ECB were observed in the experimental field. Preliminary results show that the 23 maize lines were contrasted for their flowering dates (with up to 35 days between the earliest and the latest line for a same sowing date) and their susceptibility to insects borers (with 30% to 90% of attacked plants). The fraction of attacked plants was correlated with the phenology of lines with early lines less attacked than latest ones on average. Furthermore, on average, plants sowed earlier were less attacked by the first generation of insects than those sowed on the second and third date. These results suggest that match/mismatch may affect the success of the first generation of the pest and combining early sewing with the use of tolerant varieties could be an efficient strategy to control pest outbreaks.

**Keywords:** phenology match/mismatch, plant-pest interactions, maize corn borer, pest outbreaks