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Phenology:

Plant ecology and diversity

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CONFERENCE ABSTRACTS

SAC   ROYAL BOTANIC GARDEN EDINBURGH   THE UNIVERSITY OF EDINBURGH

Platform papers and abstracts

Plenary Speakers

Plasticity in plant growth and flower development allows multiple pathways to altered flowering phenology

Rebecca Sherry
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Phenological data from a one-year +4°C field warming experiment indicated that climate warming can affect the different stages of flowering differently, and that how different stages are affected varies between species. Advances in flowering time with warming can be due to earlier emergence, earlier attainment of reproductive status, or faster progression through the bud phase. Delays in flowering, seen in only three of thirteen species, were all due to a longer period of time spent in the bud phase. Advanced flowering with spring warming was not related to survival through the reproductive stages, maximum population size, or the time of population senescence. So, unlike plants in arctic and alpine environments, plants in temperate to mild climates may not experience fitness consequences because of their ability or inability to vary flowering time. However, when differences in the length of flowering stages were observed between treatments and control, it cannot be decisively determined whether the differences are due only to the warming treatment or also by differences in ambient climate experienced in each stage by the faster and slower developing plants.

Genetics and evolution of timing of growth in forest trees, especially Scots pine

Outi Savolainen
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Genetics and evolution of timing of growth in forest trees, especially Scots pine
Adaptation to climatic conditions means that forest trees time their growth and reproduction to coincide with favourable weather conditions. In common garden experiments of widely distributed species, such as Scots pine, populations show considerable variation between in the timing of growth or flowering. These differences between populations are maintained by strong natural selection in the face of often extensive gene flow. Quantitative trait locus mapping studies suggest that the differences between populations are mostly due to many loci with rather small effects. Association studies are being used to identify the actual loci responsible for the variation. Climate change induces selection for changes in the timing of growth; the potential for evolutionary responses will be discussed.

Satellite remote sensing of vegetation phenology for climate modeling

Reto Stöckli
MeteoSwiss, Zuerich, Switzerland & NASA Earth Observatory

Vegetation phenology serves as boundary condition for calculating terrestrial energy, water and carbon fluxes in climate models. Satellite-based vegetation phenology has become widely used in this field since it offers the required spatiotemporal coverage. During three decades of model development the state and function of vegetation became an integral part of land surface models since it couples the water and carbon cycle. A case study covering temperate, mediterranean and boreal climate zones demonstrates the role of vegetation for simulating terrestrial water and carbon fluxes with such models.

Retrieving the state of vegetation from satellites is hampered by clouds, snow, aerosols and technical artifacts. A few methods are shown for how to correct for these issues. We're now able to generate 20+ year long climate data records of global vegetation phenology, useful for a better understanding of vegetation - climate interaction. However, satellites cannot provide information for future climate simulations. On the other hand, the performance of empirical phenology models used in climate simulations need to be critically reviewed. It is demonstrated how the fusion of satellite data and predictive models yield a more realistic phenology and therefore a better carbon and water cycle in future climate simulations.

Phenology and terrestrial primary production; a modelling perspective

Mathew Williams
School of GeoSciences, University of Edinburgh, Scotland

The timing and magnitude of leaf expression is a critical control on primary production in terrestrial ecosystems. Measurements of primary production, limited in time and space, therefore make use of phenology data for upscaling. Estimates of landscape and regional primary production are constructed using models driven with appropriate phenological data. A key source of these data is earth observation, whereby satellite measurements of surface reflectance are used to map phenology. For predictive purposes, models require a phenology component that simulates the timing of leaf expression and senescence. These models are usually based on thermal or photo-thermal equations, or soil moisture triggers in the tropics (“rain green vegetation”). In this talk I use examples from Arctic tundra, temperate forests and croplands, and tropical woodlands to explore our understanding of phenology in models, the implications for primary production, and the links to remote sensing capabilities.

Phenology: Four current grand challenges

Roy Thompson
School of GeoSciences, University of Edinburgh, Scotland

Grand Challenges were originally conceived as goals for high-performance computing concerning fundamental problems in science, or engineering, with broad applications. Four grand challenges can be identified in phenology. Here the tasks have many affinities with the 'Labours of Hercules'. The challenges currently appear to be too difficult for mere mortals. Their solution seems to require the gifts, and fortitude, of a demi-god if not of Zeus himself. Attempts at assessing the impacts of climate change are reminiscent of Hercules' battle with the many-headed Hydra of Lernaea. As soon as one problem is dealt with, two immediately arise in its place. Mankind's trek into the future global greenhouse will be as perilous as Hercules' journey into Hades. Like Hercules we need to be prepared. Phenology can help forewarn us of many perils ahead.

Challenge 1 (for the statistician & physiologist)
Question: Can the world's best models and observations be reconciled?

Challenge 2 (for the remote sensor & modeller)
Question: Can we upscale from plant to patch to planet?

Challenge 3 (for the ecologist and manager)
Question: Where will biota move to? And how quickly?

Challenge 4 (for the geneticist)
Question: Will plants keep pace with future climate change?

Session speakers *(alphabetical order by first author)*

A new data-constrained model of leaf phenology for the Amazon basin

Silvia Caldararu[1], Paul Palmer[1] and Drew Purves[2]
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Quantitatively understanding temporal and spatial variations in contemporary vegetation, and associated changes in biogeochemical cycles, is key for helping to decrease uncertainty in future climate projections. This is particularly true for the Amazon basin, which constitutes one of the largest areas of continuous tropical forest and as such plays a central role in the global carbon and water cycles. *In situ* measurements over tropical ecosystems are sparse, as year round access in many regions is often difficult. Space-borne measurements of canopy optical properties offer new spatially and temporally continuous measurements allowing a better characterisation of vegetation dynamics. We propose a new model for leaf phenology, which describes variation in leaf areas index (LAI) as a response to the level of incident photosynthetically active radiation. The model uses leaf gain and loss to describe leaf age distributions as a function of time, an aspect which is essential to describing forest level dynamics. We use a Bayesian fitting technique to fit the model in an 8-year record of LAI data over the Amazon basin as observed by the MODIS instrument aboard the NASA Terra satellite. We will interpret inferred spatial and temporal variations in leaf production and loss in relation to climate and canopy properties.

Sampling bias in the determination of first flowering dates

Malcolm Clark[1] and Roy Thompson[2]
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Flowering, leafing and migration dates have been getting earlier over the past 100 years, suggesting that spring is starting earlier. But in some instances this apparent change could be simply due to more people observing phenological data, and in particular simply recording first occurrences. This recorded date will be generally less than the correct *mean* First Flowering Date (expressed as Day of the Year), resulting in biased observations.
In this paper, we demonstrate to what extent this sampling bias depends on the size of the population being observed, the frequency of observations, and the number of observers, using two plausible statistical models describing how the unobserved First Flowering Dates vary. We find that in practical terms the bias effect is not insignificant. We give examples of circumstances in which it is larger than the observed advancement of spring.

Continuous monitoring of seasonal phenological development by BBCH code

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Keywords: Phenology, BBCH-scale, phenological stages

Phenology, the science of recurrent seasonal natural events, is a proxy for changes in ecosystems due to recent global climate change. Phenological studies mostly deal with data considering the beginning of different development stages e.g. budburst. Just few

studies focus on the end of phenological stages, like the end of flowering. Information about the entire development cycle of plants, including data of the end of stages, are received by observing plants according to the extended BBCH-scale (MEIER 1997).
For this study the original BBCH-scale was adjusted to the needs of different wild grass species. Due to the new observation keys grasses could be observed in a weekly rhythm, which is less labor intensive. So in 2009 frequencies of all occurring phenological stages were noted every week for each grass species from April to October.
Due to the lack of studies using the BBCH-scale as a basis for observations over the entire development cycle there is no common methodology to analyze the data. So our objective was to find a method of analysis, with which onset dates as well as endpoints of each development stage could be defined. Three different methods of analysis were compared on the basis of grass data from 2009. Results show that there is no significant difference in onset dates of phenological stages between all methods tested. However, the method of pooled pre/post stage development seems to be most suitable for climate change studies, followed by the method of cumulative stage development and the method of weighted plant development.

The presence of a single peak of number of species in bloom in different plant communities - relationship to community characterisation and to biotic & abiotic factors

Richard Gulliver
Open University

Recording the sequence of flowering of the component species in different plant communities assists in the process of determining the degree of similarity between the communities. A single peak of flowering was widespread in managed and unmanaged communities. The effect of abiotic factors e.g. light, and biotic factors e.g. grazing, on the sequence and on the peak of flowering will be discussed.

Phenology and the restoration of ecosystems: practical problems and moral dilemmas

Barbra Harvie
Botanical Society of Scotland & School of GeoSciences, University of Edinburgh, Scotland

Ecological restoration applies scientific understanding of successional processes and the autecological characteristics of species within a damaged ecosystem to assist the recovery of that system to a functioning and sustainable habitat. Interspecific differences in phenological shifts of both plants and animals as a response to changes in climate can affect interactions between species within an ecosystem to such an extent that the system may no longer function. The implications of the potential functional collapse of key habitats are highlighted by reviewing existing literature on heather moorland and other heathlands.
Examples of native species displacement, losses and gains will be introduced from the perspective of both restoration ecology and phenological change. Some of dilemmas resulting from a rapidly changing environment will be discussed in the context of restoring and maintaining diversity of species and habitats in this International Year of Biodiversity.

Seasonal adaptation in *Arabidopsis thaliana*

Andrew Hudson, Poay Lim, Hayley McCulloch and Abigail Harter
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We have studied populations of the cruciferous weed, *Arabidopsis thaliana*, from around Edinburgh, and found surprisingly high levels of genetically determined variation in life history traits such as seed dormancy, growth rate and flowering time. Much of this variation appears to have evolved locally and is not due to recent immigration, suggesting that it might reflect adaptations to the environments that vary on a local scale. In common garden experiments we found no evidence for adaptation to elevation (year-to-year environmental differences have a greater effect on fitness than 230m difference in altitude) but find evidence for adaptation to season – i.e. some genotypes perform consistently better as biennials that germinate in late summer and flower the following spring, and some as summer annuals that germinate in spring and flower in early summer. Different plants appear to be adapted to different aspects of seasonal variation (e.g. day length or temperature). We propose that seed dormancy determines whether plants grow as biennials or summer annuals and that direct selection for this trait might have an indirect effect on flowering time variation because the two processes are regulated by common genes.

Beyond gradual warming – extreme weather events alter flower phenology of European grassland and heath species

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Shifts in the phenology of plant and animal species or in the migratory arrival of birds are seen as “fingerprints” of global warming. However, even if such responses have been documented in large continent-wide datasets of the northern hemisphere, all studies to date correlate the phenological pattern of various taxa with gradual climatic trends. Here we report a previously unobserved phenomenon: severe drought and heavy rain events caused phenological shifts in plants of the same magnitude as one decade of gradual warming. We present data from two vegetation periods in an experimental setting containing the first evidence of shifted phenological response of 10 grassland and heath species to simulated 100-year extreme weather events in Central Europe. Averaged over all species, 32 days of drought significantly advanced the mid-flowering date by 4 days. The flowering length was significantly extended by 4 days. Heavy rainfall (170mm over 14 days) had no significant effect on mid flowering date, however heavy rainfall reduced flowering length by several days. Observed shifts were species-specific, e.g. drought advanced the mid-flowering date for *Holcus lanatus* by 1.5 days and delayed the mid-flowering date for *Calluna vulgaris* by 5.7 days; heavy rain advanced mid-flowering date of *Lotus corniculatus* by 26.6 days and shortened the flowering length of the same species by 36.9 days. Interestingly, the phenological response of individual species was modified by community composition. For examples the mid-flowering date of *Calluna vulgaris* was delayed after drought by 9.3 days in communities composed of grasses and dwarf shrubs compared to communities composed of dwarf shrubs only. This indicates that responses to extreme events are context-specific. Additionally, the phenological responses to experimental communities to extreme weather events can be modified by the functional diversity of a stand. Future studies on phenological response patterns related to climate change would profit from explicitly addressing the role of extreme weather events.

GIS-assisted regionalisation of phenological data in Southern Bavaria using discriminant analysis

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Keywords: phenology, discriminant analysis, GIS, regionalisation, modelling, meso-climate, land use, flowering of *Forsythia suspensa* L., Southern Bavaria.

In this approach we explore the power of digital land use information to support the regionalisation of phenological data on the mesoscale in Southern Bavaria. While meteorological data are difficult to generate for the chosen resolution, area-wide digital data (elevation models, land cover data) are frequently available.
The dates of beginning of flowering for *Forsythia suspensa* L. (1995-2008) of 70 stations and selected spatial data are combined in a discriminant analysis. The peculiarity of this new study is that no meteorological data are used at all.
The analytical result of the statistical analysis is used to conduct a GIS-based regionalisation beyond the known values of phenological dates of onset on the mesoscale. Thus, a map with modelled group membership was developed which offers a spatial interpretation of phenological behaviour and is therefore appropriate for matters of forecast and validation.
We demonstrated that the selected factors (mostly land use) are able to represent the mesoclimate adequately. The application of the discriminant analysis seems to be a suitable alternative to the commonly used regression analysis.

Satellite-based mapping of the growing season in Scandinavia and on Svalbard

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The aim of this study is to map the trends, extreme years, and mean date in onset, end, and length of the growing season in Scandinavia and on Svalbard for the 1982-2009 period. Phenological in-situ data, mainly on birch (*Betula pubescens*), from Scandinavia were used to interpret satellite data in measuring the growing season. Since no tree grows on Svalbard we use observations on the small willow *Salix polaris* in the interpreting process.
We explore 8 and 16 days composite satellite datasets from the 250/500m resolution MODIS sensor for the 2000-2009 period. In most cases the use of the 16-days resolution NDVI dataset show high correlation with field observations during spring in Scandinavia. In autumn the use of NDVI show less correlation with phenological field data, and combinations of other bands gave better results. Due to the short growing season on Svalbard, the 8-days composite dataset, show more reliable results than the 16-days composite data.
To further prolong the period we used the 15-days composite GIMMS-NDVI dataset with 8 km resolution from the period 1982 to 2006 to measure the growing season. The GIMMS-NDVI dataset is based on NOAA-AVHRR data series. Within Scandinavia the trends in onset of the growing season shows a pattern following the north-south, oceanic-continental and altitude gradients. Based on these studies there are indications of three weeks earlier onset of the growing season in southern and western oceanic parts of Scandinavia, while in alpine and northern continental parts of Scandinavia there are only small changes.

Onset of flowering: its association with annual variations of temperature and changing climate

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A wide-raging study was made of an East Lothian coastal garden. The flowering of c. 1,000 species/cultivars was monitored over 30 years starting in January 1978 and concluding in December 2007. This contribution focuses on the first dates of flowering (FFD) of the 208 species with the most complete data sets, including 29 British natives. For those species that produced more than one flush of flowers, analyses were restricted to their first flushes. Data related to flowering duration and numbers of flower flushes per year await analyses. Weather data from the Royal Botanic Garden, Edinburgh was kindly supplied by Dr. Stephan Helfer.
Over the 30 years, the range of FFDs observed varied considerably between species: for example Martagon Lily (two weeks); Apple (five weeks); Wild Daffodil (7.5 weeks); Flowering Currant (nine weeks) and Mexican Orange (15.5 weeks). Using a number of methods, variations in FFD in 139 species were found to be associated with temperature changes, particularly between January and April. For 28 species, there were delaying associations with warmer autumns in the previous year. Looking over the species, there is the suggestion that later flowering species tend to be affected by later temperatures.
We will show the results of more detailed analyses, including thermal-time models and examine the extent to which factors such as the time of year of flowering and the growth type influence relationships with temperature.

A comparison of phenological models of leaf bud burst and flowering of boreal trees using independent observations

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Keywords: *Betula pendula*, *Betula pubescens*, chilling, dormancy, forcing, *Prunus padus*, *Sorbus aucuparia,* spring phenology*.*

We compared several phenological models for the leaf bud burst of birch, as well as the flowering of bird cherry and. The models represented a selection of Thermal Time, Sequential, Parallel and Flexible models. Phenological recordings from one site in Central Finland for the 1953 to 2002 period were used to estimate the values of the model parameters. The models were then tested with data collected between 1896 and 2002 in Southern and Central Finland; dividing this long dataset into two datasets, each 50 years long. The use of three datasets enabled testing the models with data that was independent of the parameter fitting data. Several different models fitted the parameterization data well, but the test with independent data showed poorer performance. This may be due to the models being over-parameterized, and able to adapt to the measuring noise in the data, in addition to the phenological phenomenon itself. Thermal Time -type models performed best in the test with independent data, but Sequential and Parallel type models were almost equal in prediction accuracy. The Thermal Time models thus seem to be most useful in describing boreal spring

phenological events under current climatic conditions. Some precaution needs to be taken with simulations of climatic warming, as the changed conditions may highlight the relevance of chilling in the timing of budburst under elevated temperature conditions, which may have a major impact for the model predictions. Finally, I will briefly discuss the physiological interpretation of the parameters of the Thermal Time model.

Ref. **Linkosalo, T.**, Lappalainen, H. K., Hari, P. 2008. A comparison of phenological models of leaf bud burst and flowering of boreal trees using independent observations. Tree Physiology 28:1873–1882.

Thoughts on ecological effects of global change

Annette Menzel
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The use of digital cameras for remote assessments of forest phenology: a modern approach to an old problem

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Improving our understanding of how forest trees are likely to react to response to climate change is fundamental to the development of robust forestry mitigation and adaptation strategies. Long term phenology records are now contributing to a strong evidence base of climate change indicators. However, taking daily/sub-daily manual observations is often impractical, particularly in remote locations, resulting in a lack of precision about the timing of events such as bud-burst and leaf-fall. In addition, measurements from the ground may biaised to lower parts of the canopy and may not reflect the condition of the whole canopy that will be determining functional activity such as light interception, CO_2 flux or evaporation, for example. Therefore, there is growing interest in the use of digital cameras for the remote measurement of phenological events at higher frequency, and potentially assessing larger canopy areas. Two different camera systems mounted on a tower have been used to capture canopy images over the full 2009 growing season for an oak-dominated mixed deciduous woodland at the Alice Holt Research Forest (Hampshire, UK). One system uses a standard digital camera with hemispherical lens, the other uses a webcam. This paper will examine hoe theses remotely recorded digital images can be used for manual interpretation of key phenological stages both at the individual tree and at canopy level. We will also demonstrate techniques for quantitative assessment of canopy changes using automatic image processing freeware.

Comprehensive ground observation network connecting satellite remote-sensing with in situ ecosystem observations: Phenological Eyes Network (PEN)

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Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan

Satellite remote-sensing (SR) is a strong method to evaluate the ecosystem structure and function for regional to global scales. For example, RS detects the interannual variations of the timing of leaf expansion and defoliation due to global warming. However, from the in situ ecological research viewpoint, the RS method has not been tested or validated by the ground-truthing observations. We should study the uniqueness, generality, and robustness of the relationship between the dynamics of the ecosystem structure and functions and its interpretation of the RS. For the sake of it, a stable, robust, continuous, long-term, and multi-ecosystem ground validation network is required. We have organized the "Phenological Eyes Network (PEN; see http://www.pheno-eye.org/ for details)" since 2003. PEN is a network of ground observatories for long-term automatic observation of the vegetation dynamics (including phenology of foliage and canopy growth) by using a digital camera, vegetation's optical properties (such as spectral reflectance) by using a spectroradiometer, and the atmospheric optical properties (such as aerosol optical thickness) by using a sunphotometer. PEN ground sites have been set up at the multi-ecosystem sites in Asia. For example, we identified that the previously reported criteria of the timing of leaf expansion and defoliation by using NDVI (Normalized Difference Vegetation Index) are misleading in a deciduous broad-leaved forest by examining the relationship between the canopy surface images and spectral reflectance data for multiple years.

Regression methods for phenology

Adrian MI Roberts
Biomathematics & Statistics Scotland, Edinburgh, Scotland

Phenological records can be related to weather data using association-based models or mechanistic models. Examples of the latter include thermal time models. In these the event is expected to occur once sufficient temperature-time units have been accumulated. There may also be a chilling requirement. Although in principle mechanistic models seem to provide the better approach because of their biological basis, they can be difficult to fit and are less flexible. This can be a particular problem for observational data. Also such models are not available for all types of natural event. In the case of association-based methods, linear regression is commonly used, particularly stepwise regression. However such methods generally do not perform well with many highly correlated regressors, so weather data is typically aggregated to monthly means. Penalised regression has been proposed as a way to analyse daily measurements, giving more interpretable results than other methods for high dimensional data such as partial least squares or ridge regression. Differences between consecutive regression coefficients are penalised, resulting in a smooth profile of coefficients. Extensions of this methodology allow the exploration of the effects of covariates, generating multidimensional surfaces of coefficients.
Here we compare stepwise and different forms of penalised regression with some examples of mechanistic models. We investigate to what degree results from a regression can be interpreted in terms of an underlying biological model and how the number of observations affects the quality of results.

Timing of bud flush shows evidence of local adaptation in native woodlands of Scots pine (*Pinus sylvestris*) in Scotland

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Scots pine is a keystone species in the Caledonian forests and also a national icon. Native pinewood in Scotland covers~18,000 hectares in 84 separate, differently sized fragments found in highly heterogeneous environments. For instance, the length of the growing season can vary between about 110 and almost 300 days within only 200 km.

Adaptation to local environments is a common phenomenon in trees and has been extensively studied for the development of seed transfer guidelines. Currently there is only little evidence of local adaptation in Scottish pinewoods, and the current seed transfer guidelines are based on molecular variation which might not reflect fine scale patterns of local adaptation.
We are studying variation of adaptive traits in native pinewoods in a common-garden trial or ~3,300 seedlings from 21 populations and 84 open-pollinated families. In the spring of the 2nd growing season, timing of bud flush was found to be significantly different between populations and among families within populations. Bud flush generally occurred earlier in populations from colder regions, which could reflect their adaptation to shorter growing periods. The difference between the means of the earliest populations was seven days. The trait also shows high evolutionary potential: additive genetic variance (i.e. the heritable portion of the variation) accounts for 66% of the total variation. The results of the study are to be used in further development of the seed zones of pine in Scotland.

Norwegian long-term plant phenological observations 1928-1977

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The time for first flowering was observed in several plant species through 50 years (1928-1977) along Norway from about 58°N to nearly 71°N. For woody plants the time was also often observed for first leaf bud break, autumn colouring and leaf fall. Generally, there were highly significant correlations (0.1% level) between the timing of nearly all spring/early summer observations in plants and gridded mean monthly temperatures (1 km resolution adjusted for elevation differences) during more than one month before the various phenophases. Up to 65% of the variance was accounted for but less for the autumn phenophases. Analyses by a low pass Gaussian smoothing technique showed early phenophases in the warm period of the early 1930s, delayed phases for most sites and species in the early 1940s, mid 1950s, late 1960s and also towards the end of the study period in the late 1970s. During those periods the temperatures were lower than average in most places. This study start in a relatively early (warm) period and a study end towards a late (cooler) period may be the main reasons for no significant linear trends in the phenophases throughout the total period. The end of the observation period in 1977 is also before the strongly increasing earlyness of plants in most Norwegian lowland areas due to global change. However, the strong altitudinal and latitudinal variations in Norway do cause regional differences in earlyness and variations in trends.

Poster presentations and abstracts

Flowering, fruiting and flight curves

Malcolm Clark[1] and Roy Thompson[2]

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In many phenological studies an easy, practical approach that is often adopted is to observe first occurrences. More information, however, can be obtained from the full flight curve, of aphids, or the full flowering, or fruiting, behaviour of plants. A straightforward approach to modelling flowering, fruiting or flight curves is to fit them by a normal distribution curve. However, many phenological data sets, of both individual and population behaviour, are skewed. We have explored a range of alternative models, including Richards curves, Markov models, skew-normal and the beta family of curves. The poster illustrates some of the advantages and disadvantages of various types of model.

A 2-threshold temperature sum model to describe the whole flowering period of *Betula* ssp.

Tapio Linkosalo[1], Hanna Ranta[2], Annukka Oksanen[2], Pilvi Siljamo[3], Alpo Luomajoki[4], Mikhail Sofiev[3] and Jaakko Kukkonen[3]

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Most events of spring phenology can be considered as point events. The flowering of wind-pollinated trees like birch, however, is a continuous event; for many applications, like pollen forecasts and prediction of long-range transport episodes, a model for the whole flowering event would be useful.

We developed a phenological model that predicts the pollen release throughout the whole flowering period. The model is based on the common Thermal Time model, where an event is predicted to take place when accumulated temperature sum meets a threshold. Our model has two temperature thresholds so that the flowering is predicted to start when the accumulated temperature sum, $S(t)$, meets the first threshold, T_1, and to end by meeting of the second threshold, T_2. The cumulative pollen release, $R(S)$, between these two thresholds depends on a linear interpolation of the accumulated temperature sum:

$$R(S) = [S(t)-T_1] / [T_2-T_1].$$

For model evaluation we used historical phenological data for 1963 to 1971 in 16 sites in Finland for birch. The overall fit of the model to the data was good, comparable to that of point-event phenological models. The starting and ending dates of the flowering period were also estimated with accuracy similar to that of ordinary Thermal Time models. Our model underestimated the length of the flowering period slightly, with the onset 1.2 to 1.5 days later than observed, and the end 3.1 to 5.1 days earlier than observed. The model is utilised in the Pollen project, that models the long-range transport of airborne birch pollen.

Investigating temperature-related genotypic and phenotypic variation in european aspen (*Populus tremula* L.)

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***Keywords**:* phenology, adaptation, dormancy, Populus, genetic variation, climate change

It is well established that climate change, in the form of increasing temperature, is causing changes in tree phenology particularly in temperate latitudes. Changes in the timing of budburst and flowering can put trees under selective pressure, as their reproductive success and ultimately their survival may be effected. It has been shown that rapid responses to higher temperatures are occurring in natural populations of forest tree species. However, the genetic basis of this response is as yet unclear. There are strong indications of links between flowering genes and dormancy regulation, both of which are controlled by temperature and photoperiod. The twofold study on *Populus tremula* presented here includes both a genotypic and a phenotypic approach. Firstly, a list of candidate genes related to dormancy is being developed and any variation within these genes assessed. Plant material from natural European populations are being used to determine (1) clinal variations of SNPs and patterns of DNA sequence variation in targeted temperature-related genes across the geographical area examined, and (2) the diversity of these genes that is present within certain populations, showing the capacity of such populations to adapt to predicted rises in temperature. The second element of this study is to quantify the effects of temperature and photoperiod on the percentage and timing of bud burst and bud formation in clones of Aspen, using controlled environment experiments. The results will be integrated into a mechanistic phenological model, in order to make future projections of bud burst under predicted climatic changes.

The Rhododendron Phenology Project at Royal Botanic Garden Edinburgh

Christine Thompson
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This project, piloted in 2007 and formally begun in 2008, monitors the flowering curves, leafing and capsule-dehiscence of a wide variety of rhododendron species in order to:

- Detect climate change impacts on rhododendrons
- Determine the phenological variability of rhododendrons
- Identify any phenologically functional groupings

The data collected in this project, and in a pre-existing RBGE phenological project, already indicate that:

- Rhododendrons display unusually high variations in their annual flowering and leafing patterns, not only between species but also within species
- Their flowering dates are strongly influenced by the air temperatures in the weeks immediately before flowering
- For *R. ponticum*, springtime warming of 1°C causes the date of flowering to advance by 12.5 days.

Science reporting to the public: does the message get twisted? A phenological example.

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The daily press has found its own place in modern democracies, that of entertaining readers and stimulating debate. Inevitably, nowadays, the reporter's reframing of original scientific information seems to puts its own strong slant on the science. In this

case example our key concern is that the pace of climate warming is faster than the ability of plants – particularly long-lived trees - to adapt and evolve.
Increasingly, as you talk to scientists about how their work and the journalism about it meet each other, they talk of parallel universes. What scientists do, how they do it, and what they discover all seem to exist quite separately from journalists' descriptions about what the scientists have done. We explore these conflicts in our case example.

What are the causes of variation in flowering phenology of *Campanula rotundifolia* – products of adaptation or population history?

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Two cytotypes of *C. rotundifolia* occur in the British Isles: tetraploid and hexaploid. These show a strong spatial pattern with hexaploids occurring in oceanic western areas, and tetraploids occurring elsewhere. Historical records of flowering phenology indicate that dates of first flowering of plants growing in oceanic districts are less affected by variation in temperature in preceding months than those from more continental districts.
The genetic and environmental effects on flowering and fecundity are being explored in a common garden study which has brought together both cytotypes of *C. rotundifolia* from a wide range of localities. In parallel, examination of ITS sequence data identified several types in the tetraploid population whereas the hexaploid was monomorphic.

Phenological responses to climate change and their trait-induced differences

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An increasing risk of pollinosis is one of the most likely expected consequences of climate change, and the detection of differences in responses of wind-pollinated plants with respect to other vegetation categories is important to understand the impact of increasing temperatures on the behaviour of allergenic plants. Wind pollinated plants can be considered as representative of allergenic species because the latter include those ones with the highest capability of causing allergy-related diseases in human subjects.
With this aim, on the basis of an extensive plant phenological dataset which involves a number of phenological stations distributed in Central Europe, we assessed those differences in temporal trends related to Plant Functional Types (PFTs, i.e. woodiness), ecological traits (i.e. dates of flowering) and functional traits (i.e. pollination mode) for 40 species wide-distributed in the considered area. We focused on the response of different flowering substages (beginning of flowering, full flowering, end of flowering), this specific phenological phase showing to be so far one of the most affected by climate change.
Our main results indicate that, during the last three decades, wind-pollinated plants advanced more than insect-pollinated ones, moreover showing a significant linear dependence of trends on phenodates (trends are stronger for phases that occur earlier in the year). With a statistical significance smaller than in the previous case, woody species are advancing more than non-woody ones, any dependence of trends on phenodates shown. These findings identify woody wind-pollinated plants as a category to carefully keep under control, because the respective flowering phases show a major propensity to advance.