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Environmental Protection Agency
*An Ghníomhaireacht um Chaomhnú Comhshaoil*

## Climate Change Research Programme (CCRP) 2007-2013
## Report Series No. 22

# Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems

SSTI
Strategy for Science, Technology and Innovation

**Comhshaol, Pobal agus Rialtas Áitiúil**
Environment, Community and Local Government

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**Climate Change Research Programme 2006–2013**

# Climate Change Impacts on Phenology: Implications for Terrestrial Ecoystems

## (2007-CCRP-2.4)

## FINAL REPORT

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

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## ACKNOWLEDGEMENTS

This report has been prepared as part of the Science, Technology, Research & Innovation for the Environment (STRIVE) Programme under the Climate Change Research Programme (CCRP 2006–2013). The programme is financed by the Irish Government under the National Development Plan 2006–2013. It is administered on behalf of the Department of the Environment and Local Government by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to express their thanks and indebtedness to Met Éireann, particularly Dr Emily Gleeson, Dr Tido Semmler and Dr Ray McGrath for their cooperation and providing of essential climate records. We also would like to thank the National Biodiversity Data Centre, particularly Dr Eugenie Reagan, Dr Liam Lysaght and Mr Barry O'Neill for their assistance in the creation, maintenance and publicity of Nature Watch. We acknowledge the assistance and use of propagation facilities at provided to us at Teagasc, Kinsealy by Dr Gerry Douglas. We also gratefully acknowledge the on-going encouragement, advice and wisdom of Dr Tim Sparks (University of Cambridge, Technical University of Munich and Poznań University of Life Sciences), Dr Matthew Jebb (National Botanic Garden, Ireland) and Dr Esa Lehikonen (University of Turku, Finland) who served as project consultants, and whose comments helped us considerably during the production of this report. Any errors or omissions however, are entirely the responsibility of the authors. And finally we would like to thank all of the volunteers who made observations of plants, birds, moths, or on Nature Watch; we could not have completed this project without your fine work.

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ISBN: 978-1-84095-463-0

**Price: Free** **Online version**

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# Executive Summary

This large-scale 'Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems' project aimed to: (i) establish a sustainable network of phenology gardens across Ireland, (ii) locate and analyse historic phenological records of birds and trees, (iii) conduct experiments to provide data upon which to develop models to predict future timing of bud burst resulting from rising temperature and (iv) raise awareness among the scientific community and the general public of the impact of climate change on the environment.

## Sustainable Phenology Network

At the inception of this project there were already six phenological gardens located in Ireland, all of which were members of the International Phenological Gardens (IPG) network. This is a Europe-wide network established by the German Weather Service in the 1950s and comprising 50+ gardens, each planted with clones of a series of tree species. There were four such gardens planted in Ireland in the early 1960s and subsequently two more were established in the early 2000s. Records of the timing of a range of phenological phases (such as bud burst, leaf unfolding, flowering, fruiting, leaf colouring and leaf fall) are taken of each tree throughout the year. Since the timing of these events is influenced by temperature these data were used as an indicator of the impact of climate warming on trees.

In 2009, as part of the current project, the number of IPG sites was expanded to 16 and a series of 11 native species gardens was also established. The combined networks will enable comparison of the timing of phenological phases at a European level using the IPG data and at a national level using the native species. The number of sites across the country is continuing to evolve as some sites withdraw from the networks and others are added. The co-ordination of the networks is carried out as part of Ireland's newly established National Phenology Network (IE-NPN) which co-ordinates all phenology activity, both monitoring and research, in the country. A strategic plan for IE-NPN has been drafted: this proposes a series of priorities which will guide its activities into the future.

## Phenological Datasets and Analyses

In addition to the bird and plant records that were to be analysed within the project, a number of other, unforeseen, datasets were uncovered. These included the analysis of flowering and fruiting dates (1852–2007) of *Rubus* (bramble) from herbarium specimens located at the National Botanic Gardens. These results showed that the phenophases were significantly advanced as average January–June temperature increased. In addition, a series of moth records (59 species) over a 36-year period (1974–2009) were analysed in relation to temperature variables; this revealed that many of the common moth species in Ireland, such as the flame carpet, are not only now emerging earlier than 36 years ago but that their period of activity has also extended. The change in phenology of these moths has been attributed primarily to rising June temperatures.

In relation to the timing of arrival and departure of migrant bird species, it was revealed that the whooper swan, a winter visitor, is now departing earlier in spring than in the 1970s. This earlier departure is strongly correlated with average February temperature which, in turn, is an indicator of grass growth – the major food source of this grazing species. As the food source is available earlier in the season the swans get in condition sooner, which aids earlier departure. Interestingly, their arrival time in autumn did not change significantly over the study period and the possible reasons for this require further investigation. Analysis of 40 species of non-passerine migrant bird species to the east coast of Ireland indicated that response to temperature was species specific but that more than half of the species were arriving earlier over the 24-year period (1980–2003) and that this was correlated with spring temperature.

A wide range of climatic variables, including minimum, maximum and mean air temperature (°C), soil temperature (°C), rainfall (mm), sunshine (hours), number of air frost days and number of rain days were correlated with the beginning of the growing season (BGS) as determined by leaf-unfolding dates of a suite of tree species at Valentia Observatory to investigate the influence of weather on this phenophase. The data showed that the highest correlations were between BGS and minimum air and soil temperature, with poplar and aspen showing the strongest relationships.

Due to the adverse influence of pollen on the proportion of the population who suffer from hay fever an investigation of the beginning, peak and end of the birch (and related species) pollen season was carried out in 2010 and 2011. The birch pollen season started earlier in 2011 and lasted longer than in 2010 as a direct result of warmer temperatures. Given the correlation between phenophases such as bud burst and flowering, this result, at least in part, confirms model findings which suggest that bud burst of birch will continue to advance in future as a result of increases in temperature.

Methods of recording phenology other than using direct observation are increasing in popularity. These include the use of remotely sensed data from satellites which can provide evidence of ‘greening’ of the landscape. Satellite-derived vegetation index data can be used to monitor the start of the growing season. Results revealed that the growing season in Ireland first starts in the south-west of the country and continues northwards. In addition, evidence of double cropping, which was the result of silage being cut several times over the summer months, was noted.

## Experimental Data and Model Development

To refine previously developed phenological models on bud burst of birch in order to increase predictive capability, controlled environment experiments were conducted on birch and aspen trees. The plants were subjected to a range of chilling and forcing temperatures and the subsequent impact on bud-burst timing and percentage of bud burst were recorded. The distributions of these results were modelled with a view to incorporating a dynamic component of bud burst into phenological models rather than the currently used static (average) value.

The historic data for leaf unfolding of birch from the four longest-running IPG sites in Ireland were used in conjunction with future projections of temperature in a phenological model (DORMPHOT) to predict the timing of bud burst up to 2100. The model output for the timing of birch tree leafing suggests that, as temperatures continue to rise, leafing will become earlier. The rate of advancement was greater at some sites than at others. Furthermore, the future projections showed that the advance in the timing of bud burst would be greater in the east of the country than in the west.

A novel study was carried out which aimed to quantify genetic variation involved in the release of dormancy, both within and between natural populations of European aspen, and to investigate if genetic variation existed along latitudinal and longitudinal gradients in Europe. The traits of interest were spring phenological phases such as bud burst and reactivation of growth after dormancy; and the genes of interest were linked to temperature. The study analysed single nucleotide polymorphisms (SNPs) and patterns of DNA sequence variation in candidate genes between different European populations in order to test whether variation between the populations exists at the level of individual SNPs, which would suggest that an adaptive response to local conditions has occurred.

## Awareness-raising of the Impact of Climate Change on Phenology

In order to raise awareness among the general public of the impact that climate warming could have on plant and animal life, popular articles were written for environment magazines and a series of media interviews and public lectures given. In addition, the Nature Watch website was developed in collaboration with the National Biodiversity Data Centre. This invites members of the general public to record phenological observations online. An initial series of phenophases of common plants, birds and insects was set up and it is envisaged that a greater number of species and phases will be made available to record in future.

An international conference entitled Phenology 2010 was held in Trinity College Dublin to engage and inspire the scientific community in phenological research. This resulted in the publication of 14 peer-reviewed scientific papers in a special issue of the International Journal of Biometeorology. In addition, a number of peer-reviewed scientific papers and book chapters have been published by project participants adding to the body of knowledge on phenology.

## Conclusion

Overall, this has been a hugely successful project which has not only reached all its initial goals but completed a substantial number of additional objectives within the timeframe of the project. The results clearly demonstrate for the first time the impact of climate change on a range of plant and animal phenologies across the country. This information is not only useful from an Irish perspective but will be of practical use at a European level for climate change policy development. It is imperative that the network of sites is maintained into the future as the results will yield valuable information on how biodiversity and ecosystem services will respond as temperatures continue to rise.

## Recommendations

### *Phenological Network*

- Identify indicator plants specific to the Irish climate in order to substantiate the influence of climate change on the Irish growing season.
- Develop a website which would enable the participants of the gardens network to discuss observations as they happen. A blog or Twitter account may be suitable.
- Establish a centralised group of gardens within the Irish IPG network that would oversee the annual observations and report directly to the IPG and a national co-ordinator.

### *Pollen Release*

- Further expand the study on Ireland's pollen season to include grass which is the most virulent plant source causing allergenic rhinitis globally.

### *Strategic Plan*

- Implement the findings of the Strategic Plan.
- Facilitate propagation of both IPG and native species between site participants.
- Continue to raise awareness of the importance of phenology among both the scientific community and the general public through publishing research findings and providing information leaflets, public talks and media interviews.

### *Herbarium Records*

- Digitise herbarium specimens, which would be useful on a global scale.
- Research the potential for trophic level asynchrony in herbarium collections further.
- Include additional species that are available in herbaria.

### *Bird Migration*

- Carry out further studies on bird wintering populations.
- In order to continue to develop our understanding of how climate change is impacting bird migration, broaden the range of temperature variables.
- Examine arrival dates of northern species to determine if arrival is getting later over time.

### *Moth Phenology*

- Locate and analyse datasets from additional trophic partners (e.g. bats or herbaceous plants) for moths for potential future mismatches.
- Analyse moth phenology in relation to changes in precipitation in addition to temperature.
- Establish a more uniform network of moth observers across the country, similar to the IPG network for future observations.

### *Remote Sensing*

- Assess the feasibility of obtaining and using higher spatial resolution vegetation measures over Ireland from the European Space Agency (ESA) for continued Start of Season (SOS) monitoring. There are considerable opportunities with the replacement of the MERIS satellite instruments with the Sentinel satellites which will provide vegetation observations at spatial resolutions of about 60 m.
- Further explore and define the land covers underlying the seasonality clusters.
- Assess the potential of the land cover clustering method to aid national-scale mapping of land-use practices such as intensive grassland agriculture for more precise carbon budget accounting under the Kyoto Protocol.

### *Photoperiod Experiments*

- Investigate further the detailed response of bud burst to forcing temperatures and the interactions with other environmental factors.
- The effect of forcing temperature and photoperiod on the timing and progress of bud burst as these could not be investigated due to mechanical failure of growth chambers.
- Clones were used in this experiment to rule out intra-specific variability as a factor of bud burst variation. However, in order to generalise findings for forest ecosystems studies evaluating more species and different genotypes per species are needed.
- As vegetative tree buds go through several phases of dormancy release, invisible to the naked eye but happening on a microscopic or molecular level, bud developmental studies are needed to fully understand the influence of environmental factors on dormancy release. These observations would greatly improve phenological models.

### *Phenological Modelling*

- Projections for changes in flowering phenology of birch using the ENSEMBLEs simulations of climate change in order to simulate the impact of climate change on the timing and duration of the allergy season for birch pollen.
- Improve the computational efficiency of the spatialised DORMPHOT algorithm in order to use all the ensemble scenarios available and create an efficient and user-friendly tool for the spatialisation of phenology in Ireland.
- Conduct experiments under controlled conditions to explore how the spread in the timing of bud burst /leaf unfolding of tree species is affected by the main drivers of this phenophase (temperature and photoperiod) and include in phenological models of bud burst /leaf unfolding the environmental control over the variance of these phenophases.

### *Bud-burst Genetics*

- Obtain larger sample sizes for the individual sites examined for the *P. tremula* genetic research.
- Examine a wider range of species and genes.

### *Citizen Science Website*

- Add mapping software to the *Nature Watch* system so observers may look at where phenophases are occurring across the country at any time.
- Create individual accounts for Nature Watch observers so personal details need not be entered for each observation.
- Distribute biannual newsletters with information about phenology, timing of events each season, and the first recording of each event, with space for users' photographs to be printed.

# 1 General Introduction

## 1.1 Background

It is now accepted unequivocally by the scientific community that climate is warming on a global scale, but change at a local level may be more variable and therefore more difficult to detect (Intergovernmental Panel on Climate Change [IPCC], 2007). One approach to assessing effects of climate change at a local level is through establishing the relationships between developmental processes in living organisms (phenology) and seasonal climatic conditions, and using these relationships as indicators of ambient climate. Evidence of the impact of global warming in the last half of the twentieth century on the phenology of plants has been widely reported (Walther et al., 2002; Menzel et al., 2006; Donnelly et al., 2006). Long-term records of the timing of phenological stages of plants have successfully been used in Ireland to indicate changes in climate, in particular spring warming where leafing of some tree species has advanced by as much as 10 days per decade over the past 30 years (Sweeney et al., 2002; Donnelly et al., 2004; Donnelly et al., 2006), and it is anticipated that these changes will continue into the future as a consequence of increasing temperature.

Phenology is the study of the timing of periodic biological events in the animal and plant world as influenced by the environment (Schwartz, 2003). Records of long-term phenological observations on trees, such as the dates of leaf unfolding, flowering, leaf discolouration and leaf fall, provide historical information to indicate how plants have responded to variations in climatic conditions. In mid-latitudes, bud burst, leaf emergence and flowering of many species are dependent on spring air temperatures (Chmielewski and Rötzer, 2001; Sparks et al., 2000a). Numerous studies, particularly in Europe and North America (Ahas, 1999; Beaubien and Freeland, 2000; Chmielewski and Rötzer, 2001; Menzel, 2000; Sparks et al., 2000b; Defila and Clot, 2001; Menzel et al., 2006; Donnelly et al., 2006) have shown that the timing of spring events has become earlier, particularly since the 1970s and the earlier onset of spring growth in plants in temperate climates (Schwartz, 1999) has been used as an indicator of climate change. On the other hand, the timing of autumn events such as leaf discolouring and leaf fall has shown less change (Chmielewski and Rötzer, 2001; Menzel, 2000; Defila and Clot, 2001) over the same time period. This suggests that the length of the growing season (LGS) is increasing, mainly due to the earlier onset of spring and that factors other than temperature, such as photoperiod, may have a stronger influence than temperature on the timing of events at the end of the growing season.

Records show that bird migration phenology is also changing throughout Europe (Hüppop and Hüppop, 2003; Sparks et al., 2005; Lehikoinen and Sparks, 2010). The likely causes of a shift towards earlier arrival dates are changes in climatic conditions (Sparks et al., 2005). Recent climate change due to human activity has resulted in increasing temperatures and changing patterns of rainfall on a global scale (IPCC, 2007). Typical life-cycle events that are influenced by climatic variables are the leafing and flowering of plants, migration dates of birds and appearance dates and abundance of insects (Walther et al., 2002; Menzel et al., 2006; Donnelly et al., 2006; Donnelly et al., 2009).

Migratory birds are particularly vulnerable to global climatic changes since their annual cycle, which involves breeding, moult and two migration events, is more complex than resident birds (Pulido et al., 2001). Short-distance migrants may be able to adjust their migration patterns in response to local changes in climatic conditions as they spend the winter close to their breeding grounds (Jonzén et al., 2006). On the other hand, long-distance migrants may be constrained in their plastic responses to climatic changes by endogenous rhythms that control migration, as migration onset is unlikely to be linked to climate in the breeding ground (Visser et al., 1998; Cotton, 2003; Jonzén et al., 2006). It is not yet known whether the changes in migratory behaviour that have been attributed to global warming are due to phenotypic plasticity or whether they are as a consequence of adaptive evolution (Pulido et al., 2001; Jonzén et al., 2006).

Many bird phenological phases have been shown to be affected by changes in climate. The obvious causes of changing arrival dates of migrants are climatic changes encountered in the wintering area, passage route and breeding area of the birds (Sparks et al., 2005). Both spring arrival of migratory birds and egg-laying dates are earlier. In the UK, Sparks and Carey (1995) analysed an historic dataset from the Marsham series which showed that the swallow (*Hirundo rustica*) appeared later and the cuckoo (*Cuculus canorus*) earlier over the same time period (1736-1958). More recent datasets, from the UK county bird reports (1942–1996) and coastal bird observatories (1960–1996) have shown a significantly earlier arrival date of many migratory species, including the cuckoo and swallow (Sparks et al. 2007). The authors suggested an increase in temperature along the migration route was a possible contributing factor to the early arrival of these birds to Britain. These recent datasets showed that the arrival of the swallow would be 1.6–1.8 days earlier with every 1°C increase in temperature.

Temporal variations in the growth resumption of temperate trees might lead to large changes in forest productivity (Lieth, 1970; Kellomäki and Kolström, 1994), and cause mismatches between the life cycles of interacting species (Edwards and Richardson, 2004; Winder and Schindler, 2004). In order to predict and attempt to mitigate the impacts of climate change, it is crucial to understand its effects on plant growth and to develop mathematical models that describe the causal relationship between climatic drivers and the timing of phenological events. A number of process-based models of tree phenology have been developed to predict the timing of bud burst and flowering of tree species using environmental variables such as temperature and day length (Landsberg, 1974; Richardson et al., 1974; Sarvas, 1974; Hänninen, 1995; Chuine, 2000). All these models use mathematical functions describing either known or assumed relationships between the environmental drivers and bud development from dormancy induction until bud burst. However, as the physiological mechanisms regulating dormancy are still unclear (Arora et al., 2003), formulating a mechanistic description of the events leading to dormancy release and bud burst is particularly complicated, and at present the hypotheses contained in the models can only be based on whole-tree responses to changes in environmental conditions. In order to be able to predict the changes in tree phenology under climate change scenarios it is crucial to improve our understanding of the effects and interactions of climate on the life cycle of trees through experimental studies.

Due to the growing awareness of the importance of phenological data in climate change studies, a three-year project to build on work already carried out as part of various Environmental Protection Agency (EPA)-funded projects was proposed. In addition, it was proposed to build on: (i) the expertise and established collaborative links forged during the EU COST Action 725 (Establishing a European Phenological Data Platform for Climatological Applications) project and (ii) the nationally established phenological network, Phenology in Ireland, coordinated by Trinity College Dublin (TCD). This project allowed for the first time a thorough analysis of existing phenological data in Ireland, and this formed a platform for the establishment of a range of experiments and models focused on clearly identifying the current and future impacts of climate change on the natural environment. Prior to this project, knowledge of climate change impacts was at too coarse a scale for the information to be of real use to endusers such as local authorities. This project provided information in a form which could be utilised directly by endusers and in doing so provided an opportunity for Ireland to adapt to and mitigate the impacts of climate change.

## 1.2 Overall Aims

This large-scale project entitled 'Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems' aimed to (i) establish a sustainable network of phenology gardens across Ireland, (ii) locate and analyse historic phenological records of birds and trees, (iii) conduct experiments to provide data upon which to develop models to predict future timing of bud burst resulting from rising temperature and (iv) to raise awareness among the scientific community and the general public alike of the impact of climate change on the environment. The overall aims of the project were laid out in five defined objectives with associated measurable targets by which to assess the progress of the project:

### *1.2.1 Objective 1. Establish a Sustainable Phenological Network*

This objective facilitated the regeneration of existing IPGs, added a suite of native species to the existing plants and established new phenological gardens. Training in recording techniques and the provision of a manual for observers with photographs and descriptions of phenophases to monitor were required. For regenerating existing gardens, the status of gardens was assessed and recommendations were made on how to regenerate those in disrepair. It was attempted to establish a network of inter-disciplinary stakeholders to be involved in maintenance of the phenological gardens, but this was unsuccessful. A long-term strategic plan for phenology in Ireland was drafted.

### *1.2.2 Objective 2. Identify Existing Phenological Datasets*

Phenological datasets were identified from around the country and an inventory was placed on the project's website. Migratory bird records were obtained from a variety of organisations and phenological trends were analysed in relation to temperature. Other sources of data were identified (historic data from the Irish Naturalist Journal, herbarium specimens and moth flight period records) and phenological trends were analysed in relation to temperature. These datasets were also used to test methods of statistical analysis.

### *1.2.3 Objective 3. Establish a Robust Set of Analytical Techniques*

A range of trend analyses, including regression, time-series and data presentation techniques were tested and applied where appropriate. In addition, a review of current remote sensing techniques used to measure spring 'greening' was carried out. Green-up dates of vegetated land surface were derived from satellite observations.

### *1.2.4 Objective 4. Experimental Analysis for Validation of Phenological Modelling*

The UnPhot bud burst model was tested to establish whether its inherent structure reflected the effects and interactions of photoperiod and temperature on dormancy progress and bud-burst timing appropriately. The model was calibrated on a large dataset of birch bud burst across Europe. A series of controlled environment experiments quantified the effects of summer–autumn temperature and photoperiod on the rate of dormancy induction. The response of bud burst to forcing temperatures was investigated in detail. Changes in bud burst under climate change scenarios were predicted for Ireland.

### *1.2.5 Objective 5. Establish a Web-Based Facility for Recording Observations and Presenting Phenological Data*

An interactive website for observation recording and educational purposes was developed in cooperation with the National Biodiversity Data Centre (NBDC) based in Waterford. Schools and members of the general public were encouraged to record observations online.

## 1.3 Deviation from Original Project Plan

As with any large-scale research project the various objectives evolved during the course of the three-and-a-half year timeframe which resulted in deviations from the original aims. Table 1.1 sets out an overview of the project outputs at a glance. The main additions to the original aims were in the following areas and are detailed further in the remainder of this report:

- Exploration of herbarium specimens;
- Use of temperature projections to predict future bud burst;
- Examination of moth datasets;
- Review of mismatches in phenology;
- Determination of genetic variation in phenology traits;
- Examination of the pollen season in Ireland.

Unfortunately, one area that received less attention than originally anticipated was a comprehensive database on migratory birds; this was not realised due to the resignation of a team member. In order to compensate, at least in part, for this exclusion, a number of other project tasks were carried out. These included a book chapter on climate change and bird conservation in Ireland, and a scientific paper on non-passerine migrant bird arrival times, which has been submitted for publication.

**Table 1.1. Project outputs at a glance.***

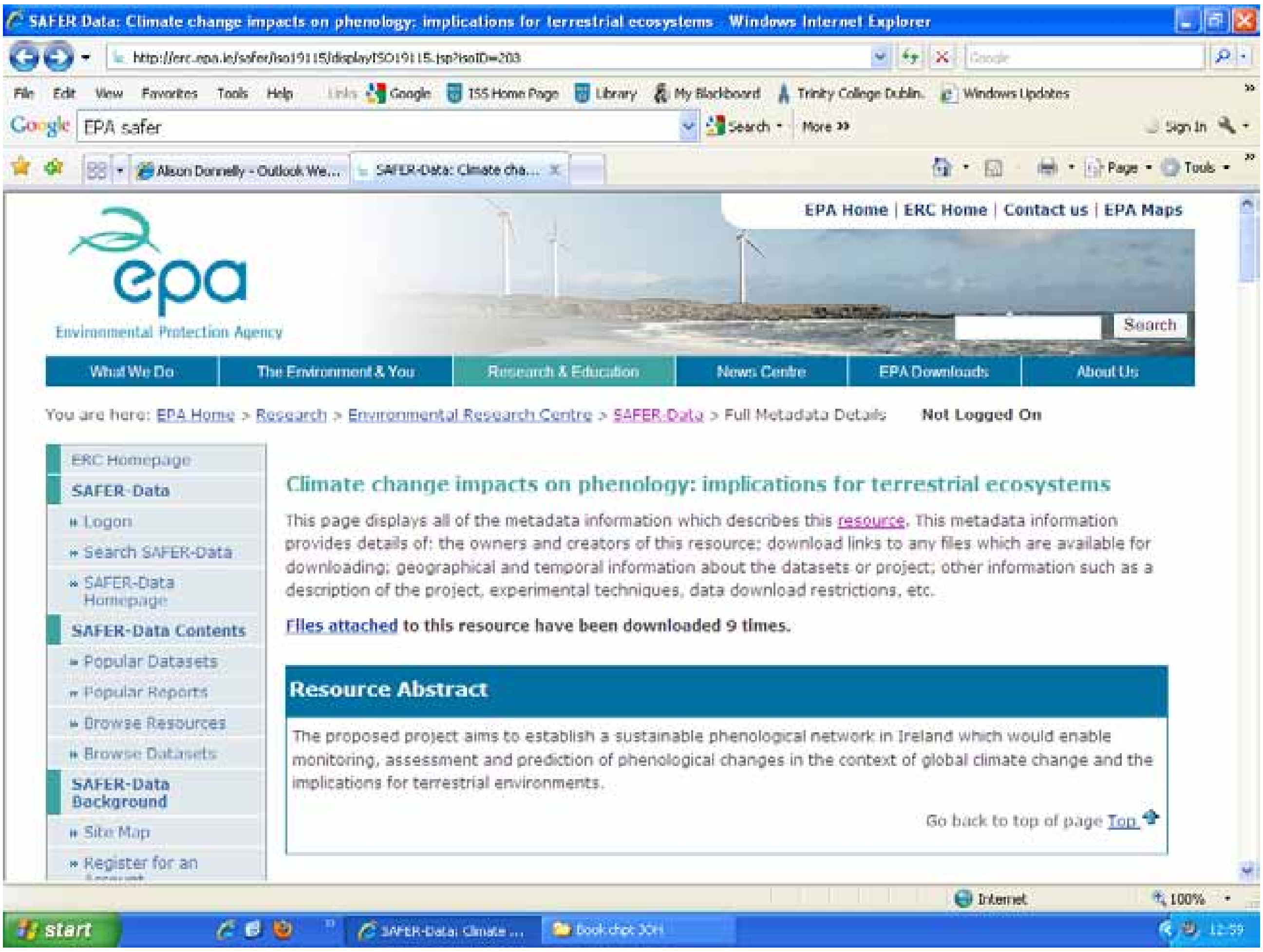
| Number | Tangible outputs |
|---|---|
| 1 | PhD submitted |
| 1 | PhD undertaken in University College Cork (UCC) and partly supported by CCIP (Climate Change Impacts on Phenology) |
| 2 | MScs submitted (2 research) |
| 2 | Book chapters complete (1 on birds and 1 on phenotype vs. genotype) |
| 12 | Scientific papers complete or submitted (multi-species, birds [2], experiments, modelling, ecology, mismatch, met variables, herbarium, phenotype vs. genotype, remote sensing [2]) |
| 9 | Scientific papers soon to be submitted (birds, experiments, modelling, genetics, moths [2], pollen) |
| 4 | Reports (History of phenology in Ireland, State of the phenology network, glossy brochure, strategic plan) |
|  | Other publications: |
| 14 papers | Special Issue, *International Journal of Biometeorology* |
| 1 preface | Editors, Special Issue |
| 1 | Scientific Statement for the Royal Irish Academy |
| 9 | Newspaper coverage – national and local articles relating to *Nature Watch* and other phenology events |
|  | Conference, meetings and training contributions |
| 12 | National |
| 17 | International |
| 6 | Media interviews – various radio and TV interviews |
| 10 | Popular articles for newsletters (5), *Biodiversity Ireland* (3), *Irish Garden* (1), Agri-environment conference proceedings (1) |
| 1 | International conference hosted – Phenology 2010 |
| 3 | Workshops hosted – Phenology in UK, past present and future, Phenology workshop for participants, Earth Observing Satellites workshop |
| 4 | Workshop contributions – phenology workshop Sweden, forest monitoring, agri-environment, Dundalk Institute for Technology (DKIT) |
| 16 sites | Expansion of the Phenological gardens network |
| 1 | Production of *Nature Watch* website |
| 8 | Other funding received from – Heritage Council; Failte Ireland, USGS, Trinity College, Royal Irish Academy, Greenwave, PEP-725. |

* Further details are available in Appendix 1.

This report presents the main findings of the 'Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems' (2007-CCRP-2.4) project based on the objectives outlined above. The final section presents a set of recommendations for further work based on the experience gained over the course of this project. The appendices set out a detailed list of project outputs, including all publications and presentations made by the team on behalf of the project and all conference, both national and international, contributions made.

### *1.3.1 Data Storage*

Given the quantity of data collated and used during the course of this project it was considered necessary to make it available to other researchers and endusers. However, the nature of the data was such that it was not owned by the project since it was primarily mined from a range of sources, such as the IPG network, BirdWatch Ireland, etc. Therefore, the raw data were not made available on the EPA's data storage facility – SAFER (http://erc.epa.ie/safer/). However, detailed metadata was uploaded (Fig. 3.4) and this includes information on the length of the dataset, the parameters recorded, the data owner, etc.



You are here: EPA Home > Research > Environmental Research Centre > SAFER-Data > Full Metadata Details **Not Logged On**

Climate change impacts on phenology: implications for terrestrial ecosystems

This page displays all of the metadata information which describes this resource. This metadata information provides details of: the owners and creators of this resource; download links to any files which are available for downloading; geographical and temporal information about the datasets or project; other information such as a description of the project, experimental techniques, data download restrictions, etc.

**Files attached to this resource have been downloaded 9 times.**

**Resource Abstract**

The proposed project aims to establish a sustainable phenological network in Ireland which would enable monitoring, assessment and prediction of phenological changes in the context of global climate change and the implications for terrestrial environments.

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**Figure 1.1. Screen-shot of the data storage facility where metadata on phenological data are available.**

# 2 Establishment of a Sustainable Phenology Network

## 2.1 Regeneration of Existing Sites, Network Expansion and Incorporation of Native Species

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This section sets out how the network of phenology gardens in Ireland was extended and proposes a strategic plan for its continuation into the future.

### 2.1.1 *Background*

As part of Ireland's National Phenology Network (IE-NPN) (full report on IE-NPN in Appendix 2) in 2008 a series of sites was established to monitor the growing season of trees in Ireland from bud burst to leaf fall to determine if climate change is influencing the timing of these events. This incorporates the IPG network and the Native Phenology Network. The IPG network, established in 1957, represents a group of gardens across Europe that monitor the growing season of plants and shrubs from bud burst in spring to leaf fall in autumn. Prior to this project, Ireland had six IPG, four of which are the longest-running gardens in the network and have been actively recording phenophases since the 1960s: Valentia, Botanical Gardens, Johnstown Castle Estate, John F. Kennedy Park.

### 2.1.2 *Aims*

As observations produced by these gardens have provided valuable information on the timing of the growing season in Ireland for the past 40 years it was decided to expand the network to provide a broader spatial representation. This would enable identification of whether these trends are continuing to occur across the country. In addition, it was considered useful to add a number of native tree species to the already established international list of trees.

### 2.1.3 *Methods*

The number of IPG sites was increased to ensure a more representative spatial distribution of sites across the country. In order to achieve this, a list of potential gardens was collated that were considered to be interested in participating in a long-term study. The first group of sites considered was those under the management of the state institutions, such as the Office of Public Works, the National Parks and Wildlife Service, local county councils, Coillte forests and nature reserves. The second group comprised heritage properties such as castles and country manors which had sizeable estates (>200 acres) with sufficient staff to carry out observations. The third group included private estates, golf and country clubs, hotels and educational organisations such as horticultural and agricultural colleges.

Criteria used to select the IPGs were as follows:

- Must be within 20 km of a climate station which records air temperature;
- Should be typical of the region in terms of soil types etc.;
- Should not be overshadowed by other trees, buildings or close to main roadways;
- Have adequate space to accommodate a collection of trees for a long-term study.

In total, 60 gardens were contacted with a letter introducing the project and including a brief history of the phenology network in Europe and an invitation to join the network, explaining what role they would play in the proposed expansion. It also included a brief survey requesting information regarding the topography of the site and general land usage of the surrounding countryside. The response rate was very successful with replies from over 30% of those contacted. Following this, all suitable sites were visited by the network co-ordinator to determine if they were suitable for inclusion. During these visits the proposed site where the trees would be situated was assessed. These visits provided a platform for potential participants to query the co-ordinator directly about phenology and their role as observers. This exercise also formed the basis for establishing good relations with the participants.

Over the course of 2008 and 2009 all original gardens involved in the IPG network were also visited to determine the condition of the plant collections which had last been assessed in 2005. The gardens varied in condition, details of which are included in the report (Proctor and Donnelly, 2010a).

The coordinating office of the IPG in Berlin agreed to the establishment of 10 additional IPG sites in Ireland, bringing the total to 16. These were established at the locations incidated in Fig 2.1. However, in 2011, the operators at two of these sites decided to withdraw from the network because of reductions in resources. In response an additional site in NUI Galway was established. Therefore, at this time, 16 IPG are established and active within the network.

Eleven other gardens and institutions who had expressed an interest in the participation were invited to host sites within the Native Phenology Network, which runs in parallel with the IPG, and bases observations on phenological indicators on cloned native Irish tree species.

Plants for the IPG network only were ordered from the nursery used by the IPG in Germany – Gartenbaumschule Kraus, which propagated the cloned plant material for distribution throughout Europe. A proportion of the order was delivered to the gardens in spring 2009, the remainder delivered in spring 2011 when the full complement had been propagated. These plants require a number of years to acclimatise to their new surroundings, as advised by the IPG, before observations of phenophases can begin. In order to ensure all gardens begin observations in the same year the original gardens were also provided with specimens of hazel (*Corylus* avellana), forsythia (Forsythia suspensa) and the common lilac (Syringa chinensis 'Red Rothomagensis'). The lilac was introduced from the observation programme established in the 1950s in the USA and now co-ordinated by the USA National Phenology Network (USA-NPN). This may in future enable direct comparison of the growing season of this species in both continents.

The native gardens were provided with birch (*Betula pubescens*) donated by Dr Elaine O'Connor from the Irish Birch Improvement Programme. Ash (Fraxinus excelsior), graft scions of which were taken from a mature specimen in John F. Kennedy Arboretum, were also propagated by the network co-ordinator, Hazel Proctor, at the facilities in Teagasc, Kinsealy Centre, Dublin.

It is intended to increase the native plant collection through active participation by the members of the native phenology network. Previous attempts to propagate native species from the Birr Castle estate unfortunately were unsuccessful. However, this is a site which may be used for future propagation campaigns. Other members of the native network such as Blarney Castle have also suggested using native plant material from that estate.

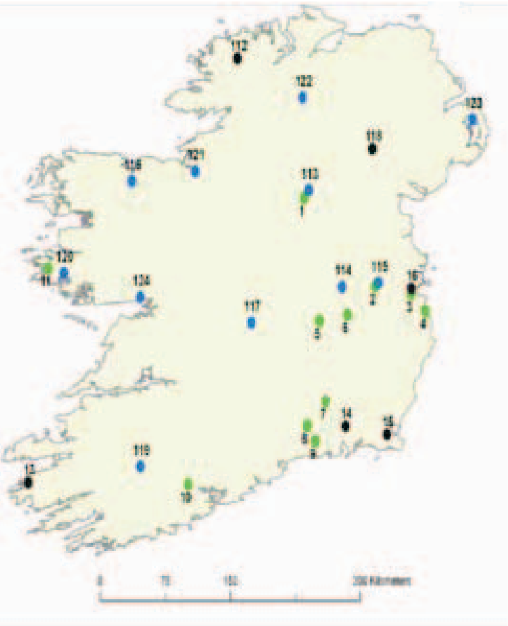

**Figure 2.1. Location of gardens involved in Ireland's National Phenology Network (IE-NPN). Black: International Phenological Gardens (IPG) sites pre-2009. Blue: IPG sites post-2009. Green: native species sites.**

In order to strengthen links and share knowledge across the IPG network a training session was organised between the IPG network coordinator and the Irish co-ordinator. This involved actively observing general phenophases of IPG species such as leaf colour and leaf fall and training in species specific phases. Observation literature produced by the German weather service (Deutsche Wetterdienst [DWD]) was provided by the IPG co-ordinator, some of which was adapted and included in the IE-NPN *Observations Manual* produced for all participating gardens in Ireland. Following on from this, a workshop was hosted at the National Botanic Gardens in Dublin for all participants in the Irish network. The workshop was attended by

**Table 2.1. Gardens participating in Ireland's National Phenology Network (IE-NPN).**

| Ireland's National Phenology Network (IE-NPN) | |
|---|---|
| 1 Farnham Estate | 113 Ballyhaise College |
| 2 Lodge Park Walled Garden | 114 Williamstown House |
| 3 Airfield Trust | 115 Carton Estate |
| 4 Kilruddery House | 116 Enniscoe House |
| 5 Emo Court | 117 Birr Castle |
| 6 Irish National Stud | 118 Armagh Observatory |
| 7 Mount Juliet | 119 Millstreet Country Park |
| 8 Kildalton College | 120 Ballynahinch Castle |
| 9 Mount Congreve | 121 Markree Castle |
| 10 Blarney Castle | 122 Baronscourt* |
| 11 Errislannan Manor Gardens | 123 Mount Stewart* |
| 13 Valentia Observatory | 124 NUI Galway |
| 14 JFK Arboretum | |
| 15 Johnstown Castle | 1–10: Native Gardens |
| 16 National Botanic Gardens | 13–124: IPG Gardens |
| 112 Glenveagh National Park | * Gardens no longer participating as of 2011 |

members of the IPG and Native Phenology Networks. A range of speakers presented their practical experience to the newcomers and this was followed by a tour of the tree collection at the National Botanic Gardens. Further details of the outcomes of the workshop are detailed in the Workshop Summary (Proctor and Donnelly, 2010b).

### *2.1.4 Results*

In October 2009, a grant application was made to the Heritage Council under the Heritage Education, Community & Outreach category. This was in order to supply the phenology network with promotional material to display in each of the gardens. This included leaflets and laminated A0 posters which were suitable for visitor's centres or reception areas. Durable stainless steel outdoor signs and observation manuals for each of the participants were also provided.

A grant of €15,000 was successfully awarded to the project in spring 2010, providing the network with these educational tools. These permanent structures will bring awareness to the importance of phenology in climate change research. All material directed observers to the Nature Watch website currently hosted by the NBDC website (http://phenology.biodiversityireland.ie/).

Unfortunately, there were a number of losses in plant material as a result of the freezing conditions and snow experienced during the winters of 2009/2010 and 2010/2011 (Table 2.2). Two gardens also decided to discontinue their involvement in the network due to lack of personnel. These were IPG 122, Baronscourt in Omagh, Northern Ireland and IPG 123, Mount Stewart in Down, Northern Ireland. However, since the trees are already established it would be possible to resume observations at a later date if they so wished. A new site was added to the IPG network in 2010 – the Department of Botany of the National University of Ireland, Galway (NUI Galway).

**Table 2.2. Plant losses across the network as a result of the 2009/2010 severe weather conditions during winter and other trees reaching maturity.**

| Garden | Species lost |
|---|---|
| 4. Kilruddery House | 1 birch (*Betula pubescens*) |
| 5. Emo Court | 2 ash (*Fraxinus excelsior*) |
| 13. Valentia Observatory | 2 poplar (*Populus* spp.) |
| 115. Carton Estate | 2 forsythia (*Forsythia suspensa*) |
| 116. Enniscoe House | 1 forsythia (*Forsythia suspensa*)<br>1 larch (*Larix decidua*) |
| 121. Markree Castle | 2 lilac (*Syringa chinensis*)<br>1 Norway spruce (*Picea abies*)<br>1 basket willow (*Salix viminalis*)<br>3 forsythia (*Forsythia suspensa*) |
| 122. Baronscourt | 1 Norway spruce (*Picea abies*)<br>1 Scots pine (*Pinus sylvestris*)<br>1 beech (*Fagus sylvatica* 'H')<br>1 lime (*Tilia cordata*)<br>1 pussy willow (*Salix aucutifolia*)<br>1 Smith's willow (*Salix smithiana*)<br>3 hazel (*Corylus avellana*)<br>3 forsythia (*Forsythia suspensa*)<br>3 lilac (*Syringa chinensis*) |
| 123. Mount Stewart | 1 Norway spruce (*Picea abies*)<br>1 Scots pine (*Pinus sylvestris*)<br>1 beech (*Fagus sylvatica* 'H')<br>1 lime (*Tilia cordata*)<br>1 pussy willow (*Salix aucutifolia*)<br>1 basket willow (*Salix viminalis*)<br>3 forsythia (*Forsythia suspensa* 'Fortunei') |

### *2.1.5 Discussion and Conclusions*

In order to ensure each garden from the IPG network is observing a full complement of plants it is suggested that a propagation drive is promoted amongst the participating gardens. This was initially discussed at the Workshop and would be more cost effective than ordering new plants from the IPG headquarters in Germany. This means different gardens could take responsibility for specific species to share the workload and therefore ensure there is a continuous supply of material to observe in the event of another harsh winter or other unforeseen events which may damage the plants. Similarly, provision of native trees should be co-ordinated and facilitated in order to increase the range of species currently being observed. Finally, new sites should be encouraged to join the network based on the experience of the existing sites.

The active network of phenological gardens, including both IPG sites and native sites in Ireland has been increased from 6 to 26. This is a substantial achievement in such a short time period. In addition, the framework for running the network into the future has been established. A phenology community among the professional networks has been established and the general public has been given the opportunity to engage in climate change research through the establishment of the Nature Watch website. Finally, numerous promotional materials have been distributed to raise awareness of the usefulness of this kind of research.

## 2.2 Proposed Strategic Plan for Phenology in Ireland

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### 2.2.1 *Background*

Phenology activity in Ireland can be divided into two distinct but not mutually exclusive areas (Table 2.3). The first deals with phenology research and is focused on analysing historic datasets of plants, birds and insects, conducting experiments to determine the environmental triggers of bud burst and developing phenological models to make projections of what may happen as temperatures continue to rise. In addition, other areas of research include remote sensing, genetic variation in phenological traits and publishing research findings. The second area of phenological activity in Ireland relates to monitoring and the collection of accurate and reliable phenological observations, which are useful for research purposes. Monitoring, in turn, takes two forms. A series of approximately 30 phenology gardens is located throughout the country, and run by professional horticulturalists who record phenological events. A second monitoring programme involves members of the general public who submit phenological observations to an online facility from anywhere in the country.

**Table 2.3. Summary of current phenology activity in Ireland.**

| Phenology activity | Details of current activity |
|---|---|
| **Research** | Sourcing and analysing historic datasets on both plants and animals.<br>Experiments and modelling bud burst. Making future predictions of bud burst.<br>Investigating genetic variations involved in phenological events.<br>Using satellite data to identify the beginning of the growing season.<br>Publishing scientific findings. |
| **Monitoring** | Maintaining current IPG and native species networks and sourcing new sites.<br>Maintaining and developing appropriate databases.<br>Promoting participation and collaboration with other national projects. |

### 2.2.2 *Aims*

The aim of the Strategic Plan is to provide a framework by which to co-ordinate, develop and advance phenology activity in Ireland. In addition, it should establish research and monitoring priorities and propose ways of achieving overall goals. It should also provide guidance on how to manage the running of activities into the future.

### 2.2.3 *Methods*

#### 2.2.3.1 *Phenology research*

Three main groups of species comprise phenological research in Ireland: (i) trees, (ii) birds and (iii) insects. The vast majority of our research has focused on trees due to our expertise and the historic data available. Formal phenological recording began in Ireland in the early 1960s as part of the Europe-wide IPG network, whereby four sites were established at Valentia Observatory, Co. Kerry, John F. Kennedy Arboretum, Co. Wexford, Johnstown Castle, Co. Wexford and the National Botanic Gardens in Dublin. Observations were made in line with the guidance provided by the co-ordinators in Berlin. Little attention was paid to the analysis of the data collected until recently. In 2001 a study on ‘Indicators of Climate Change’ was commissioned by the EPA and interest in this valuable phenological data source was established as the relationship between spring phenology and temperature was recognised. The data from the IPG sites were used as an indicator of spring warming for Ireland and also contributed to a pan-European meta-analysis, which showed that phenological events closely matched climate warming over a 30-year period (1971–2000). Two additional IPGs were established in recent years, at Armagh Observatory (2003) and Glenveagh National Park (2007). Some earlier data (1925) were located in the Irish Naturalists' Journal, which showed an advance in phenological events in the Irish countryside during the twentieth century, which was strongly correlated with increasing air temperatures.

In addition to analysing historical observations, the current project's research on trees also included conducting experiments under controlled environment conditions to determine the environmental variables most associated with bud burst in birch. This data are in turn used to develop phenological models of future bud burst timing under different climate scenarios. Most recently, investigations into the variation of genes involved in the release of dormancy both within and between natural populations of poplar across Europe have begun.

The above-mentioned phenological datasets were the first to be analysed in Ireland and were mainly based on plant phenophases, in particular, bud burst or leaf unfolding. However, arrival dates of long-distance spring migrant birds from the *Irish East Coast Bird Reports* provided more than 20 years' data from which to determine trends. This dataset became the first published record of bird phenology for Ireland. Subsequently, spring departure dates of a winter visitor were analysed. As regards insects, the only group located with sufficient data to date is moths. At present, the project collaborates with MothsIreland to analyse data of the timing of emergence and the length of the flight period at a number of locations in Ireland. It is hoped to increase the number of species of bird and insect in a future research programme.

#### *2.2.3.2 Phenology monitoring*

As noted above, the monitoring takes two basic forms: (i) a professional network where the species are constant and sourced from known stock (either from the IPG network or from known native Irish sources) and (ii) a citizen science network where members of the general public record phenological observations on a very limited number of plant, bird and insect species and submit their findings to the *Nature Watch* website. The data from the professional network forms part of a Europe-wide database and is held at the co-ordinating centre in Berlin, but available to any of the IPG members, whereas the National Biodiversity Data Centre holds the data from *Nature Watch*. The other difference between the two networks is that the IPG has been running for more than 40 years whereas *Nature Watch* was established in 2010 (Table 2.4).

In addition to the Nature Watch website there are two other phenology-based citizen-science projects in Ireland – Greenwave encourages primary schools to record phenological events and biology.ie does the same for secondary schools.

#### *2.2.3.3 Participants – who is involved in phenology activity in Ireland*

The Phenology Research Group based in the Centre for the Environment at TCD is the first group of its kind in Ireland. They are mainly supported by funding from the EPA but have also gained support from the Heritage Council, the NBDC and a number of smaller donations. The group has active collaborators in Ireland based in University College Cork (UCC), the NBDC, the National Botanic Gardens, Teagasc and Met Éireann. International partners are based in Italy at the Research and Innovation Centre, Fondazione Edmund Mach, in San Michele all'Adige, Trento.

The group also has links with a range of European organisations, including a previously funded COST Action 725, 'Establishing a European Phenological Data Platform for Climatological Applications' which was established in October 2003 and ran for five years. When COST 725 finished, the network of collaborators continued to work closely together and a Pan-European Phenology network was established with support from EUMETNET and the Austrian ministry for science and research.

#### *2.2.3.4 Ireland's National Phenology Network*

The main catalyst for setting up a national phenology network was as a result of the need to co-ordinate phenology activity in Ireland in order to help determine the impact of climate change on the Irish environment.

Prior to 2008 all phenology research was carried out in a piecemeal manner and tagged on to other activities. However, when several important scientific papers and reports were published on the back of this research, this highlighted the need for a more coherent approach to establishing a sustainable phenological network which would enable the monitoring, assessment and prediction of phenological changes in the context of global climate change and the consequential implications for terrestrial ecosystems.

The role of IE-NPN is to co-ordinate all phenology activity in Ireland and to encourage people of all ages and backgrounds to observe and record phenology of plants and animals across the country. Together with researchers it helps develop various ways of using these observations to support decision-making by citizens, managers, scientists, and others. The network comprises a wide range of stakeholders, including researchers in various universities, members of the general public and a range of governmental organisations. The network links science and society by providing a broad understanding of the relationship between phenology and climate change and encouraging public participation in science.

IE-NPN is also the contact point for collaboration with other similar networks around the world such as the National Phenology Networks in Sweden (SWE-NPN) and the USA (USA-NPN), Nature's Calendar in the UK and the Netherlands and many others.

**Table 2.4. History of phenology recording in Ireland at a glance.**

| | |
|---|---|
| 1927–1947 | Phenological reports in the *Irish Naturalist's Journal* provided plant, animal and farming activity observations for 15 years. |
| 1960s | Establishment of 4 International Phenological Garden sites at Valentia Observatory, John F. Kennedy Arboretum, Johnstown Castle and the National Botanic Gardens. |
| 2003 | Armagh Observatory establishes a phenology garden. |
| 2007 | Glenveagh National Park establishes a phenology garden. |
| 2008 | Climate change impacts on phenology project established in TCD and funded by the EPA. |
| 2009 | IPG network in Ireland expanded and 10 new sites are established. A native species network is also established and contains 18 sites. |
| 2010 | *Nature Watch* website is launched in collaboration with the National Biodiversity Data Centre and encourages the general public to record phenological observations. |

### 2.2.4 *Strategic Plan*

In order to maintain and advance phenology activity in Ireland it would be necessary to establish a national co-ordinating office under the umbrella of the IE-NPN. The role of this office would be to maintain a phenology information-management system, promote standardised recording, encourage data collection and communicate the findings both to the scientific and public communities. In addition, the co-ordinating office would encourage research and educational programmes related to phenology.

#### *2.2.4.1 Research priorities*

- Determine long-term trends in phenology and their link with climate change;
- Identify appropriate species as indicators of environmental (including climate) change;
- Perform controlled environment experiments to provide data for model refinement to enable accurate forecasting;
- Explore the genetical basis to phenology;
- Determine the link between phenology and ecosystem processes and services.

#### *2.2.4.2 Monitoring priorities*

- Maintain and strengthen the monitoring networks by communicating regularly with participants;
- Identify appropriate phenology-related datasets and maintain a useable database;
- Identify data gaps and suggest ways of dealing with them.

#### *2.2.4.3 Co-ordinated approach*

Phenology-related data are recorded at many different scales – from individual experiments on individual genes and species to extensive networks with standardised protocols (e.g. volunteer networks) to landscape scale phenology based on the use of remote sensing products. These scales represent different levels of spatial coverage and different intensities of monitoring and ideally should be co-ordinated on a national scale similar to the USA-NPN-proposed national-scale phenology observatory.

#### *2.2.4.4 Data-management system*

It is important to develop an integrated data management system in order to ensure data are appropriately handled and easily shared. This in turn will help facilitate a collaborative approach to monitoring and research. The proposed system would include an online database and a variety of online interfaces to facilitate data entry and download, and visualisation tools. The system would be for all phenology users and would be based on the currently operating *Nature Watch* website. Collaboration with the NBDC would be essential in running the data management system.

**Aims and objectives**

- Store all phenology data securely on a national scale:
  - Ensure reliability of phenology data;
  - Provide a data backup facility;
- Provide searchable metadata on all datasets and other documents:
- Supply educational and research material;
  - Provide easy access to data for different purposes;
  - Provide visualisation tools and summarise data.

#### *2.2.4.5 Monitoring system*

An integrated monitoring system should comprise current professional and citizen science phenology networks together with historic datasets with a view to providing a data resource for research, education and decision support. The monitoring system should include standard species and protocols for data collection together with clear descriptions and images – where possible – of the phenophases being observed. It would be necessary to collaborate with all stakeholders, especially observers, to ensure the monitoring system is effective and flexible enough to potentially integrate new species.

**Aims and objectives**

- Maintain and expand the existing monitoring networks:
  - Promote participation of professionals and citizen scientists;
  - Promote participation of a range of observer groups;
  - Refine phenophases;
  - Identify potential new species and phases to be observed;
- Encourage high-quality data collection:
  - Host regular workshops;
  - Provide unambiguous guidelines;
  - Provide feedback facilities.

#### *2.2.4.6 Outreach and education*

The communication of findings from the network to a wider audience is important both in terms of informing general understand of the impacts of claimte change in an Irish context, but also in terms of creating a high level of public engagement with the need for long-term monitoring infrastructure to inform decision making.

#### *2.2.4.7 Promote use of data for research and education:*

- Communicate findings;
- Run competitions (e.g. first photograph of a particular phase).

#### *2.2.4.8 Collaboration*

IE-NPN has a range of collaborators, which can be roughly divided into the following categories:

- Universities:
  - TCD;
  - UCC;
  - NUIG;
- Research institutes:
  - Coastal and Marine Resource Centre (Ireland);
  - Instituto Agrario, Research and Innovation Centre, Fondazione Edmund Mach, San Michele all’Adige, Trento, Italy;
- Scientists (individuals or groups conducting scientific research into phenology related topics);
- Citizen scientists (individuals contributing to our online recording system);
- Citizen science websites:
  - Greenwave;
  - Biology.ie;
- Participants in the IPG and Native species network of gardens in Ireland;

- Supporting organisations;
    - National Biodiversity Data Centre – facilitate database and Nature Watch website;
    - Met Éireann who provide non-phenology data such as temperature (past, present and future), precipitation, etc.;
    - Teagasc facilitate phenology sites and provide plant material;
    - IPG network – provide plant material;
    - JFK Arobortum also provide plant material;
    - EPA – provide research funding;
    - Heritage Council – provide infrastructural funding;
- International networks:
    - COST 725;
    - PEP 725;
    - USA-NPN;
    - SWE-NPN;
    - Nature's Calendar UK;
    - Nature's Calendar Netherlands;
    - USGS;
    - International Society of Biometeorology.

**Aims and objectives**

- Promote collaboration:
    - Actively encourage collaboration at a national and international level;
- Seek funding opportunities:
    - Apply for research funding through appropriate calls;
    - Suggest research areas of importance;
    - Approach a range of funding agencies to maintain and expand the Network;
- Raise the profile of IE-NPN:
    - Host research meetings and conferences;
    - Inform the media of the existence of the Network and the work being carried out.

#### *2.2.4.9 Proposed management*

Thus far IE-NPN has been established and run on a voluntary basis through the phenology research group in TCD. In order to establish a co-ordination office as mentioned above, it was necessary to get an estimate of similar organisations in other countries. An email was sent to a number of NPNs but not all of them responded. However, a summary of the annual costs associated with running a similar enterprise is presented and a budget for an Irish version is proposed based on the findings of the survey (Table 2.5).

It is evident from the summary table that the funding available to national phenology networks ranges between €65k and €1M and really reflects the type of organisation and the level of activity of each country. Not surprisingly, the USA has the largest budget, is a well-established organisation and employs a number of permanent staff. The phenology network in Germany is run by the German weather service and supports two full-time staff and pays over 1600 observers a small annual sum. The Woodland Trust in Britain sponsors two part-time staff to manage Nature's Calendar (http://www.naturescalendar.org.uk/). In Sweden, the budget is divided between a part-time co-ordinator, individual observers, provision of workshops and professional field observers. Clearly, there are no direct comparisons between organisations and none of the budgets include funding for research.

The Irish budget is estimated on the basis of funding a full-time staff member, individual observers, website maintenance, provision of workshops and materials for network expansion.

**Table 2.5. Annual budget summary and funding source of phenology organizations in a range of countries. The figures for Ireland are estimated.**

| National organisation | USA | Sweden | Germany | Britain | Ireland |
|---|---|---|---|---|---|
| Annual budget (€) | 1,000,000 | 260,000 | 500,000 | 65,000 | 200,000 |
| Funding body | Federal funding | State and individual projects | State funded | Woodland Trust | State and individual projects |

### *2.2.5 Overall Conclusions*

In order to expand the current level of phenology activity in Ireland in a sustainable manner it is important to have in place a framework by which to ensure continuity into the future. A rigorous set of research and monitoring priorities will guide the development of phenology activity while the inclusion of a wide range of stakeholders will strengthen the network and encourage further participation. It will be important to capitalise on the success of IE-NPN to date by demonstrating the value of its collaborative outputs in contributing to raising public awareness of the impact of climate change on the environment and publishing scientific communications.

# 3 Phenological Datasets

Phenological datasets can be acquired and presented in a variety of ways depending upon the ultimate questions being addressed and the scale at which the data were collected. Due to the sensitivity of many phenological phases to changes in temperature, the timing of past, present and even future impacts of climate warming on the environment can be assessed by examining and modelling phenology. In this section a range of plant, insect and bird phenological datasets relating to Ireland were examined to identify any changes that may be attributed to climate change. In order to confirm the relationship between temperature and spring phenology in trees a wide range of climatic variables was correlated, including minimum, maximum and mean air temperature (°C), soil temperature (°C), rainfall (mm), sunshine (hours), number of air frost days and number of rain days with the beginning of the growing season (BGS) as determined by leaf-unfolding dates of a suite of tree species at Valentia Observatory (Gleeson et al., in press). The data showed that the highest correlations were between BGS and minimum air and soil temperature, with *Populus canescens* and *Populus tremula* showing the strongest relationships. Soil temperature was the only other variable that showed a strongly correlation with BGS. This confirms the important role spring temperature plays in spring tree phenology.

In order to determine the impact of temperature on Ireland's environment a number of datasets from a range of sources from which to test the theory were identified. Firstly, a dataset was constructed from the examination of Rubus specimens collected over many years and stored in a herbarium. Rubus are a family of plants whicih include the familiar blackberry (*R. fruticosus*)and rasberry (*R. idaeus*) species. Secondly, exploration of historical records made by direct observations of the timing of a range of phenophases on birds and insects was examined. Thirdly, current pollen data collected during the course of the project was examined and finally remotely sensed data were used to demonstrate the start of the growing season at a landscape scale across the country.

Most of the results of this work are in process of being published in peer-reviewed scientific journals. However, at this time the papers are not yet in the public domain and therefore it was considered appropriate to include a comprehensive outline of the research that was carried out. Short sections on background and aims are included at the start of each section in order to inform the reader of the section content.

## 3.1 Location of *Rubus* Herbarium Records and Analysis of Trends in relation to Temperature Variables

**Eileen Diskin,[1] Hazel Proctor,[1] Matthew Jebb,[2] Tim Sparks[3] and Alison Donnelly[1]**

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### *3.1.1 Background*

Although historic records and present-day fieldwork of phenological events have proven invaluable in climate change research, the sourcing of alternative datasets has become necessary as known records begin to be exhausted. Herbaria are one such novel source of data. Most herbarium specimens have a label card onto which the species name, the collector's name, and the date and location of collection are recorded. With this information, spatial and temporal analysis is possible and can be used in climate change research.

### *3.1.2 Aims*

Phenological research in Ireland has, to date, focused on correlating the timing of spring events in plants and birds with temperature variables through the use of historic records and datasets. Such studies extended over the period between 1927 and 2009. In this section, the use of herbarium specimens as a method to extend this time-series backwards was evaluated, enabling the investigation of the impacts of climate warming on phenology in Ireland as far back as the nineteenth century.

### 3.1.3 Methods

The 5° grid square (50–55°N, 10–5°W) covering Ireland was isolated from the CRUTEM3V gridded temperature dataset, which contains monthly temperature anomalies from the 1961–1990 average. January to June mean temperatures were calculated for the study period (1852–2007), and were examined against year to determine trends in Irish temperature over the study period.

Over 600 herbarium specimens of *Rubus spp.*, collected in Ireland, were systematically examined. Collector, collection date, and location were recorded from the information cards of each specimen. Only specimens with a complete collection date (day, month, and year) were used in this study; each date was translated into a Julian day number (days after 31 December). Each specimen was then assigned a score from 0–5, corresponding to particular phenophases, with reference to the stage of development of the apical branch (Table 3.1).

**Table 3.1. Phenophase scoring system for *Rubus spp*. herbarium specimens.**

| Score | Phenophase | Defined by |
|---|---|---|
| 0 | No flowers | No flowers |
| 1 | First flower | < 50% flowers open |
| 2 | Full flower | > 50% flowers open |
| 3 | First fruit | < 50% fruits ripe |
| 4 | Full fruit | > 50% fruits ripe |
| 5 | End of fruiting | > 90% fruits ripe (most dispersed) |

The data were divided into five species groups: *R. caesius, R. fruticosus agg., R. idaeus, R. saxatilis*, and *R. spectabilis*. Within each species, where more than one specimen was collected in a particular phenophase within a given year, the records were averaged to give a single date for the occurrence of that phenophase in that year (number of specimens = sample size). Sample size was then used as a weight in weighted linear regression. Since records of other species covered only 5–12 years, only *R. fruticosus* (which comprised 86% of all records) was examined further. Weighted linear regression analysis of dates of first flower, full flower, first fruit and full fruit on mean January–June temperature anomalies was undertaken to identify responses to temperature. Analyses were carried out using the SPSS statistical package.

### 3.1.4 Results

The January–June mean temperature anomalies (relative to 1961–1990), as calculated from the East Anglia University Climate Research Unit dataset for each year of the study period, indicate a recent trend towards warmer temperatures. Indeed, positive temperature anomalies are evident in 19 of the last 20 years of the study period (Fig. 3.1).

Of over 600 specimens examined, 540 were found to have complete information: of these, *R. fruticosus agg.* dominated (n=464); the other species were represented by many fewer specimens (*R. caesius*: n=40, *R. idaeus*:

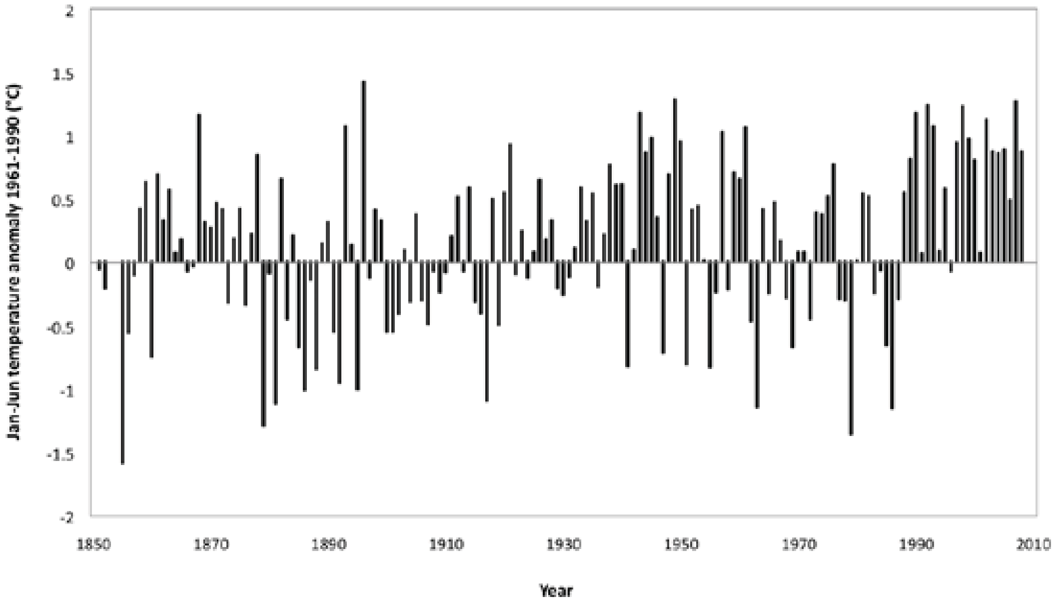

**Figure 3.1. January–June temperature anomalies 1852–2007 relative to the 1961–1990 mean shown as the horizontal line.**

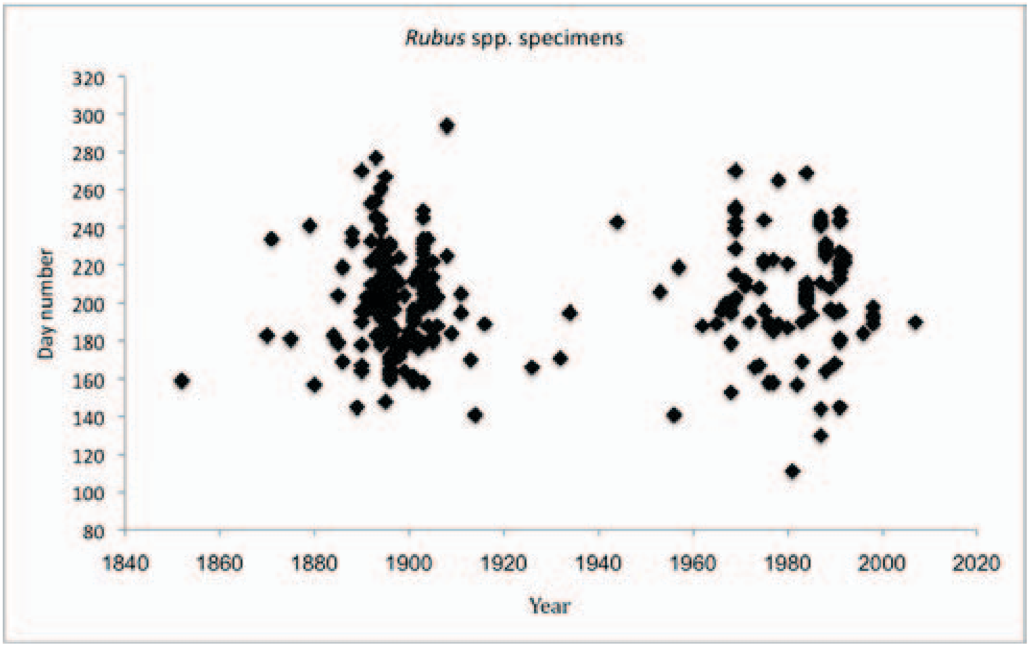

**Figure 3.2. Collection dates of all *Rubus spp.* specimens (*R. caesius, R. fruticosus, R. idaeus, R. saxatilis,* and *R. spectabilis*). Two main collecting periods are evident (~1880–1910 and ~1960–2000).**

n=15, *R. saxatilis*: n=15, *R. spectabilis*: n=6). The time-series were not continuous due to a decrease in collections between 1915 and 1965 (Fig. 3.2). Of the two primary collecting periods (pre-1915 and post-1965), the former represents that period during which a larger number of specimens were collected: leaving the lone specimen collected in 1852, an average of 8.3 specimens were collected per year pre-1915, 0.2 per year between 1915 and 1965 (inclusive), and 3.3 per year post-1965. As a result of the paucity of specimens between 1915 and 1965, no time-series analysis was undertaken; instead, the focus was on determining the extent to which temperature influenced phenophase dates in *R. fruticosus* using the Julian dates calculated from the collection dates on the information cards. The earliest collection date was Julian Day (JD) 111 (a specimen collected in the 'full flower' phenophase), the latest, JD 294 (a specimen collected in the 'end of fruiting' phenophase).

Analyses of the four phenophases in *R. fruticosus* found significant responses in first flower, full flower and first fruit ($p<0.05$) and a marginally statistically significant trend in the full fruit phenophase (Table 3.2 and Fig. 3.3). All suggested earlier phases of 7 to 13 days per 1°C of warming, with first flower and first fruit exhibiting the greatest responses.

**Table 3.2. Results of the weighted linear regression of the four *R. fruticosus* phenophases on January–June mean temperature. Statistically significant responses are shown in bold.**

| Phenophase | n | b | SE | $R^2$ | P |
|---|---|---|---|---|---|
| **First flower** | **24** | **-13.094** | **4.033** | **0.226** | **0.019** |
| **Full flower** | **37** | **-9.549** | **3.292** | **0.194** | **0.006** |
| **First fruit** | **21** | **-11.761** | **3.650** | **0.353** | **0.004** |
| Full fruit | 19 | -7.183 | 4.042 | 0.157 | 0.093 |

Where 'n' is the number of samples; 'b; is the estimated linear response in terms of days per degree celcius; SE is the standard error in 'b'; $R^2$ is the correlation coefficient and P a statistical measure of the significance of the result. The closer the value of $R^2$ is to 1.0, the more important temperature is as a driver of variation in the timing of phenological event. The smaller the value of P, the more unlikely the observed correlation is the result of random chance, a value less than 0.05 is consider highly significant.

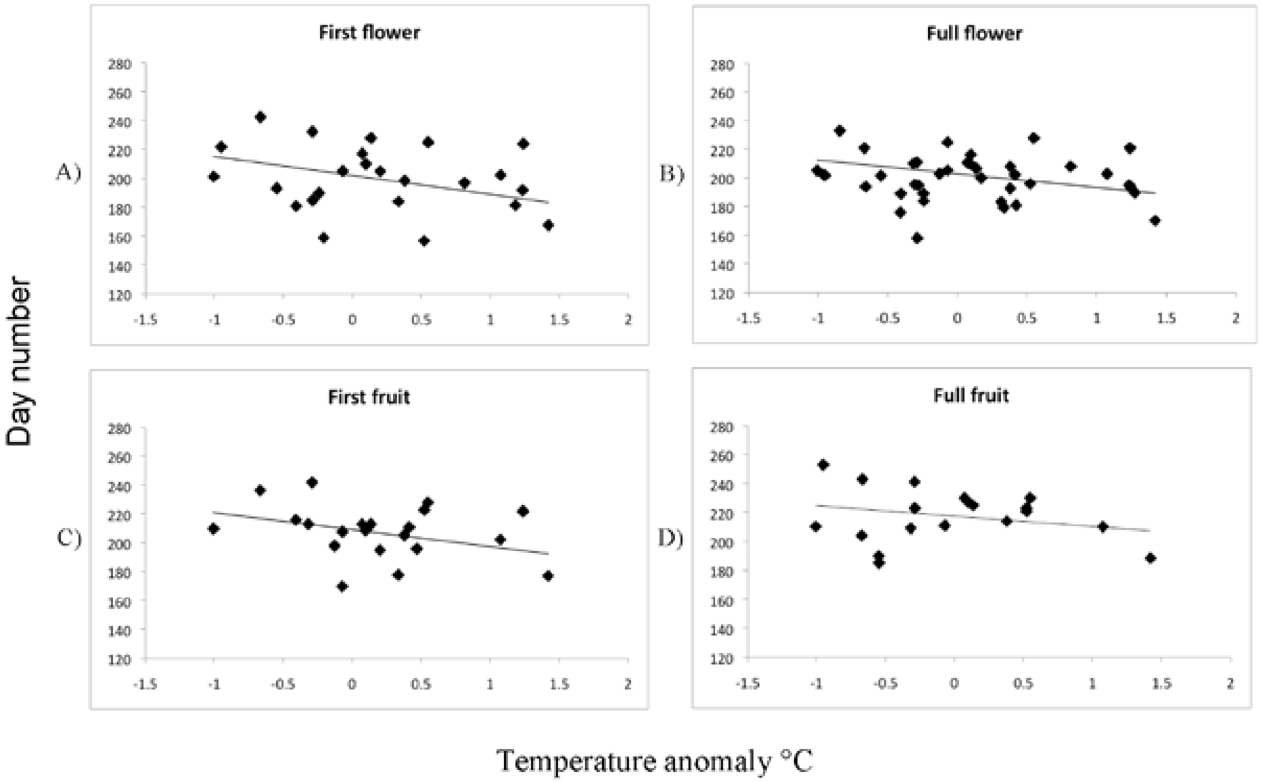

**Figure 3.3. Mean date (day number) for first flower (A), full flower (B), first fruit (C), and full fruit (D) against January–June temperature anomaly in *R. fruticosus.* Regression lines superimposed.**

### 3.1.5 *Discussion and Conclusions*

Using herbarium specimens collected between 1852 and 2007, a statistically significant response to mean January–June temperature for first flower, full flower, and first fruit phenophases in *R. fruticosus* and a marginally significant response in full fruit date was demonstrated. These responses correspond to responses in flowering and fruiting demonstrated in meta-analyses on phenology and climate warming (Parmesan & Yohe, 2002; Menzel et al., 2006). However, with regards to flowering, the scale of responses found here (7 to 13 days per 1°C) was greater than that in other studies focused on flowering, such as the four days determined by Fitter et al. (1995) and the 2–10 days by Sparks et al. (2000b). The other four Rubus species in this study were considered too sparse to reveal a response to temperature.

Complicating the comparison amongst species is the complex taxonomy of *Rubus spp*. This has resulted in thousands of species having been proposed and a taxonomy that has been described as ‘challenging’, ‘difficult’, ‘controversial’, and ‘confused’ (Blackman et al., 1977; Alice & Campbell, 1999; Nybom & Kraft, 1995; Kraft et al., 1996; Wada & Reed, 2006). *R. fruticosus* agg. serves as an ‘umbrella group’ into which species of a questionable status are placed (Kraft et al., 1996). As a result, although previous research has suggested a significant response towards earlier fruit ripening in *R. idaeus* (Carroll et al., 2009), because our dataset contained only two *R. idaeus* specimens collected in first or full fruit, no comparative analysis was undertaken.

Because of a large gap in collections in the mid-twentieth century, the current analysis did not take into account change over time. However, the advance in dates in response to increasing temperatures which was found confirms the results of previous research in Ireland that have utilised conventional data sources (Donnelly et al., 2006; Carroll et al., 2009). Consequently, it can be postulated that with a more complete dataset, a similar temporal trend would be revealed for *R. fruticosus* agg. With reference to work carried out elsewhere has used future climate scenarios to make phenological projections, it is likely that given projected temperature increases in Ireland, trends towards earlier first flower, full flower, and first fruit will continue (McGrath et al., 2008). The result that these phenophases are intimately linked to temperature is of critical importance to an understanding of how future climate warming will impact ecological processes.

This research is interesting in the light of an emerging paradigm in phenological research in the past decade, in which a move from a single-species approach towards a more holistic approach has occurred through consideration of species interactions (Harrington et al., 1999; Sutherst et al., 2007; Thackeray et al., 2010). This is done with the aim of determining the potential for mismatches that may result where changes in a species at one trophic level are not matched by the changes in another dependent species at a different trophic level. Such disruption in synchrony is important to consider given its potential impacts on ecosystem function and services (Thackeray et al., 2010). It is important to consider the implications for the higher trophic levels that depend on *Rubus spp*., and the lower trophic levels upon which *Rubus spp*. itself depends; these would be worthwhile pursuing in future investigations. Because *Rubus spp*. is so abundant in Ireland, asynchronous changes in phenology could likely have impacts across ecosystems.

**Further reading:** Diskin, E., Proctor, H., Jebb, M., Sparks, T. and Donnelly, A. (2012) *Rubus spp*. phenology in Ireland in response to climate warming: an exploration using herbarium specimens. *International Journal of Biometeorology* (doi:10.1007/s00484-012-0524-z).

## 3.2 Location of Migratory Bird Records and Analysis of Trends in relation to Temperature Variables

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### 3.2.1 Background

Changes in the growing season have altered the timing of available resources upon which the phenological events of many species depend (Visser et al., 2004). As a result, higher trophic level species, i.e. higher on the food chain, such as migratory birds, which rely on lower trophic level primary resources, must adapt their behaviour to keep pace with changes (Visser et al., 2004). Migratory birds can potentially respond to temperature changes by altering their distribution (Thomas and Lennon, 1999) or changing the timing of life-cycle events (Sparks et al., 2005; Cotton, 2003).

Despite numerous studies on phenological changes in migratory birds at breeding grounds, the mechanisms behind these changes are still unclear (Coppack and Both, 2002). This is primarily because most data are collected during passage as birds migrate or upon spring arrival. In addition, little published data exist on wintering migrants' phenology. As such, previous changes in the timing of migration have been predominantly investigated by correlating breeding ground arrival dates with environmental conditions in the breeding grounds (Sparks, 1999; Donnelly et al., 2009). In the breeding grounds, it is not possible to isolate whether the determining factor for early arrival is en route conditions, spatial shifts in wintering distributions, or changes in wintering departure times (Tøttrup et al., 2008; Marra et al., 1998). However, by examining the timing of departure from a constant wintering ground, phenological changes can be assessed without spatial shifts or en route conditions influencing the timing of migration.

Changing environmental conditions in the wintering grounds can impact the timing of arrival at breeding grounds (Sparks, 1999; Saino et al., 2004; Bearhop et al., 2004; Gordo et al., 2005). Indeed, poor quality winter habitat has been shown to adversely affect the physical condition of birds during migration (Bearhop et al., 2004), the timing of arrival and physical condition upon arrival at the breeding sites (Gill et al., 2001), sexual selection (Saino et al., 2004) and reproductive success (Norris, 2004). Few published phenological studies have investigated whether departure dates from the wintering grounds have been changing to the same extent as temperature at the breeding grounds (Sparks and Mason, 2004).

Local weather conditions may influence wintering ground departure either directly by improving the climatic conditions experienced during departure or indirectly by altering resource availability prior to departure. Improved conditions immediately prior to departure would enable easier progression of migration in favourable conditions since energetic costs are lower (Tsvey et al., 2007). For instance, sufficient body fat stores to fuel flight and reproduction at the breeding grounds may be required before departure can progress (Prop et al., 2003). Local climatic conditions are in turn influenced by large-scale climatic patterns (Hurrell, 1995). The timing of migration of some species has shown clear correlations with large-scale climatic systems such as the North Atlantic Oscillation (NAO) (Hüppop and Hüppop, 2003). The NAO is the primary driver of weather and climate variability over much of the Northern Hemisphere (Hurrell, 1995) and causes noticeable changes in monthly and seasonal average temperatures in both Iceland and Ireland (Hanna et al., 2004; Jennings et al., 2000). It has been suggested these large-scale climatic systems may function as a signal that allows birds to predict likely spring conditions in the breeding areas in advance of return migration (Frederiksen et al., 2004). However, with unequal climate-driven temperature change over Northern and Southern latitudes, large-scale cues experienced at the wintering ground may no longer predict future conditions at the breeding ground (Luterbacher et al., 2004; Menzel et al., 2006; Stine et al., 2009).

### 3.2.2 Aims

In this study, a long-term dataset of daily counts from a large, grazing, migratory species, the whooper swan (*Cygnus cygnus*), was used to investigate changes in the timing of arrival at and departure from, the wintering grounds in Ireland. The aims of this study were to investigate whether (a) the timing of arrival and departure of the whooper swan had changed over the 7-year study period, (b) the entire population was responding at the same rate and (c) changes in the timing of departure were correlated with changes in air temperature at the wintering and breeding grounds. In addition, the influence of food availability was also examined as a cue for departure.

### 3.2.3 Methods

#### 3.2.3.1 Study species

The Icelandic whooper swan breeds in Iceland and migrates to Scandinavia, Scotland and Ireland to winter. In Iceland, all breeding activities occur within a narrow timeframe (Einarsson and Rees, 2002; Rees et al., 1991). Onset of laying is dependent on weather conditions but generally occurs in April–May (Einarsson and Rees, 2002). Adults undergo a post-breeding moult period between late July and early August when they are flightless for approximately 30 days. Arrival at the wintering grounds in Ireland typically occurs between October and December and departure from the wintering grounds typically occurs between March and May (O'Halloran et al., 1993). Previous studies of the migrational phenology of whooper swans have recorded changes in the first arrival date and last departure dates at the wintering ground (O'Halloran et al., 1993). Though whooper swans are generalist feeders of a mix of aquatic and terrestrial plants, during February and March various grass species form the primary food resource in Ireland (Colhoun, 1998).

#### 3.2.3.2 Dataset and study site

The migratory phenology of wintering whooper swan was explored with a long-term dataset of the arrival of whooper swan which spanned the years 1972–2008 from Kilcolman Wildfowl Refuge (52 acres), Co. Cork, Ireland. This dataset included a nearly complete daily count of whooper swan numbers. Counts of whooper swan were conducted daily by sighting how many birds arrived onto the lake from two key observational hides surrounding the fen by rangers at Kilcolman Reserve. Given the close proximity and ease of viewing of this species when they landed on the fen in the evening and when they departed in the morning, counts were considered to be highly accurate.

#### 3.2.3.3 Migration variables

In order to obtain the annual migratory variables, daily counts over time were fitted to a relatively simple function model. Changes over time to the best fit parameters of this model give insight into changes in the phenology. A double Gaussian model was determined to be the optimal fit because preliminary exploration of the raw data showed two peaks (early and late) in the annual arrival dates and variation in the departure and arrival slopes. The date of the maximum rate of departure or arrival is comparable, in biological terms, with the peak date of arrival or departure of birds as they migrate through an area allowing direct comparison with other studies. Estimates of the points when 50% and 90% of whooper swan had departed were calculated for each year from the maximum point of the fitted curve (Fig. 3.4). For the analysis of annual arrival and departure dates, the following migratory variables were used: (i) the date when the first whooper swan were sighted at Kilcolman Reserve ('first arrival'), (ii) the date when arriving numbers increased the most, calculated from

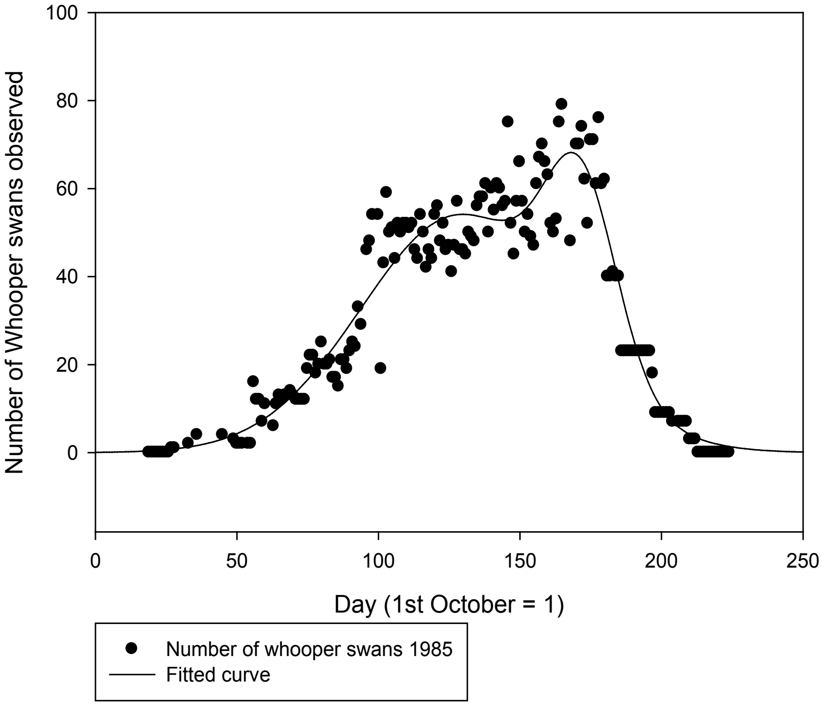

**Figure 3.4. Example of daily counts of whooper swans at Kilcolman Reserve from 1985 with a fitted curve.**

the inflection point during arrival ('date of maximum rate of arrival'), (iii) the date when departure numbers were largest calculated from the departure inflection point ('date of maximum rate of departure'), (iv) the date when 50% of the whooper swans had departed ('50% departure date'), (v) the date when 90% of the whooper swans had departed ('90% departure date'), (vi) the date when the last swan departed from Kilcolman Reserve ('last departure'). The duration of stay was calculated as the length of time between each of the migratory parameters (number of days between the first arrival date and the last departure date). For all calculations, calendar days were converted to day numbers where the 1 October was considered Day 1 and corrections were made for leap years.

#### *3.2.3.4 Trends in the timing of migration between years*

Linear models and non-linear generalised additive models (GAMs) for the relationships between migrational variables with time were compared by cross-validation analysis (Wood, 2006). Cross validation analysis of linear and GAMs indicated that trends in the first arrival date, date of maximum rate of departure and points when 50% and 90% of the birds had departed were non-linear over the study period, and GAMs with a cubic smoothing function were fitted to data series to assess the temporal trends (Zuur et al., 2009). Because population size may either mask or accentuate phenological changes (Miller-Rushing et al., 2008) the maximum number of birds present prior to departure (max. pop) was included as a covariate in all initial global models.

#### *3.2.3.5 Climatic variables*

Monthly air temperature (°C) (mean, maximum and minimum) and rainfall (mm) measured at Moorepark (Fermoy, Ireland) (52.1650 N, 8.262 W) the closest weather station, approximately 34 kilometres from the study site, were obtained from Met Éireann, Ireland. Grass yield data measured at Moorepark (Fermoy, Ireland) was obtained from Teagasc (http://www.agresearch.teagasc.ie/moorepark/grassgrowth/mpn_grassgrowth.asp). Weekly grass yield (kg dry matter per hectare) of perennial ryegrass plots/swards had been measured between 1982 and 2008 at Moorepark using the methods described by Corral and Fenlon (1978). Grass yield from 9 February to 9 March was used for the analysis since this period was indicative of both the start and the intensity of growth as defined by Mitchell and Hulme (2002). The data collected from Moorepark were used as indicators of local climate and grass growth at the wintering site at Kilcolman Wildfowl Reserve. Changes in the Icelandic breeding ground temperature (°C) (mean, maximum and minimum) and rainfall (mm) that whooper swans were experiencing upon arrival were calculated by averaging data from Stykkishólmur (65:04:25 N, 22:43:39 W) and Reykjavik (64.0800 N, 21.5400 W); both 15 and 30 days after the maximum date of departure from the wintering ground. The Icelandic data were obtained from the European Climate Assessment and Dataset (ECAD): http://eca.knmi.nl

#### 3.2.3.6 *Multiple logistic regressions of local wintering climatic variables*

Monthly maximum and minimum temperatures from the wintering grounds in January (Jan) and February (Feb), when plant growth is initiated, and in the month prior to departure (month of dept) were included in the initial global model. Mean monthly precipitation (precip.) during January (Jan precip.) and February (Feb precip.) were also included in the original model since precipitation can affect the stage of plant phenology (Ottersen et al., 2001). The initial logistic regression model was (Eq. 3.1):

$$\text{Peak departure} = \text{Jan Max Temp} + \text{Jan Min Temp} + \text{Feb Max Temp} + \text{Feb Min Temp} + \text{month of dept} + \text{Jan precip.} + \text{Feb precip.} + \text{Max pop.} \qquad \text{(Eq. 3.1)}$$

To determine if plant growth was an important predictor of departure, the following linear model was constructed (Eq. 3.2):

$$\text{Departure phase} = \text{grass growth} + \text{Max pop.} \qquad \text{(Eq. 3.2)}$$

To determine if grass growth explained variability in departure equally during early and late phases of migratory departure, this model was fitted to: (i) peak departure, (ii) the date when 50% of birds had departed and (iii) the date when 90% of birds had departed. The date of maximum departure was related to mean temperature conditions at the breeding site to determine how beneficial (or detrimental) earlier departure might be. Temperature averages from 15 and 30 days after the maximum date of departure were calculated. The maximum date of departure was correlated against each of these climatic variables.

All statistical analyses were carried out with R statistical software (R development core team, 2009) with mgcv (Wood, 2004) and nlme packages (Pinheiro et al., 2009).

### *3.2.4 Results*

#### 3.2.4.1 *Temporal trends in migration patterns*

Trends in first arrival dates of whooper swan from 1970 to 2008 were non-linear and advanced from 1971 until 1983, after which they no longer changed significantly (linear regression, p=0.165). The date of the maximum rate of arrival showed a non-significant tendency towards earlier arrival over the study period. Non-linear trends towards later departure were observed for: (i) the date of the maximum rate of departure, (ii) the date when 50% of the whooper swans had departed and (iii) the date when 90% of the whooper swans had departed from 1971 to 1979. The date of maximum rate of departure and the date of 50% departure showed similar patterns whereby both occurred later until 1976. After 1976, strongly significant linear trends towards earlier departure were apparent for both the date of maximum rate of departure (slope=-0.989, r=0.49, p<0.0001) and the date when 50% of birds departed (slope=-0.805, r=0.485, p=0.003). The date at which 90% of the population had departed showed a significant linear trend towards earlier departure from 1979–2009 (slope=-0.534, r=0.30, p=0.024). No significant directional trend was observed for last departure (p=0.776). A tendency towards earlier departure was stronger in the first 50% of birds which departed than for the later birds to depart, as measured by the date when 90% of birds departed. This resulted in a significant increase in the duration of departure over time (slope=0.334, p=0.005, r=0.22). The increase in the duration of departure was partially explained by an increase in the number of whooper swans at the wintering grounds (slope =0.09, p=0.021, r=0.169). The total number of days that whooper swan were present had increased significantly, as calculated from the date of last departure minus the date of first arrival (p=0.05, r=0.10). In addition, there was also a significant lengthening between the date of maximum rate of arrival and last departure (p=0.02, r=0.16). However, the length of stay between the dates of maximum arrival and departure did not change significantly (p=0.12, r=0.16).

In brief, there is limited evidence of whooper swans arriving earlier to the Kilcolman wintering site. There is stronger evidence that birds have been departing earlier since the later 1970s. However, the birds do not depart en masse: therefore the period over which birds depart has extended. The combined impact of early arrival and extended departure period means the birds are present at the wintering grounds has lengthened.

#### *3.2.4.2 Influence of local temperature on departure*

From 1972 to 2009, the mean maximum February air temperature at the wintering ground showed a significant tendency towards higher temperatures (slope=0.03, r=0.341, p=0.039, df=35). An increase in maximum February temperature was significantly correlated with an increase in grass yield (p=0.012, Rsq=22.89%). From 1982 to 2009 early spring grass yield showed a significant (p=0.01, r=0.34) nonlinear pattern, increasing until year 2000, after which it declined slightly. Mean maximum temperature and the local whooper swan population size prior to departure were the two determining factors driving the date of maximum rate of departure from the local wintering climatic variables (global model i). Mean maximum February temperature was positively associated with the date of maximum rate of departure, indicating that as mean maximum February temperature increased whooper swans departed earlier. The peak population size of whooper swan present at the wintering grounds prior to the start of departure was also positively related to departure. Rainfall was not a significant factor in predicting the peak date of departure after taking temperature into account. Annual changes in the date of the maximum rate of departure were also explained by a multiple regression model which included both early spring grass yield and population size prior to departure. An earlier date of the maximum rate of departure was correlated with years when grass yield was greatest and representative of more intense growth in the spring growing season. Variation in the departure date when 50% of the birds had migrated was also significantly predicted by early spring grass yield. In addition to early spring grass yield, population size at the reserve prior to the start of departure was also a significant variable, contributing towards an earlier date when 50% of the population had departed over time. The date when 90% of the wintering whooper swan population departed, was also significantly influenced by early grass yield. Population size (at the reserve prior to the start of departure) was not an important variable explaining variation in the date when 90% of individuals had departed.

#### *3.2.4.3 Influence of North Atlantic Oscillation, on departure*

The logistic regression model of the influence of carry-over effects on peak departure, favoured a model which included NAO conditions in both February and January (Rsq=60.95%). In years when the February and January NAO was high (indicative of high temperatures and rainfall), birds departed earlier. The best fitting multiple regression model for when 50% of swans departed indicated that both spring and wintering conditions contributed to departure significantly. NAO conditions in April and May prior to arrival in the wintering grounds as well as conditions in the wintering ground in February were all retained in the final model. In addition, maximum population size was also an important variable and was retained in the final model predicting the date of departure of 50% of the individuals. Positive NAO conditions (indicative of higher temperatures and rainfall) in both the breeding ground and the wintering grounds contributed to the earlier departure of this migrational phase. Population size prior to departure, though still an important variable in explaining the departure date of 50% of the population, contributed only slightly to earlier departure. The best-fitting multiple regression model of the date when 90% of the annual population had departed included only NAO in February (slope= -0.119, p=0.006, Rsq=30.97). Earlier departure at this phase of migration was again associated with a positive NAO index during February. However, neither the maximum population size nor conditions in the breeding grounds contributed significantly to this phase of departure.

### *3.2.5 Discussion and Conclusions*

Whooper swans have altered their departure phenology from the wintering grounds in correlation with maximum mean temperature changes in February. However, the influence of increasing temperatures is unlikely to be a direct cue for departure since birds departed the wintering grounds approximately one month later. Instead, the results showed departure is mediated by the influence of temperature on food resources, such as grass growth. Grass growth is temperature dependent and is initiated when ground temperatures exceed 5°C in early spring (Keane and Collins, 2004; Sparks et al., 2005). An increase in temperature also increased the intensity of grass growth (Keane and Collins, 2004).

The peak in the nutrient biomass of grass occurs early in the growing season and is a particularly important source of energy for migration and reproductive activity in large grazing birds (van der Graaf et al., 2006) such as whooper swan.

Earlier arrival at spring breeding grounds will potentially enable first access to the best breeding habitat increasing reproductive success (Alerstam, 1991; Noordwijk and Jong, 1986; Møller, 2004). In the breeding grounds whooper swans arrive prior to first plant growth, enabling their chicks to take advantage of peaks in high nutrient biomass of food resources (van der Graaf et al., 2006; Earnst, 2002). The maximum departure date was not found to be significantly correlated with future climatic conditions at the breeding site either 15 or 30 days after departure from Ireland. If conditions in the breeding grounds are not increasing at a corresponding rate to conditions in the wintering grounds, the time between arrival and egg-laying may increase. This could be detrimental for an individual if fat reserves are not sufficient to cover this extended period and still enable successful reproduction.

Changes in whooper swan phenology were not equal for all departure phases of migration. A stronger trend towards earlier departure was evident in the earlier departure phases ('date 50% departed' and 'date of maximum rate of departure') than for the later phase ('date 90% departed'). This difference was clearly apparent in the significant lengthening of the departure window ('number of days') between the earlier ('date 50% departed') and the later ('date 90% departed') phases over time. Stronger responses in the earlier phases of migration in spring arrival of various migratory passerine species have previously been reported (MacMynowski and Root, 2007; Miller-Rushing, 2008). MacMynowski and Root (2007) suggested that stronger responses in the early phases of migration can be explained by different conditions experienced en route. However, in this study this pattern was apparent at the wintering site and therefore the influence of en route conditions could be ruled out. Instead, it is suggested that the various departure phases are composed of different sectors of the population. For instance, the last individuals to depart may cover a specific age or sex class that are not as strongly affected by time constraints (Spottiswoode et al., 2006). Indeed, it is quite possible that the last birds to depart are young and do not strive to breed. Variability in arrival dates at the breeding ground in individuals that do not reproduce has previously been observed in other large arctic avian species, such as pink-footed geese, Anser bachyrhynchus (Tombre et al., 2008). There is no advantage for young pink-footed geese to arrive early at the breeding grounds since there is no pressure to reproduce (Tombre et al., 2008). This results in different migratory behaviour between the breeding and the nonbreeding individuals. In addition, a longer stay could potentially allow non-breeders to take additional advantage of resources in the wintering ground. However, early population sectors may benefit by arriving at spring breeding grounds earlier than competitors where they will potentially have first access to prime breeding habitat (Noordwijk and Jong, 1986; Alerstam, 1991; Møller, 2004).

Rather than birds using NAO conditions to predict conditions in the breeding grounds, the results suggested that in positive NAO winters the onset of spring was earlier, which consequently enabled early departure. Variation in departure dates is likely to be because different migrational phase estimates for different population sections (Vahatalo et al., 2004). Thus the last individuals to depart may cover a specific age or sex class and therefore show a different response than the first 50% of individuals to depart. In the Irish–Icelandic whooper swan population the annual life strategy is likely only to permit minor shifts in phenology of the breeding individuals if the wintering grounds are not altering at an equal rate, since breeding events and moulting must occur within a narrow time frame. As a result, it is possible that different climatic variables drive the migratory behaviour of breeding and non-breeding individuals.

North Atlantic Oscillation conditions in May and April in the prior breeding season are likely to influence the timing of breeding in the whooper swan by both delaying the timing of breeding and by influencing the size of the population using the wintering area prior to departure. A delay in breeding in a colder year (when the NAO is negative) may carry over to influence the timing of moult, and thus arrival at the wintering ground. This delay in arrival may in turn influence food uptake and the timing of winter departure. Carry-over effects of NAO conditions at the breeding grounds would predominately influence the timing of arrival of breeding birds, and it is therefore not surprising that the entire departing population is not affected by NAO conditions during the breeding season.

In conclusion, increasing temperatures in early spring at the wintering grounds indirectly enabled earlier departure of whooper swan by altering the availability of their food resource. An advance in the date of departure is likely to result in an advanced arrival at the breeding grounds in Iceland. Earlier arrival may consequently influence timing of breeding of birds, strongly influencing breeding success (Fulin et al., 2009). This study adds to the growing evidence showing that the wintering grounds of migratory birds can strongly influence population dynamics (Marra et al., 1998; Saino et al., 2004; Møller et al., 2006). To correctly determine why arrival dates in the breeding grounds have altered, environmental conditions in the wintering grounds must also be taken into account.

**Further reading:** Stirnemann, R.L., O'Halloran, J., Ridgway, M. and Donnelly, A. (in press) Can wintering condition determine the migration phenology of whooper swan (*Cygnus cygnus*). Ibis

## 3.3 Analysis of Additional Long-term Datasets on Bird Migration

In addition to the study outlined above data from a range of spring migrant birds, generally passerine species, i.e. perching birds, were analysed to determine if they are arriving to Ireland earlier over a 30-year period (Donnelly et al., 2009). All the birds studied were arriving from sub-Saharan Africa and only 2 out of the 11 birds examined showed a tendency to arrive later. The majority of the birds were arriving earlier at the end of the time-series than at the beginning. This trend has, at least in part, been attributed to rising spring temperature. Table 3.3 shows the list of birds examined and whether they were occurring earlier or later over the 1969–1999 time period.

In addition, a step change observed in the pattern of occurrences of non-breeding and breeding migrant bird species was found to correlate with a step change in March temperature in 1987/88. A sudden increase in the number of hobbys and ospreys was recorded in Ireland while step changes in the numbers of reed warblers, blackcap, roseate, arctic and common terns being ringed were also noted. This provides evidence that long-term monotonic increases in temperature and short-term relatively sudden increases in temperature can influence arrival dates of migrant birds to Ireland (Donnelly et al., 2009).

More recently, trends in arrival dates of non-passerine birds, i.e. non perching, to the east coast of Ireland have begun to be examined to determine if there is any change in the pattern of arrival over a 24-year period (1980–2003) for which data exist. After examination of 40 species it transpired that about half of the birds were arriving earlier at the end of the time-series than at the beginning with only a number of these showing a significant trend (Table 3.4).

**Table 3.3. Common spring passerine migrant birds arriving to the east coast of Ireland, 1969–1999.**

| Species | N | MK-Stat | p-value |
|---|---|---|---|
| Common cuckoo *Cuculus canorus* | 23 | 1.113 | 0.266 |
| Common swift *Apus apus* | 30 | -0.751 | 0.453 |
| Sand martin *Riparia riparia* | 25 | -2.221 | 0.026 |
| Barn swallow *Hirundo rustica* | 31 | -2.792 | 0.005 |
| Common house martin *Delichon urbicum* | 19 | -3.575 | 0.000 |
| Whinchat *Saxicola rubetra* | 23 | -1.787 | 0.074 |
| Northern wheatear *Oenanthe oenanthe* | 30 | -3.005 | 0.003 |
| Common grasshopper warbler *Locustella naevia* | 21 | -1.913 | 0.056 |
| Sedge warbler *Acrocephalus schoenobaenus* | 18 | 1.221 | 0.222 |
| Common whitethroat *Sylvia communis* | 18 | -2.136 | 0.033 |
| Willow warbler *Phylloscopus trochilus* | 26 | -0.332 | 0.740 |

MK-Stat: Mann-Kendall indicates the nature of the trend, negative values indicate earlier arrival and positive values later.

**Table 3.4. Common spring non-passerine migrant birds arriving to the east coast of Ireland, 1980–2003.**

| Species | *n* | MK-Stat | p-value |
|---|---|---|---|
| Red-throated diver *Gavia stellata* | 22 | -2.288 | 0.022 |
| Fulmar *Fulmarus glacialis* | 12 | -0.411 | 0.681 |
| Manx shearwater *Puffinus puffinus* | 20 | 0.260 | 0.795 |
| Gannet *Morus bassanus* | 18 | -2.505 | 0.012 |
| Greylag goose *Anser anser* | 23 | -1.745 | 0.081 |
| Shelduck *Tadorna tadorna* | 19 | -2.564 | 0.010 |
| Garganey *Anas querquedula* | 13 | -1.284 | 0.199 |
| Tufted duck *Aythya fuligula* | 18 | -0.688 | 0.492 |
| Scaup *Arthya marila* | 17 | 1.613 | 0.107 |
| Common scoter *Melanitta nigra* | 16 | -1.037 | 0.300 |
| Goosander *Mergus merganser* | 12 | 1.234 | 0.217 |
| Marsh harrier *Circus aeruginosus* | 12 | -1.168 | 0.243 |
| Hen harrier *Circus cyaneus* | 20 | 1.429 | 0.153 |
| Buzzard *Buteo buteo* | 18 | -2.390 | 0.017 |
| Osprey *Pandion haliaetus* | 13 | -1.650 | 0.099 |
| Ringed plover *Charadrius hiaticula* | 12 | 1.654 | 0.098 |
| Grey plover *Pluvialis squatarola* | 16 | -0.541 | 0.588 |
| Knot *Calidris canutus* | 13 | -0.980 | 0.327 |
| Sanderling *Calidris alba* | 18 | -0.417 | 0.676 |
| Purple sandpiper *Calidris maritima* | 17 | 0.248 | 0.804 |
| Dunlin *Calidris alpine* | 15 | 0.991 | 0.322 |
| Ruff *Philomachus pugnax* | 23 | 0.372 | 0.710 |
| Jack snipe *Lymncryptes minimus* | 21 | -0.030 | 0.976 |
| Black-tailed godwit *Limosa limosa* | 15 | -0.645 | 0.519 |
| Bar-tailed godwit *Limosa lapponica* | 13 | 1.837 | 0.066 |
| Whimbrel *Numenius phaeopus* | 24 | -0.970 | 0.332 |
| Spotted redshank *Tringa erythropus* | 22 | 0.480 | 0.631 |
| Redshank *Tringa totanus* | 15 | 1.836 | 0.066 |
| Greenshank *Tringa nebularia* | 12 | 0.069 | 0.945 |
| Green sandpiper *Tringa ochropus* | 14 | 1.043 | 0.297 |
| Common sandpiper *Actitis hypoleucos* | 15 | -2.431 | 0.015 |
| Turnstone *Arenaria interpres* | 17 | 0.908 | 0.364 |
| Arctic skua *Stercorarius parasiticus* | 15 | -0.247 | 0.805 |
| Iceland gull *Larus glaucoides* | 23 | 0.186 | 0.852 |
| Sandwich tern *Sterna sandvicensis* | 24 | -2.996 | 0.003 |
| Roseate tern *Sterna dougallii* | 15 | 0.000 | 1.000 |
| Little tern *Sterna albifrons* | 15 | -1.192 | 0.233 |
| Black guillemot *Cepphus grylle* | 12 | 0.137 | 0.891 |
| Puffin *Fratercula arctica* | 14 | 0.329 | 0.742 |

MK-Stat: Mann-Kendall indicates the nature of the trend, negative values indicate earlier arrival and positive values later.

One possible explanation for the difference in arrival between the passerines and non-passerines may be due to the extended time-series available for analysis for the passerines. The influence of spring temperature on the timing of arrival was evident with significant correlations between arrival and average March temperature in particular. Further details are available in Geyer and Donnelly (submitted).

It is interesting to note that a range of both passerine and non-passerine spring/summer migrant birds have shown a trend towards earlier arrival to the east coast of Ireland and that this trend shows a correlation with spring temperature variables. However, since not all species are expected to respond to climate warming at the same rate these trends were found to be species specific. The timing of departure of the whooper swan, a winter visitor, demonstrated a stronger correlation with spring temperature than the timing of arrival in autumn, indicating that spring phenology may be more sensitive to changes in temperature than later phenophases.

### *3.3.1 Climate-driven Mismatches between Birds and their Host Prey*

While rising temperature has clearly been shown to affect bird phenology in the form of altering the timing of arrival and departure it is important to explore the indirect impacts of climate change on bird phenology. More and more studies are reporting that climate change may result in mistiming between birds and their food source as climate warming has the potential to disrupt existing synchronies between interdependent species as a result of differential responses of species to increasing temperature (Parmesan and Yohe, 2003; Visser and Both, 2005; Durant et al., 2007; van Asch and Visser, 2007; Singer and Parmesan, 2010). A review of the literature relating to mistiming between birds and their food source and/or prey can be found in Donnelly et al. (2011).

In addition to negative consequences of climate change on synchrony of birds and their resources climate change may also have positive effects for some bird species. Just as asynchronous relationships may develop between a species and its food source, equally weak synchronies may be strengthened or new synchronies forged. In addition, rising temperatures may permit a northward and upward range expansion in bird populations adapted to warmer temperatures allowing them to exploit new territories if suitable food source and habitat are available for them to thrive. Earlier arrival at breeding grounds coupled with earlier egg-laying may also lead to greater survival rates and larger population size – if, of course resources are not limiting.

### *3.3.2 Evidence of Genetic Adaptation in Birds as a result of Climate Change*

Phenotypic plasticity allows organisms to adapt to environmental change but if the range of environmental conditions exceeds the plastic limits of an organism, genetic adaptation is likely to occur which may help prevent local extinction (Price et al., 2003; Gienapp et al., 2008). If there is sufficient selective pressure, climate change can contribute to the evolution of new species.

Bearhop et al. (2005) reported evidence of speciation through assortative mating in populations of Blackcaps in Europe. In the 1960s, Blackcaps spent their summers in Germany/Austria and wintered in Iberia and northern Africa. However, more and more of these birds have begun to over-winter in Britain and Ireland, attributed at least in part to milder winters, thus leading to a change in their migration pattern. This resulted in the birds that spent the winter in Britain and Ireland arriving at their breeding grounds earlier, because critical photoperiods that trigger migration were found to be 10 days earlier than in more southern latitudes. In addition, because of the shorter migratory distance, these birds were possibly in better physical condition on arrival. The birds that arrived early tended to mate together and chose the best breeding territories, all of which resulted in greater reproductive success. The later-arriving birds also mated together and, therefore, these two populations paired assortatively. According to Bearhop et al. (2005), this temporal separation may result in subpopulations becoming isolated. Consequently, it may be that changes in environmental conditions that result in new migration routes may lead to the evolution of genetically distinct populations or species. It is therefore likely that, for some birds, future warming has the potential to influence speciation. However, according to Sheldon (2010), while this study remains an important demonstration of the evolution of a novel migratory pattern, and an underlying genetic change, the relationship to climate remains to be fully established.

Phenotypic plasticity at a population level is also under selective pressure. The degree of plasticity in the timing of reproduction in birds has been shown to be a heritable trait (Nussey et al., 2005; Reed et al., 2008). Selection of this heritable component could allow some individuals to track climatic changes better than others and selection of these individuals may enable the population to track food resources beyond points imposed by current plastic limits (Stenseth and Mysterud, 2002). As not all species are highly plastic the ability to genetically adapt to changing climatic conditions will inevitably vary.

To date many of the evolutionary responses reported for a range of organisms as resulting from climate warming are speculative rather than being strongly supported by empirical data (Nussey et al., 2005). This is not to say that evolutionary change, in response to recent warming, has not already occurred or will not occur in future but just that sufficient evidence has not yet been acquired (Sheldon, 2010).

Here a change in the timing of arrival and departure of a wide range of birds, including land and seabirds and winter and summer migrants, to Ireland has been demonstrated. These changes generally resulted in earlier arrival and departure in spring, which in turn was correlated with rising spring temperature. However, whereas earlier arrival may at first appear to be advantageous to survival, a review of the literature clearly showed that, in order to thrive, this change needs to be synchronous with resource availability. Phenotypic plasticity is clearly a useful mechanism which allows birds to adjust to changes in local environmental conditions but if these conditions exceed the plastic limits of the birds genetic adaptation may result.

## 3.4 Location of Moth Records and Analysis of Trends in relation to Temperature Variables

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### 3.4.1 *Background*

Insects, for the most part, are poikilothermic – depending on the temperature of their environment to drive their growth and periods of activity. Changes in activity periods, and in the speed with which insects pass through their life cycles, can be seen in changes to a species' phenology. Harrington et al. (2007) found that aphid species across Europe were showing an advanced flight period each year with rising spring temperatures. Sparks et al. (2010) found a phenological shift in one of the most domesticated of insects, the honey bee (*Apis mellifera*), with advanced first flight dates reported in the spring with rising temperatures.

Lepidoptera, and particularly moths, are a useful group of insects to monitor for changes in phenology in relation to climate change. They are an important food source for birds and mammals (Acharya, 1995; Both et al., 2009); they can be important pollinators (Nilsson et al., 1992; Bogler et al., 1995) and they can be important crop pests (Talekar and Shelton, 1993; Cardé and Minks, 1995). Many species of moth are quite common and large-bodied, and they can have striking patterns on their wings (Srinivasarao, 1999; Stevens, 2005), making visual observations of moths easily and accurately recorded. Phenology in moth species is primarily determined by temperature, but it can be modified by precipitation and/or photoperiod (Valtonen et al., 2011). Analyses of Lepidoptera phenology have typically focused on the flight period of adults (Roy and Sparks, 2000a; Forister and Shapiro, 2003; Stefanescu et al., 2003). The flight period begins with the first sighting of an individual and ends with the last sighting of an individual during the course of a year. Most Irish insects are dormant through the winter months, so first sighting generally occurs in the spring or summer, with last sighting occurring in the autumn.

While there is government-sponsored long-term record-keeping of phenology throughout Europe, and of plant phenology in particular (Sparks et al., 2000b; Chmielewski and Rötzer, 2001), many phenological observations are also made by interested amateur naturalists. These 'citizen scientists' are essential for phenological research, as many scientists would be unable to make the same number of observations over large distances over the same time periods for statistical analysis. There is some debate on the accuracy of data collection by self-trained individuals (Amano et al., 2010; Dickinson et al., 2010), but lay science is extremely effective in climate change research by engaging the public and changing perceptions of climate change and science in general (Lawrence, 2009; Mayer, 2010).

### 3.4.2 *Aims*

To further knowledge of phenological responses to climate change in Ireland, records of the flight periods of the 59 most common large-bodied species of adult moth over a period of 35 years from 1974 to 2009 were examined. Records of moth observations were obtained from an amateur naturalist group of moth enthusiasts, MothsIreland (http://www.mothsireland.com/). These records were assessed in relation to monthly temperature changes over the same locations and time periods. These records were also correlated with phenology of host plants and insectivorous migratory birds. It was hypothesised that moths in Ireland are showing advanced phenology in response to rising spring mean temperatures, as has been found in many other parts of the globe (Dingemanse and Kalkman, 2008; Sparks et al., 2010).

### 3.4.3 *Methods*

Observations of 59 moth species were recorded by volunteers of MothsIreland. Records of moth counts for 8 of the 59 species were also obtained from the Rothamsted Insect Survey's site in Fota, Co. Cork. The Rothamsted Insect Survey has been running since the 1960s collecting abundance data on multiple species of insects throughout the United Kingdom and Ireland (Conrad et al., 2006). The site at Fota is the oldest site in the Republic of Ireland in the Rothamsted network. For these 8 species, 17 years of observations were recorded and analysed in this study. Trapped moths were collected and mailed to Rothamsted Research in the United Kingdom for identification and counting.

Daily maximum and minimum temperatures were obtained from Met Éireann for each of the observer locations from 1960–2010. These temperatures were then used to calculate monthly mean maximum, mean minimum and mean daily temperatures for each collection site.

From the moth-collection records, first date of observation, last date of observation and median date of observation were determined for each species and each year, and converted to day of year. Length of flight period was determined by the number of days between first and last dates of observation. Each of these parameters for each species was analysed by GAMs in relation to year (R development core team 2009; package nlme, Pinheiro et al., 2009). The total number of moths observed each year was highly variable; the vector 'total number of individuals observed each year' was therefore added as a weight to each GAM. Relationships between each parameter for each species and between that parameter and temperature (monthly mean temperature, monthly mean maximum temperature and monthly mean minimum temperature) were analysed by Spearman correlations (SPSS 9.0, Chicago, IL). These analyses were run for each species at each of the four locations, and for each species across the country.

First dates of observation of 12 species were analysed by Spearman correlations with the beginning of growth season of select host plants and first arrival of insectivorous migratory birds. Phenological records of 11 species of trees and 11 species of migratory birds were previously analysed by Donnelly et al. (2006; 2009). These 12 moth species were chosen because they fed on previously analysed tree species and emerged in the spring when migratory bird species return to Ireland. The tree and bird species were chosen because they were either fed upon (trees) by moth species analysed for this report or feed upon them (birds). Correlations were run for first sighting of each moth species with beginning of growth season for their host plants and also for first arrival of each bird species with first sighting of the moth species.

### 3.4.4 Results

Moths in Ireland are showing a significant change in phenology over time, with 55 of the 59 moth species showing a significant change in one or more phenophases, or length of flight period. Of the 49 species showing advancement in first sighting date, the mean change in days/year over the 35 years of observations was -1.18 ± 0.83. Of the 21 species showing advancement in median sighting date, the mean change in days/year over the 35 years of observations was -1.02 ± 0.66. Of the three species showing a delay in median sighting date, the mean change in days/year over the 35 years of observations was 0.95 ± 0.82. Of the 20 species showing a delay in last sighting date, the mean change in days/year over the 35 years of observations was 1.85 ± 1.47. And of the 45 species showing an increase in length of flight period, the mean change in days/year over the 35 years of observations was 2.26 ± 1.61. Figure 3.5 shows an example of a species showing a significant change in first sighting date and length of flight period.

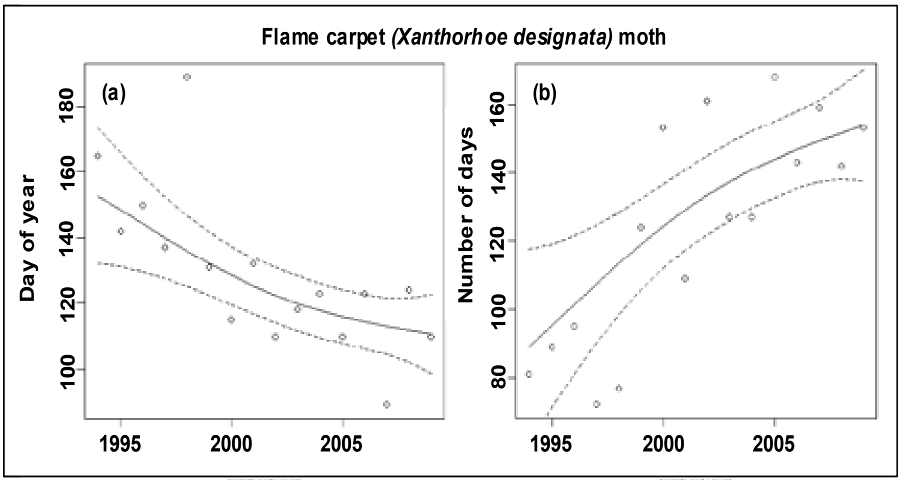

**Figure 3.5. Flame carpet moth: (a) first sighting date and (b) flight period. Appearance time is getting earlier while the length of the flight period is extending. Dashed line represents the 95% confidence interval.**

#### *3.4.4.1 Emergence*

Species were divided into three categories based on emergence time: (i) early spring, (ii) late spring and (iii) summer. Species emerging in early spring have a first sighting date advancing slightly faster than species emerging in late spring. First sighting for all spring species was advancing much faster than first sighting in summer species. Median appearance and length of flight period followed the same trend as first sighting. Last appearance was moving the most in the late spring group, and change was smaller in the summer and early spring groups progressively.

#### *3.4.4.2 Generations per year*

Species were divided into three voltinism categories: univoltine (one generation/year), multivoltine (two or more generations/year) and variable (one generation/year in the northern parts of the country and two generations/year in southern parts of the country). First appearance of univoltine species advancing the slowest over time compared to the other two categories. First appearance of multivoltine species was advancing the faster. However first appearance in variable species show a similar pattern to those in the multivoltine category.

Median appearance was advancing fastest in the varied species group, while median appearance in the other two groups advanced at a similar pace. Last sighting was seen to occur later in all categories, the most delayed by far in the multivoltine group, with last sighting delayed similarly in the other two groups. Length of flight season was increasing the most for the multivoltine group.

#### *3.4.4.3 Overwintering stage*

Species were divided into three overwintering stage categories: species that are dormant as (i) an egg, (ii) larvae and (iii) pupae. First appearance was advancing the fastest in species that overwinter as pupae, then in species that overwinter as larvae and was advancing the slowest in species that overwinter in the egg stage. Median appearance was following the same trend as first appearance in species that overwinter as pupae and larvae. Last appearance was delayed the most in species that overwinter as larvae. Length of flight period was increasing at the same rate in species that overwinter as pupae and larvae.

#### *3.4.4.4 Phagy*

Species were divided into three phagy categories: (i) monophagous (species that only feed on one plant species or family), (ii) oligophagous (species that feed on a few plant species or families) and (iii) polyphagous (species that feed on many plant species or families). First appearance date was advancing slightly faster in monophagous species, than in oligophagous and polyphagous species which were advancing at the same rate. Median appearance was advancing in oligophagous species the fastest, then monophagous and polyphagous groups in turn. Last appearance dates were being delayed at roughly the same rate for monophagous and polyphagous species, but less so for oligophagous species. Length of flight period increased the most for monophagous species.

#### *3.4.4.5 Host plant grouping*

Moth species were also examined by the plant group on which they feed: grasses, herbaceous plants and trees and shrubs. First appearance dates were advancing fastest in species that feed on trees and shrubs, then species that feed on herbaceous plants, and slowest in species that feed on grasses. Median and last appearance dates were following the same trend. Length of flight period was increasing at the same rate in the three groups.

Of the 49 species showing a significant change in first appearance date, slightly less than half were significantly correlated with temperatures in May and June. Significant correlations with temperatures in May were mostly with May mean temperatures, while significant correlations with temperatures in June were mostly with June mean maximum temperatures. Of the 24 species showing a significant change in median appearance date, the largest group were correlated with June temperatures, usually June mean minimum temperatures. Of the 20 species showing a significant change in last appearance date, half were correlated with temperatures in June and September. Significant correlations for both months were usually with mean maximum temperatures.

There were very few significant correlations between beginning of growth season and first sighting, or between first sighting and first arrival. The only

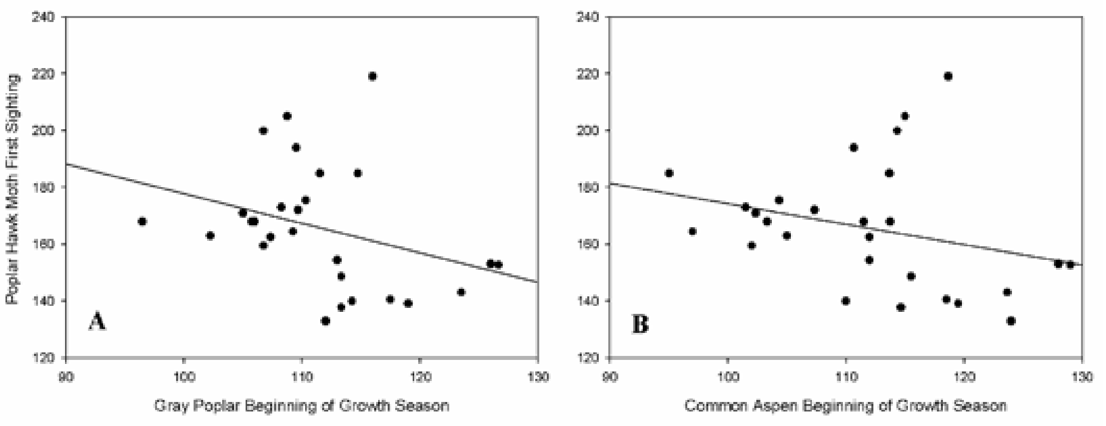

**Figure 3.6. Poplar hawk moth (a) correlation between first sighting and beginning of the growth season for gray poplar and (b) correlation between first sighting and beginning of the growth season for common aspen. Appearance time is getting earlier while the length of the flight period is extending.**

significant correlations between the beginning of the growth season and first sighting were for *Laothoe populi* (Poplar Hawk Moth) and its host plants *Populus canescens* (gray poplar; R=-0.413; P=0.032) and *P. tremula* (common aspen; R=-0.404; P=0.037) (Fig. 3.6). The only significant correlations between first sighting and first arrival were between *Sylvia communis* (common whitethroat) and its food source *Orthosia gothica* (Hebrew character; R=-0.698; P=0.037) and between *Saxicola rubetra* (whinchat) and its food source *O. gothica* (R=-0.829; P=0.042).

### *3.4.5 Discussion and Conclusions*

Temperatures in Ireland have increased in line with global increases and moths in Ireland have responded to this warming through changes in phenology. Most of the species analysed exhibited an advance in first sighting, and a subsequent lengthening of the flight period. Earlier emergence (Sparks and Yates, 1997; Peñuelas et al., 2002; Forister and Shapiro, 2003; Stefanescu et al., 2003; Gordo and Sanz, 2005; Parmesan, 2007) and longer flight periods (Roy and Sparks, 2000; Westwood and Blair, 2010) of Lepidoptera have been recorded from around the world in response to increasing mean monthly temperatures.

The longer the time-series or the more locations analysed, the more species found to be exhibiting a change. In addition to this, species in the north of the country (Co. Donegal) and at higher altitudes (Co. Wicklow) tended to have shorter lengths of flight period even though they also showed earlier first appearance dates. This suggests that the entire flight periods of species in these locations were advancing to an earlier time period in the year. The location in Fota had very few species exhibiting a change in phenology, despite a relatively longer period of trapping. This may reflect the more passive trapping practised at this location, resulting in fewer species and smaller numbers of moths recorded.

Species emerging earlier in the year showed a first appearance date that was advancing faster than that for species emerging later in the year. The earliest spring species advancing the fastest feed on trees and herbaceous plants are dependent on the young growth (buds and leaves) for larval food. The beginning of the growth season had also advanced over time for a number of tree species in Ireland (Donnelly et al., 2006), so moths that depend on these plant species for food must also advance.

Multivoltine moth species in Ireland generally have only two generations a year. With the increased lengthening of the flight period, though, due to delayed last sighting dates, a third generation may now have time to complete development. Species with variable voltinism may soon be moved to the multivoltine category as increased flight periods may allow two full generations to develop in all parts of the country. Increased flight periods in other multivoltine Lepidoptera species have led to increased number of generations in other parts of the world (Altermatt, 2010; Martín-Vertedor et al., 2010).

Most of the Irish species that overwinter in later life stages, such as pupae, were emerging earlier than species that overwinter in earlier life stages, such as eggs. Species that undergo dormancy in the pupal stage emerge in the spring as adults and mate and lay eggs as soon as possible. All of the species that overwinter as pupae feed on trees and herbaceous plants. Their larvae require new plant growth to feed upon, so it is advantageous for species phenology to advance in line with advancing plant phenology (Donnelly et al., 2006).

Irish moths that are monophagous have emergence dates that were advancing faster than species that are polyphagous and feed on a greater number of plant species. Monophagous species need to be highly tuned to the phenology and growth cycles of their limited range of host plants. Most of the monophagous species in this analysis feed on trees and herbaceous plants. Fast phenological advance and early emergence help to guarantee that larvae of these species have fresh young plant material to feed upon.

The majority of significant changes in phenology were correlated with temperatures in late spring, most likely because the majority of species in this analysis emerge during this time period. First and last sightings, and subsequently length of flight period, were significantly correlated with maximum mean temperatures more often than minimum mean temperatures. An increase in maximum temperatures may have allowed the number of degree days needed for a species' emergence from dormancy each year to be reached at a faster rate. Median appearance date, on the other hand, was more often significantly correlated with minimum mean temperatures. Increased minimum temperatures indicate fewer periods that can slow growth and reduce periods of activity. An increase in minimum temperatures may also move the period of peak activity that median appearance date is often used as a proxy for. The lack of significant correlations between most moth species and their food plants or predators does not mean that significant relationships will not develop in the future, just that they are not significant yet.

The majority of moth species examined in Ireland have shown earlier emergence and have a lengthened flight period as a result. Increases in flight period length were more pronounced in multivoltine species, potentially enabling an additional generation to complete development. Moth species feeding on plants that exhibit more of a seasonal phenology in edible parts were emerging earlier than species feeding on grasses. The rising temperatures in late spring (May–June in particular) were shown to have a large significant effect on moth emergence, potentially because most of the species studied emerge during those months. Though moths in Ireland seem to be adapting to a warming climate thus far, strained or broken species relationships may ultimately result. In addition, this collaboration between an amateur naturalists group and a team of scientists allowed for the analysis of an unused source of phenological data, and proved invaluable for the state of knowledge of climate change in Ireland.

**Further reading:** O'Neill, B., Bond, K., Tyner, A., Sheppard, R., Bryant, T., Chapman, J., Bell, J. and Donnelly, A. (2012) Climatic warming advancing phenology of moth species in Ireland. *Entomologia Experimentalis et Applicata* 143,74–88.

## 3.5 Impacts of Climate Change on the Phenology of Birch Pollen Release and other Related Species in Ireland

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**Contributors: John Sodeau[3], David Healy[3], David O'Connor[3], Emily Gleeson[4] and Gerald Fleming[4]**

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### 3.5.1 Background

Birch (*Betula spp.*) pollen released annually during spring causes respiratory problems for the proportion of the population susceptible to hay fever. Birch is one of the most allergenic tree species growing across Europe resulting in allergic rhinitis (hay fever) in up to 20% of the population (Corvalán and McMichael, 2003). *Betula*, a native pioneer tree species, is widely found across Ireland and is commonly used in roadside-planting schemes (Burns et al., 2006).

### *3.5.2 Aims*

This study investigated the start, peak and end of the pollen season at three sites in Ireland and correlated pollen counts with meteorological parameters such as temperature, wind speed and direction, and precipitation.

### *3.5.3 Methods*

Pollen was trapped at three sites in 2010: (i) Baldonnell, Dublin, (ii) Johnstown Castle, Wexford and (iii) Cork Harbour, Cork. The complete spring flowering tree pollen season was trapped at Baldonnell in 2011 which was analysed to assess if there was potential for 'priming', a phenomenon which occurs in related species such as *Alnus*, *Corylus* and *Betula*. Historic birch flowering records from the IPG garden in Johnstown Castle were further analysed to identify if climate change had influenced flowering phenology over time. Peaks in the pollen records were also examined to determine if there were any episodes of Long Range Transport (LRT).

Trapping of the pollen season at the three sites in 2010 in Ireland was conducted using two Volumetric Spore Traps (Hirst, 1952). The third trap, a 'Sporewatch' sampler, was deployed by the Biochea research project, UCC in the Cork Harbour region in 2010. These traps collected pollen and spores on a continuous basis over seven-day periods. The traps had a motorised vacuum pump which suctioned air at a rate of 10 l/min. All airborne particulate matter was trapped on an enclosed rotating drum coated with Vaseline to aid adhesion. This travelled at 2 mm an hour past a 14 mm air inlet. Every seven days this tape was removed and cut into 48 mm sections representing 24 hours. These daily samples were mounted on slides and stained with a Lactophenol and cotton blue stain to aid identification of pollen grains.

The counting technique in use was that recommended by the British Aerobiology Federation (Lacey, 1995). Twelve equidistant transverse traverses were counted on each slide producing bi-hourly counts. These were then multiplied by a correction factor to determine the total number of pollen grains/m$^3$ in each 24-hour period (Eq. 3.3.):

$$N \times \frac{(48\text{mm} \times 14\text{mm})}{(14\text{mm} \times \text{width of one traverse } (0.25) \times 12 \times 7.92)} \text{ grains} = 2.02 \quad \text{(Eq. 3.3)}$$

Where N was the number of pollen grains, 48 mm x 14 mm was the total area of one slide. Fourteen mm was the width of each strip multiplied by the width of a traverse under the microscope. Twelve was the number of traverses on each slide at 7.92 cubic metres of air in 24 hours. For example, 35 pollen grains were counted in total at Baldonnell on day 116 in 2010 (26 April). Applying the correction factor, the daily concentration of pollen grains for that day was 64 grains/m$^3$. Allergic reactions occur when *Betula* pollen counts are 30 grains/m$^3$ or higher (D'Amato et al., 1991). Therefore, on this particular day pollen would have had the potential to cause irritation in those sensitive to hay fever.

### *3.5.4 Results*

In 2010 birch (*Betula spp.*) was trapped at each of the three study sites (Baldonnell, Johnstown Castle and Cork Harbour). The season was deemed to have begun once 2.5% of the total count had been trapped (Nilsson & Persson, 1981). Table 3.5 provides an overview of the counts recorded at all three sites in 2010. The earliest count was recorded at the most southerly site in Cork Harbour on 18 April illustrated in Fig. 3.7.

In 2010 Dublin had the highest volume of pollen with a seasonal total of 1000 grains/m$^3$ followed by 798 grains/m$^3$ at Cork. The lowest seasonal count was recorded at Johnstown Castle with a total of 289 grains/m$^3$. Cork had the highest peak with 260 grains/m$^3$ counted on 24 April. However, Dublin had the highest number of days above the threshold with counts exceeding 30 grains/m$^3$ on 10 days over the days of the campaign.

In 2011 the pollen season for *Corylus, Alnus* and *Betula* was recorded in Dublin (Baldonnell) only as the spore traps were not functioning at the other sites. The results show (Table 3.6 and Fig. 3.8) that the pollen season for *Corylus* and *Alnus* began and ended before *Betula* and on average lasted for a slightly shorter period and produced less grains.

**Table 3.5. Overview of birch (*Betula pubescens*) count in 2010.**

| Site | Start | Peak | Length (in days) | Avg. count grains/m³ | Days > 30 grains/m³ | Total (grains/m³) |
|---|---|---|---|---|---|---|
| Cork | 18 April | 24 April (260 grains/m³) | 32 | 22 | 6 | 798 |
| Wexford | 20 April | 08 May (48 grains/m³) | 25 | 10 | 3 | 289 |
| Dublin | 25 April | 30 April (135 grains/m³) | 30 | 32 | 10 | 1000 |

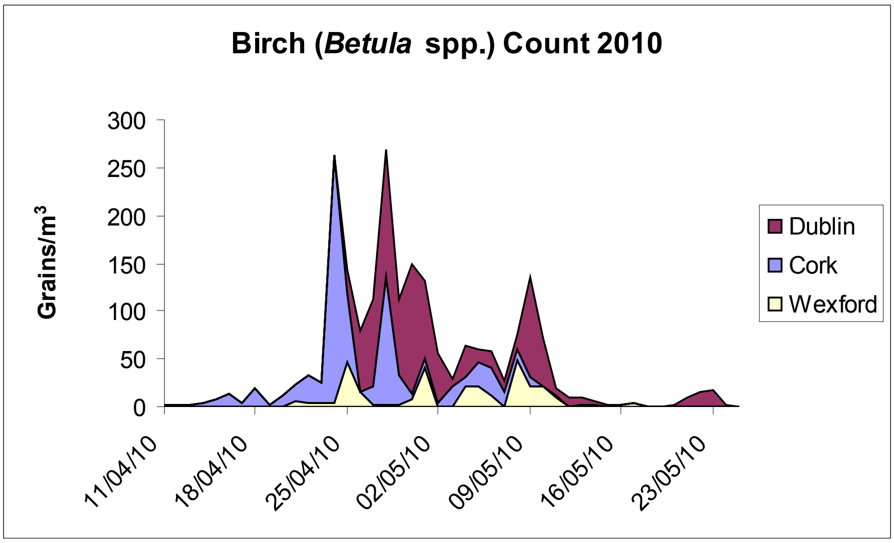

**Figure 3.7. Birch (*Betula spp.*) pollen season 2010.**

**Table 3.6. Overview of pollen count at Baldonnell 2011.**

| Species | Start 2.5% method | Peak | Length (in days) | Avg. daily grains/m³ | Total grains/m³ |
|---|---|---|---|---|---|
| *Corylus* | 31 January | 23 February (53 grains/m³) | 40 | 9 grains/m³ | 408 grains/m³ |
| *Alnus* | 08 February | 02 March (176 grains/m³) | 32 | 30 grains/m³ | 1306 grains/m³ |
| *Betula* | 05 April | 08 April (242 grains/m³) | 40 | 35 grains/m³ | 1605 grains/m³ |

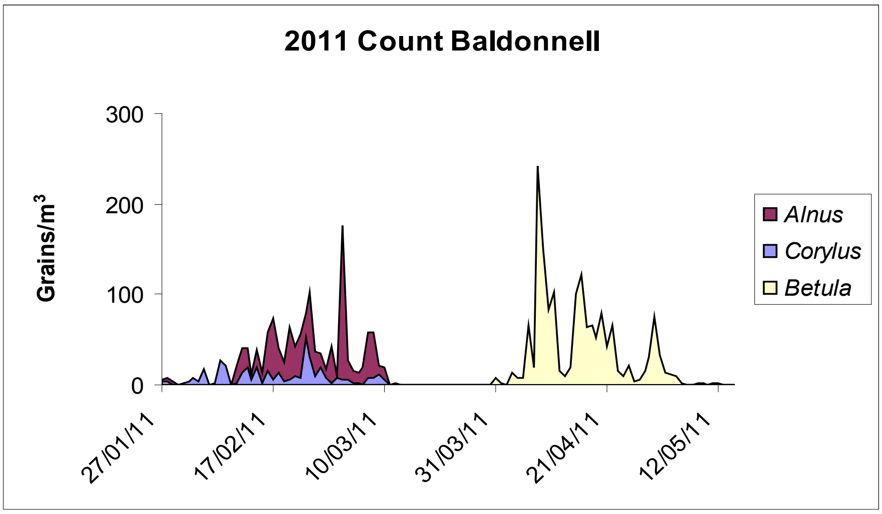

**Figure 3.8. *Alnus, Corylus* and *Betula* count at Baldonnell 2011.**

### *3.5.5 Discussion and Conclusions*

Wind speed has a direct influence on the deposition of airborne matter: low counts occur when speeds are high as dispersal is broader and pollen grains remain suspended for longer periods. During periods of suitable conditions anemophilous trees such as *Betula* will release vast quantities of pollen to ensure adequate dispersal in their locality (Whitehead, 1969). The Dublin site was surrounded by a network of roads connecting the N4 and N7 and relatively close to the M50. These roads were heavily planted with native species such as *Betula*, *Alnus* and *Corylus* which was supported by the high counts recorded at Baldonnell in 2010. In 2011 the *Alnus* and *Corylus* seasons were also trapped, with *Alnus* providing the second highest count (>1300 grains/m$^3$) over the two-year study.

In conclusion, the results indicate that the *Betula* and *Alnus* pollen seasons in Dublin are capable of reaching allergenic threshold levels, which could result in hayfever symptoms in those susceptible to pollen during the flowering periods of these trees. Since these are common trees used in roadside planting, the impact on hay fever sufferers may increase in future and the use of less problematic species should be given due consideration.

## 3.6 Use of Remote Sensing in Phenological Research in Ireland

**Brian O'Connor, Rory Scarrott and Ned Dwyer**

*University College Cork, Coastal and Marine Resources Centre, Cobh, Ireland*

### *3.6.1 Background*

The broad-scale coverage offered by satellite data has been widely used to track spatio-temporal patterns of vegetation phenology of the land surface, in a growing discipline of study known as Land Surface Phenology (LSP) monitoring.

### *3.6.2 Aims*

The aim of this section was to develop a methodology to exploit the potential of satellite-derived vegetation index (VI) data to monitor the vegetation Start of Season (SOS) across the island of Ireland at coarse spatial resolution (>1 km). This was greatly needed as noted shortcomings in the class nomenclature and classification approach were noted in the most recent detailed land cover map of Ireland, CORINE Land Cover (CLC) 2006. A second aim was to perform a feasibility study to assess the potential of using a time-series of higher spatial resolution satellite data to characterise Irish land cover based on vegetation seasonality differences. Central to these two aims was the use of the time-series analysis tool, TIMESAT, developed at the University of Lund, Sweden, where Brian O'Connor was hosted for a study period. The TIMESAT method allowed full reconstructions of surface spectral changes, even in the presence of data gaps due to cloud and signal noise. This was done using model curve fits from which seasonality metrics can be extracted per satellite image pixel. The method yielded modelled values of the input VI data from which seasonality metrics could be extracted.

### *3.6.3 Methods*

Two satellite-derived VI datasets were used in this study while an independently derived set of higher spatial resolution satellite imagery was used for verification purposes. Firstly, the reduced resolution (1.2 km) MERIS Global Vegetation Index (MGVI) was obtained from the Joint Research Centre (JRC) via the European Space Agency (ESA), European Space Research Institute, Grid Processing on Demand (G-POD) service. Secondly, the 250-m spatial resolution 16-day composite MODIS EVI was obtained from the NASA WIST service for 2006. The Image 2006 dataset composed of SPOT and IRS imagery was also obtained from the ESA.

The MGVI data were initially time-composited in 10-day and 7-day time composite periods as they were considered as potentially optimal for tracking the SOS across the island in the presence of cloud cover. Criteria based on ground-based observations of spring greening and cloud cover at representative point locations on the island were used to guide the composite period selection. The appropriate period was selected after the proportion of cloud-covered pixels which exceeded a 10% threshold in 7-day and 10-day composites of the MGVI imagery from March to June 2006 was compared (O'Connor et al., 2008). The time-composited, 7-year MGVI time-series data were processed with TIMESAT, fitting an asymmetric Gaussian curve. The SOS metric was then extracted per pixel to produce gridded SOS estimates covering the whole island. While the SOS was the only metric extracted from the MGVI time series, the full range of seasonality metrics was extracted from the EVI time-series as well as the fitted EVI curve (modelled) values themselves.

In order to examine the spatio-temporal patterns in the SOS imagery with respect to land cover, the 7-year mean SOS from 2003 to 2009 was calculated from an arithmetic average of the annual 10-day SOS estimates. The CLC 2000 for Northern Ireland and CLC 2006 for the Republic of Ireland were combined to produce a national-scale land cover image, used to extract SOS values for each land-cover class. To determine if SOS values per land-cover class exhibit statistically significant differences, the non-parametric Kruskal-Wallis (KW) test was carried out on the 2006 SOS estimates categorised by land cover type. The significance level was adjusted for multiple pair-wise comparisons of median SOS per land cover type by the Bonferroni method. Statistically similar land cover types (p-value > 0.05) were then grouped together and the interannual and intraannual variation in SOS examined per group. Annual SOS anomalies were also calculated in 10-day periods per pixel to illustrate graphically the spatio-temporal variability in the SOS across the country.

An SOS-climate correlation study was also carried out using air temperature as a climate variable. Monthly and seasonal mean air temperature values were calculated from gridded daily mean temperature values provided by Met Éireann for the Republic of Ireland (ROI). The spring mean temperature was derived from the average monthly temperature from February to April as has been done in previous ground-based studies (Donnelly et al., 2004). Winter temperatures were taken as an average of the previous three months (November–January). A Spearman rank order correlation analysis was carried out on the SOS and monthly and seasonal mean air temperature values for the 7-year period, testing the null hypothesis that there is no correlation between the SOS metric and air temperature.

Regarding the MODIS EVI dataset, the TIMESAT-modelled EVI pixel values were clustered using a data-driven approach (an adapted ISODATA clustering algorithm proposed by de Bie et al., 2008), which has been optimised to aid the user to select the optimum number of clusters to represent the variability in time-series datasets. Clusters were then analysed to ascertain their inter-cluster distinctiveness using a Jeffries-Mathusita (JM) Index measure (Swain & Davis, 1978) of spectral separability with a threshold value set to 1400. The composition of the seasonality clusters was then verified using CLC2006 for the Republic of Ireland.

### 3.6.4 Results

Less than 10% cloud cover was achieved on 77% of the 10-day composites, compared with 50% of the 7-day composites. Therefore a 10-day composite period was selected as there were likely to be fewer data gaps

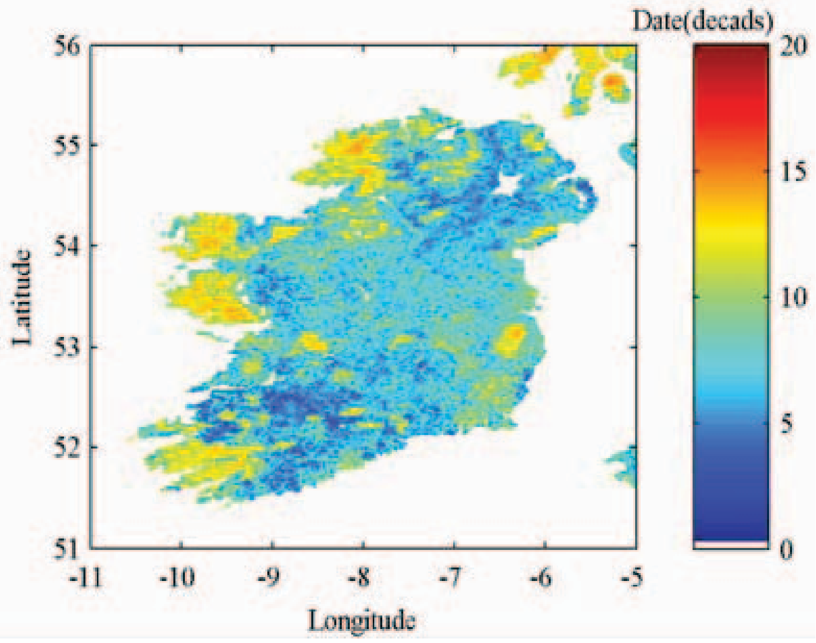

**Figure 3.9. The 7-year mean start of season (SOS) estimated from the asymmetric Gaussian fitted functions. Time is in 10-day periods from 1 (1–10 Jan) to 20 (10–19 Jul) where 0 is no data.**

due to cloud in 10-day imagery than in 7-day imagery. Subsequently, a 7-year time-series of 10-day MGVI composites from January 2003 to December 2009 was processed in TIMESAT. There were consistent spatial patterns on an interannual basis in the SOS imagery which can be best seen in the mean 2003–2009 image in Fig. 3.9. Although the spatial link between the SOS and land-cover patterns was suggested by visual analysis of spatial patterns, statistically significant differences (KW, H = 14414, 12 df, $p<0.05$) were also found between median SOS dates per land-cover class in 2006. Generally, cultivated and non-cultivated vegetation types were grouped separately while some land-cover types, for example coniferous forest, green urban areas and natural grasslands which exhibit contrasting phenology cycles, were grouped together based on similarities in their SOS.

The MODIS EVI pixel clusters also exhibited similarities in spatial distribution and size to the CLC 2006 dataset for the Republic of Ireland. However, there were also clusters exhibiting different seasonality patterns found within the CLC classes themselves. Altogether, 38 land cover clusters of spectrally separable vegetation type were found. Five statistically unique seasonality clusters were identified across the island, as well as five statistically distinct groups of clusters from the JM threshold analysis. Interestingly, clusters which exhibited a distinctive double growing season were found to occur within some CORINE 'pasture' class areas (Fig. 3.10). It is hypothesised that this subclass is characterised by the silage cutting indicative of intensive grassland management.

The Spearman maximum rank correlations of SOS-monthly air temperature varied in strength, timing and significance level when mapped per pixel across the ROI (Fig. 3.11). However, there are contrasting patterns in the maximum rank correlations as there are negative correlations in the south, south-east and parts of the west and north-west and positive correlations in the south-west, midlands and along the Northern Ireland border. The monthly timing of these correlations also varies with location. For example, the winter correlates tend to be strongest in the south and south-east, with spring correlates strongest in the west and south-west. These tendencies agree with general climate patterns in Ireland as milder temperatures are experienced in the south-east of Ireland and SOS responds strongly to winter (December, January and February) rather than spring (March, April and May) temperature as a result. In contrast, the SOS in western and north-western areas, with their associated cooler temperatures, is more responsive to spring temperature.

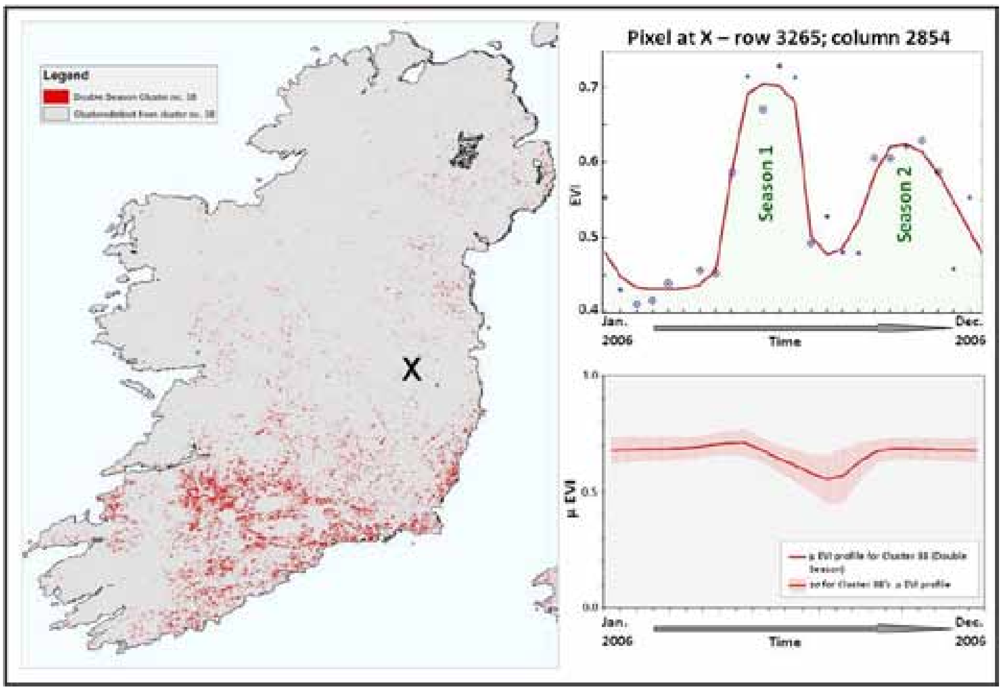

**Figure 3.10. The distribution and characteristic seasonality feature of the double-season cluster.**

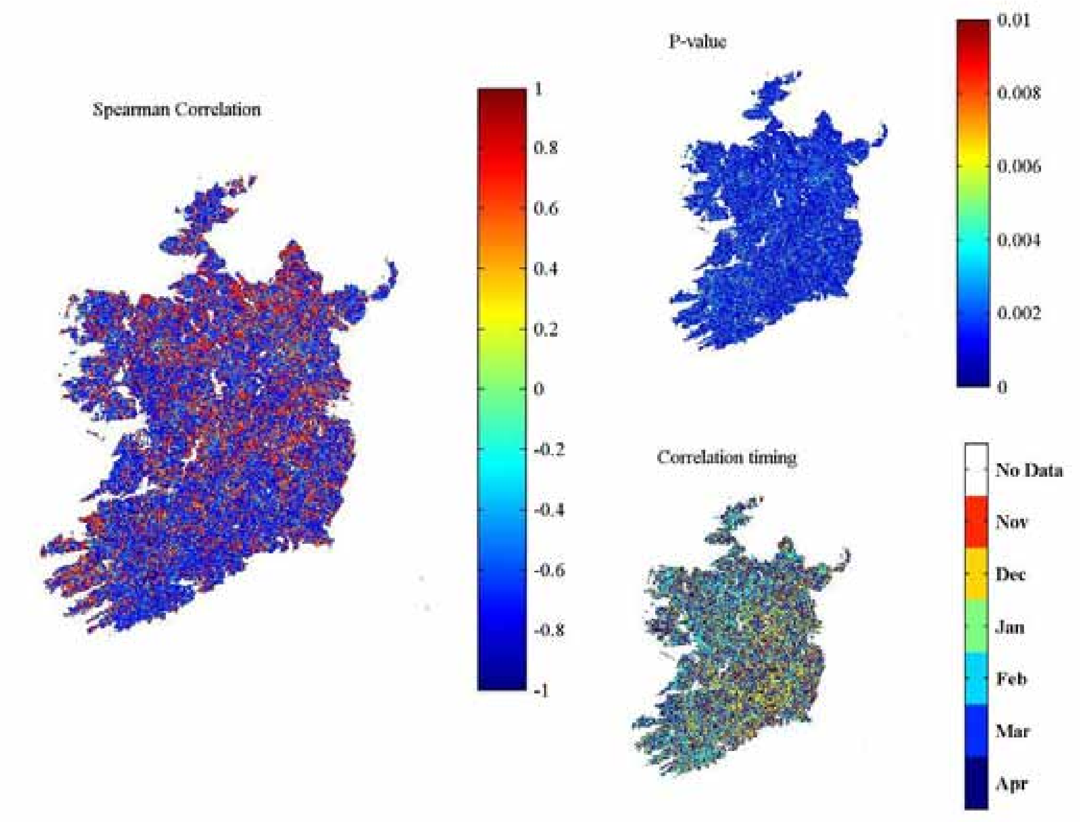

**Figure 3.11. (Left) magnitude of the maximum rank correlation between SOS and mean monthly air temperature. (Top right) *p* value of the maximum rank correlation (Bottom right) Timing of the maximum rank correlation (month).**

### *3.6.5 Discussion and Conclusions*

Cloud cover over Ireland necessitated the use of 10-day time composites of VI data so that enough cloud-free imagery could be obtained for a national-scale study. It was therefore appropriate to report SOS estimates to a 10-day period. To estimate the day of year would suggest a level of accuracy which was not present in the input data, while ensuring that relative comparisons of spatio-temporal patterns at the national scale still remained legitimate. However, it must be noted that the combined effects of time compositing and the temporal smoothing inevitably added uncertainty to the estimation of SOS dates.

Satellite estimates of SOS in this study differ considerably from ground observations. For example, spring and summer phenological phases observed in Europe between 1951 and 1996 have advanced by 2.5 days per decade (Menzel et al., 2006) while observations of leaf unfolding in Britain and Ireland based on observations from 1969 to 1998 revealed a six-day per decade advancement (Cannell et al., 1999). Therefore, it is difficult to observe changes of a fraction of a day per year with a time resolution of 10 days, particularly in Irish climates with widespread cloud cover during spring. Nevertheless, the SOS results do successfully indicate relative spatio-temporal variation in SOS across the country on an annual basis.

The inter-relationships between vegetation indices, land cover and land surface phenology were explored in this work. Time-series of two vegetation indices at different spatial and temporal resolutions revealed land-use as well as land-cover patterns across the island of Ireland. The SOS can be used as an indicator of spatio-temporal variability in vegetation phenology, as well as a correlate of other environmental variables such as air temperature. The full profile of vegetation index values per season can also be used to derive spatial land-cover patterns, and can potentially be used as a method to detect land-use patterns at equivalent spatial scales to CORINE.

**Further reading:** O'Connor, B, Dwyer, E., Cawkwell, F. and Eklundh, L. (2012) Spatio-temporal patterns in vegetation start of season acrsss the island of Ireland using MERIS Global Vegetation Index. *ISPRS Journal of Photogammetry and Remote Sensing* **68**, 79–94.

## 3.7 Overall Conclusions

This section has demonstrated clearly the influence of temperature on leaf unfolding and the wealth of phenological data that exists in Ireland with which to establish the impact of warming on the environment. Data from a range of species groups, plant, bird and insect and at a range of scales from local to national were used. Evidence from herbarium material, records of direct observations of phenophases and landscape greening indicate a clear trend, which suggests an advance in spring phenology in response to rising temperature. However, this response proved to be species specific so care must be taken when extrapolating the data to large geographic areas.

# 4 Experimental Analyses for the Validation of Phenological Modelling

This section summarises a series of controlled environment experiments that were designed to provide data to advance, validate and calibrate established phenological models of bud burst in birch. The phenological models were driven with future temperature projections to obtain bud-burst dates in birch up to 2100 at four locations in Ireland. In addition, the projections were spatially displayed for the entire country.

## 4.1 Quantification of the Effects of Summer–Autumn Temperature and Photoperiod on Bud Burst

**Annelies Pletsers[1], Amelia Caffarra[2] and Alison Donnelly[1]**

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### 4.1.1 Background

Bud dormancy is an essential part of the phenology of trees in temperate regions, where survival depends on the ability to cease and resume growth according to seasonal environmental variations. For most tree species, dormancy is induced mainly by short photoperiods during late summer and autumn (Håbjørg, 1972; Heide, 1974), while the breaking of dormancy is mainly triggered by winter chilling temperatures (Sarvas, 1974; Champagnat, 1993). Insufficient chilling during warm winters causes the endo-dormancy phase to extend and decrease more slowly (Sarvas, 1974; Cannell and Smith, 1983). Besides temperature, photoperiod also plays a role in dormancy release, especially in higher latitudes where the need for a long photoperiod for bud burst acts as an insurance against temperature-induced break of dormancy too early in the season (Körner, 2006).

Overall, bud development in temperate trees is controlled by a combination of: (i) chilling (temperature and duration), (ii) photoperiod and (iii) spring temperatures or forcing temperatures. The interactions between these factors and the differences between (and within) species require further clarification, which makes predictions of phenology responses to a warmer climate challenging. Furthermore, the interactions between photoperiod and temperature are not fixed, meaning that particularly warm temperatures can partially override photoperiod controls, and particularly long days can partially override chilling requirements (Heide, 1993; Caffarra et al., 2011). Since the timing of phenological events has an effect on the survival and reproduction of trees, selective pressures are at play and the responses measured are ultimately the results of adaptation to particular environments. Different species are therefore to be expected to have different phenological responses, which are important to understand for estimating the impacts of climate change at ecosystem level. However, most experimental studies focus on a single species (Håbjørg, 1972; Heide, 1993; Li et al., 2003). Here, bud burst is investigated in two native European and native Irish species, *Populus tremula* (European aspen) and *Betula pubescens* (downy birch).

### 4.1.2 Aims

The aim of this study was to quantify the primary effects and interactions of temperature (in the form of chilling) and photoperiod on the percentage and timing of bud burst in *B. pubescens* and *P. tremula*, using controlled environment experiments. The results will form part of the framework for use in process-based phenological models. Furthermore, the results will have implications for forestry and conservation, because as winter temperatures become milder due to climate change, critical chilling thresholds might therefore not be reached in the future.

### 4.1.3 Methods

The birch trees used in the experiments were juvenile trees (height between 30 and 45 cm) that were propagated in 2003 and 2004 (Caffarra and Donnelly, 2010) and kept outdoors in 1l plastic pots at the Trinity College Botanic Gardens, Dublin and subsequently at Teagasc Horticultural Centre in Kinsealy. The aspen trees were commercially cloned juvenile trees purchased from Cappagh nurseries (Aughrim, Co. Wicklow, Ireland;

EU Plant Passport 7238). The clones were propagated from root cuttings and were grown outdoors at the site of the nursery. For the experiments, the 3- to 4-year-old trees with heights between 80 and 120 cm were transplanted into plastic pots with diameter of 15–20 cm containing John Innes No. 3 compost, and were kept at Teagasc Horticultural Centre in Kinsealy. Experimental conditions were created in growth chambers (Conviron PGR15 and Conviron A1000) at TCD. Bud burst was defined as the first appearance of green leaf tips from between the opening bud scales.

The test statistics used were based on standard ANOVA. One of the conditions for ANOVA is that observations should be independent, while bud burst is intrinsically not independent within a single tree: a particular bud is more likely to open when other buds on the same tree have already flushed, since dormancy release has set in. Both experiments in this study involved repeated measures within-subjects (bud burst in the same individual trees) as well as a between-subjects design (created by the independent variables *chilling duration* and *photoperiod*). Therefore, variations on standard ANOVA were used: (i) repeated-measures ANOVA and (ii) mixed between-within subjects ANOVA (also known as a split-plot ANOVA) were carried out.

### 4.1.4 Results

#### 4.1.4.1 Experiment 1

In Fig. 4.1, the response variable on the Y-axis BBD (days to bud burst) refers to the timing of bud burst of all recorded data points. Figure 4.1a and 4.1b show a clear difference in timing between the two chilling conditions in both species: bud burst was earlier in fully chilled trees (white boxes) than in partially chilled trees (grey boxes), and there were no overlapping values of BBD, except one outlier in the shortest chilling and photoperiod condition in *P. tremula* (Fig. 4.1b). From the size of the boxes, it is also apparent in Fig. 4.1 that there was greater variation in the response variable BBD for the partially chilled trees compared to the fully chilled trees, in both species (Fig. 4.1a and 4.1b). There is not a great variation in response between photoperiods. However, the days to bud burst was lower for the plants under long photoperiod after partial chilling in *B. pubescens* (Fig. 4.1a), which might affect the significance of the influence of photoperiod on the timing of bud burst. Whether there is a significant effect is tested further on in this chapter. A few outlying values of bud burst timing were recorded, indicated by the dots outside the boxes. For *P. tremula*, a high variation was found in the shortest chilling condition (Fig. 4.1b, grey boxes), yet not many data points were recorded, since the frequency of bud burst within the monitoring time was extremely low. In 12 hours of daylight for instance, only 2 buds flushed across the five trees in this condition.

Comparing the means and standard deviations of both species in their timing of bud burst after transfer into growth chambers, birch had lower chilling requirements than aspen: after receiving the same chilling temperatures and duration, bud burst was on average earlier for birch than for aspen.

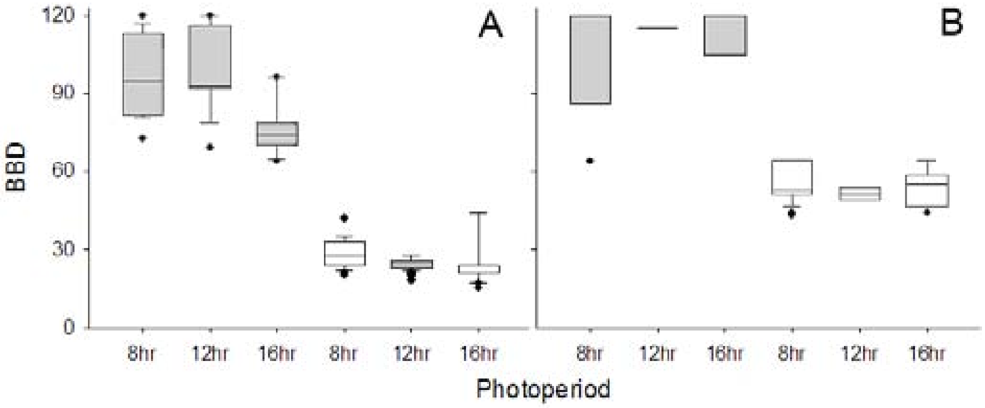

**Figure 4.1. Box plot of days to bud burst (BBD) of *B. pubsecens* (A) and *P. tremula* (B) in Experiment 1 (10°C forcing temperature), separated by photoperiod and chilling condition (grey boxes: partially chilled, white boxes: fully chilled). Horizontal bars within the boxes represent the median. Outliers (dots) are shown in the 95th/5th percentile.**

Per chilling unit, *B. pubescens* reached bud burst faster than *P. tremula*: per chilling unit (received before transfer to experimental conditions), 1.26 days were needed to accomplish the average bud burst date for *B. pubescens* after partial chilling, while *P. tremula* needed longer (1.86 days per chilling unit). For fully chilled plants, *B. pubsecens* reached bud burst on average after 0.2 days per chilling unit, while *P. tremula* buds burst occurred after 0.52 days after transfer.

The percentage of bud burst at the end of the experiment varied quite substantially between the two species. Nearly all birch trees reached 100% bud burst at the end of the monitoring period, while aspen trees had a much slower response. None of the aspen trees reached the stage of 50% bud burst within the monitoring period for the partially chilled conditions, while fully chilled aspens did show a greater bud burst response of between 60 and 85%.

Bud burst occurred sufficiently in *B. pubescens* to carry out this additional statistical test. The independent variables (fixed effects) were: (i) chilling (C), (ii) photoperiod (P), and (iii) level of bud burst (BB). The random effect was the individual subject, or tree in this experiment (considered as a random sample), and the response variable was the days to each level of bud burst. The question of interest was whether the individual trees showed a different change in bud burst over the three stages for the different treatments. For the between-subjects multivariate test a Wilks' Lambda statistic was used, which showed there was a significant interaction between bud burst and chilling ($p<0.05$). The interaction between chilling and photoperiod was not significant. There was a substantial main effect for level of bud burst and for chilling ($p<0.001$), and also a significant influence of photoperiod ($p<0.05$), indicating that the birch trees needed a significantly different number of days to reach each stage of bud burst, and this difference was due to the different chilling and photoperiod treatments. A significant interaction between level of bud burst and chilling was found ($p<0.001$), and also an interaction between all three variables tested ($p<0.05$), although the effect of photoperiod on days to each level of bud burst is minor, indicated by the non-significant p-value of interaction between level of bud burst and photoperiod ($p=0.177$). This implies that the trees responded differently to the chilling conditions for different levels of bud burst: for instance, chilling had a more significant effect on the 100% bud burst level than on the other two levels of bud burst in *B. pubescens*.

### *4.1.4.2 Experiment 2*

Figure 5.1.2 presents all BBD recorded for *B. pubescens* (Fig. 4.2a) and *P. tremula* (Fig. 4.2b) in Experiment 2. From this figure, it is clear that bud burst occurred earlier with increased chilling duration for both species: buds that received the least amount of chilling (data in grey boxes in Fig. 4.2) flushed later than buds with intermediate chilling (white boxes) and much later than buds with most chilling (patterned boxes). Also the length of the photoperiod received during forcing conditions had a possible effect on the timing of bud burst, with earlier bud burst for buds under a longer photoperiod, although this trend is not present in the condition with longest chilling duration (patterned boxes in Fig. 4.2), or for trees with the shortest chilling condition in *B. pubescens*: here, bud burst occurred earlier under shorter photoperiod (10hr) than under longer photoperiod (16hr). The trees in this treatment (10 hours of daylight and minimal chilling duration) received a heat shock due to mechanical failure. No visible trends can be noticed in the variation (box sizes) within each of the conditions (Fig. 4.2A and B).

The average number of days to bud burst was 52 days for the accidental heat shock (46 chilling units and 10 hours of daylight) condition to *B. pubescens*, with a standard deviation of 13. More variation in days to bud burst was observed in *P. tremula* than in *B. pubescens*. The mean bud burst date was generally slightly later in *P. tremula* compared to *B. pubescens*, except for the longest chilling duration, where the difference in mean days to bud burst was not very clear.

A great difference can be detected between percentage of bud burst in the minimal chilling condition and intermediate and maximal chilling. Percentage of bud burst is noticeably lower compared to the other two conditions, except for the short photoperiod condition (10 hours of daylight) in *B. pubescens*, which is the condition with heat shock treatment. Because the monitoring period was unusually long compared to other publications reporting on similar experiments (Caffarra and Donnelly, 2011; Ghelardini and Santini, 2009; Heide, 1993; Myking and Heide, 1995), a cut-off time was decided on 60 days in further analyses comparing bud burst percentages in the different treatments.

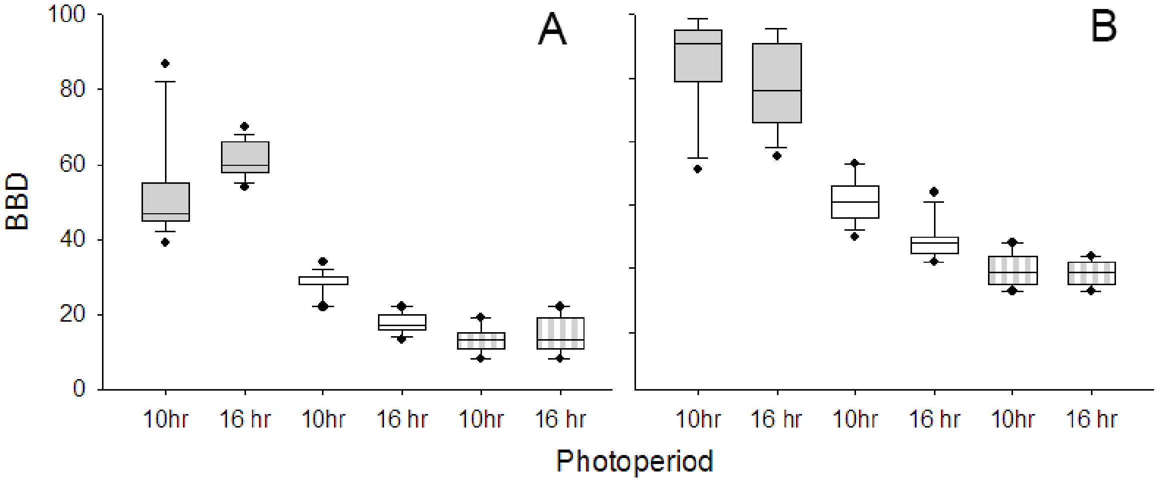

**Figure 4.2. Box plot of days to bud burst (BBD) of *B. pubescens* (A) and *P. tremula* (B) in Experiment 2 (20°C forcing temperature), separated by photoperiod length and chilling duration (grey boxes: minimal chilling, white boxes: intermediate chilling, patterned boxes: full chilling). Horizontal bars within the boxes represent the median. Outliers (dots) are shown in the 95th/5th percentile. Far left box in A: heat shock treatment.**

#### *4.1.4.3 The effect of chilling and photoperiod on percentage of bud burst*

Percentage of bud burst at 60 days of monitoring (PB) was subjected to a factorial 2-way ANOVA with fixed effects photoperiod (P), chilling duration (C) and their interaction (P x C). In order for the response variable PB to meet normality, the arcsine transformation was applied to the percentage bud burst data.

#### *4.1.4.4 Level of bud burst*

First bud burst, 50% bud burst and 100% bud burst were analysed using univariate two-way ANOVA with chilling and photoperiod as factors for each stage, species and experiment separately. The equality of variances was tested using a Levene's test of equality, and confirmed for most ANOVAs. The equality of variances could not be assumed for *B. pubescens* in Experiment 2 (1st bud burst and 50% bud burst). Moreover, the groups were uneven in these tests, since the heat shock treatment was not part of the analysis. Therefore, all birches in this chilling condition were removed from the analysis, and degrees of freedom changed from 2 to 1 for chilling. Significant p-values for the effect of all three factors on the timing of first bud burst were found for *B. pubescens* in Experiment 2. However, none of the three factors were significant for the date of first bud burst in this species in Experiment 1. Also for *P. tremula*, a significant influence of chilling was discovered on 1st bud burst date in Experiment 2, which was not present in Experiment 1. For 50% bud burst, a stage often recorded in phenological monitoring programmes, there was a significant effect of photoperiod for *B. pubescens* in Experiment 1 and for *P. tremula* in Experiment 2. Chilling duration had a significant influence on the timing of the stage of 50% bud burst for both species in Experiment 2. In all analyses, missing values (non-flushing buds) were considered as flushing after the recording time of the experiment, except for *P. tremula*, in Experiment 1, where bud flush was extremely rare after the shortest chilling duration. Therefore, the effect of chilling duration could not be measured for 50% and 100% bud burst in Experiment 1. In Experiment 2, however, the higher forcing temperature resulted in a higher percentage of bud burst, even after shorter chilling durations, and both chilling and photoperiod had significant effects on the timing of 50% bud burst and 100% bud burst for *P. tremula*. However, the condition with shortest chilling duration in Experiment 2 had to be omitted from the 100% bud burst analysis for *P. tremula* due to the low number of plants reaching this stage, again resulting in 1 degree of freedom for the chilling factor. *B. pubescens* reached 100% bud burst at a timing that was influenced by chilling and photoperiod in both experiments and by interaction of both effects in Experiment 1.

##### *4.1.4.5 Effect of chilling on thermal time to bud burst*

Bud burst is expressed in thermal time instead of days to bud burst, since different forcing temperatures were used in Experiment 1 (10°C) and Experiment 2 (20°C). A detailed and meaningful statistical test cannot be carried out on all these data together, because a different number of plants were used in each condition and a different number of chilling and photoperiod condition, which makes for an unbalanced design. However, it is clear that overall chilling duration has an effect on the timing of bud burst in the three stages: (i) 1st bud burst, (ii) 50% bud burst and (iii) 100% bud burst. Thermal time to bud burst was reduced for longer chilling periods for all stages, even though chilling was more frequently a significant factor on the timing of the different stages of bud burst in Experiment 1 than in Experiment 2.

##### *4.1.4.6 Overall effects of chilling and photoperiod on days to bud burst*

For testing the between-subjects (between trees in these experiments) effects of chilling and photoperiod on the timing of bud burst, a mixed between-within subjects ANOVA was performed for Experiment 1 (where days to bud burst was recorded only at three stages of bud burst) and a repeated-measures ANOVA for Experiment 2 (with continuous measurements of days to bud burst). The difference between both tests in this case is days to bud burst in Experiment 1 is regarded as a ‘score’ at a certain level (1st bud burst, 50% bud burst, 100% bud burst), and in Experiment 2 as a continuous response. Earlier, the within-subjects effect of chilling and photoperiod on the level of bud burst was determined, while here the interest lies also in the effect between the trees. An advantage is that when using a mixed-effect model missing values are not a problem, while individuals with missing data were removed from the within-subjects ANOVA.

### *4.1.5 Discussion and Conclusions*

An overall decrease in time to bud burst with increasing duration of chilling was found in both Experiment 1 as in Experiment 2 and for both species *B. pubescens* and *P. tremula*. This confirms previously found results (Heide, 1993; Murray et al., 1989) and is an indication that dormancy release, as with dormancy itself, is not a state in which a plant can be at a certain time, but involves continuous physiological changes within the plant.

In Norway spruce, chilling duration had no effect on the ability of the trees to emerge from bud dormancy, although bud burst was advanced with longer chilling durations (Søgaard et al., 2008). In this study, the *B. pubescens* trees were all released from dormancy as well; however many of the *P. tremula* clones failed to do so.

Long photoperiods had an effect on time to bud burst after short photoperiods (reducing the number of days to bud burst). However, this effect disappears when chilling requirements are fulfilled. This conclusion follows previous findings such as in *B. pubescens* and *B. pendula* clones (Myking and Heide, 1995).

## 4.2 Predicting Changes in Bud Burst Phenology under Climate Change Scenarios for Ireland through Use of Models

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### *4.2.1 Background*

Phenological models are important tools for the simulation of key phases in the annual cycle of trees, such as bud burst, leaf unfolding and flowering. Year-to-year variations in tree phenology are indeed responsible for large differences in forest productivity and carbon sequestration. The beginning and end of the flowering phase of allergenic species are also important phases, affecting people suffering from allergies. However, the difficulty in obtaining phenological models providing accurate predictions on a regional scale prevents them from reaching their full application value.

### *4.2.2 Aims*

The aim of this work was to obtain a robust phenological model for photoperiod-sensitive species using birch (*Betula pubescens*) as a model species, and apply it to climate change scenarios. This involved the development, calibration and validation of a phenological model, including photoperiod, building on the previous results of Caffarra et al. (2011a&b). The resulting model (DORMPHOT model) was used to project future birch bud burst in Ireland and is currently being calibrated to simulate the beginning and end of flowering.

### 4.2.3 Methods

#### *4.2.3.1 Model development*

Caffarra et al. (2011a&b) investigated the individual effects and interaction of temperature and photoperiod on the rates of dormancy induction and release in birch through a series of controlled environment experiments in order to develop a conceptual model of dormancy for this species. The experiments were conducted on the *B. pubescens* clone grown in the IPG network. The results showed that photoperiod affected the timing of bud burst only if coupled with warm, forcing temperatures, suggesting that photoperiod affected forcing rate rather than chilling rate. These findings were summarised in Caffarra et al. (2011a) in a study proposing a framework laying the foundation for the formalisation of a model explaining birch bud burst in terms of temperature and photoperiod. The effects of photoperiod and temperature were integrated into an existing model (the Unified model by Chuine, 2000) at two levels: first, photoperiod, in interaction with temperature, affects the course of dormancy induction. Secondly, photoperiod modifies the response to temperature during the phase of forcing. The resulting model (DORMPHOT) has 11 parameters and simulates the day of bud burst given mean daily temperature and photoperiod. Its structure is shown in Fig. 4.3.

#### *4.2.3.2 The DORMPHOT model: calibration and validation*

The resulting model (DORMPHOT) for the simulation of birch bud burst was calibrated and validated on seven datasets from four different European countries. In order to avoid model over fitting, experimental information to restrict or fix possible parameter values to biologically realistic values was used and a large phenological dataset including data from different countries and latitudes (Table 4.1) during model calibration. The optimisation algorithm adopted was the 'Metropolis algorithm', a simulated annealing method that is often used successfully with phenological models. The introduction of photoperiod made it necessary to fit the model on a dataset containing data from different latitudes, for a realistic adjustment of parameter values. The dataset used to fit the parameter estimates included the IPG birch dataset from Valentia (Ireland; n=24) and data taken randomly from the IPG datasets of Bergen (Norway; n=6), Freiburg and Wulfsdorf (Germany; n=6 for both). The total number of years of the combined dataset was 42. Parameter estimates of the model are shown in Table 4.1.

The model was validated on several datasets from the IPGs. Their sites of provenance were Johnstown Castle and JFK Arboretum (Ireland, n=24 and 10, respectively),

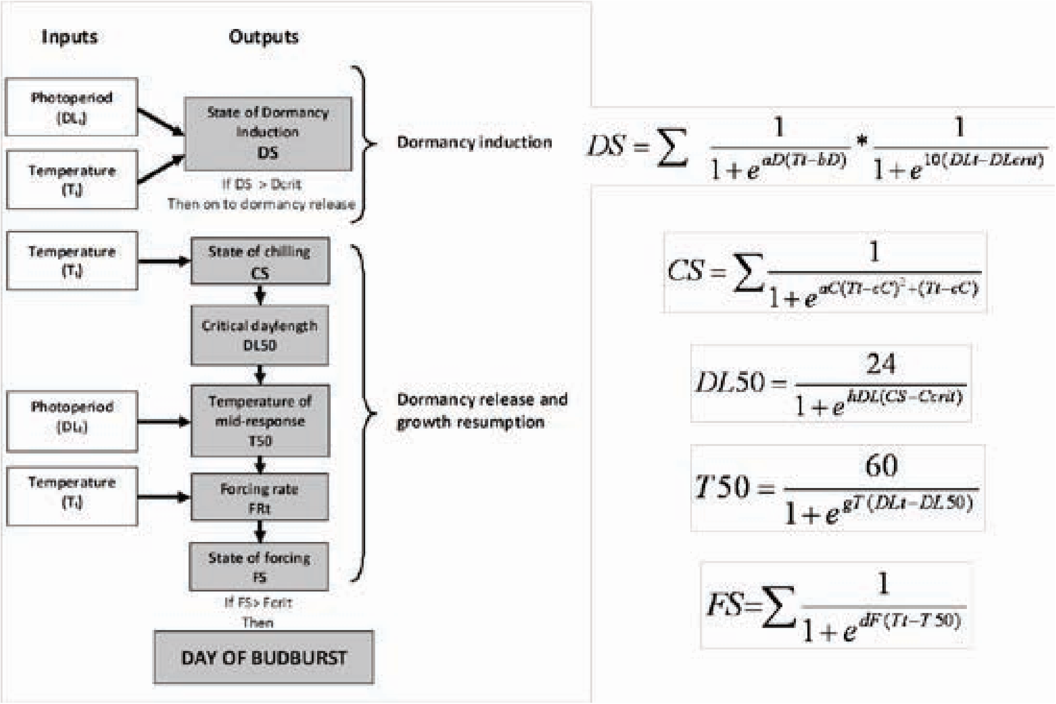

**Figure 4.3. Conceptual schematic and equations of the DORMPHOT model. White boxes: inputs required during the execution of the algorithm. Grey boxes: outputs generated as a function of input variables and previous outputs during the different stages of the algorithm, and final output 'day of bud burst'.**

Bergen (Norway, n=7), Freiburg, Munchen, Wulfsdorf (Germany, n=26, 17 and 24, respectively) and Zurich (Switzerland, n=9).

**Table 4.1. DORMPHOT model parameter estimates.**

| DORMPHOT PARAMETERS | |
|---|---|
| aD | 0.489 |
| bD | 15.135 |
| aC | 0.030 |
| cC | 13.89 |
| dF | -0.174 |
| gT | 0.1718 |
| hDL | 10 |
| Dlcrit* | 13 |
| Dcrit | 37.4 |
| Fcrit | 40 |
| Ccrit | 55.349 |

For comparative purposes the model's performance was compared with three other widely used phenological models (Unified model, Uniforc model, and linear regression model), which were calibrated and validated on the same phenological datasets.

Model performance was evaluated by their Modelling Efficiency (ME) (ME = $(SS_{tot}-SS_{res})/SS_{tot,}$ where $SS_{tot}$ is the sum of the squared deviations of the observations from their mean, and $SS_{res}$ is the sum of squared residuals of the model fit) and by the Mean Absolute Error (MAE). As one of the aims of the developed model was to forecast plant phenology in a warming climate, the model accuracy in warm years was evaluated with the 'Warm year Index' (WI), as described by Caffarra and Eccel (2009). For each validation site the three years with the warmest February–April period were selected, averaged the mean absolute errors given by the tested models in those years.A comparison between models performance was then made.

### 4.2.3.3 *Projections of bud burst under climate change scenarios*

The DORMPHOT model was applied to climate change scenarios at the four long-term Irish IPG (Valentia, Johnstown Castle, JF Kennedy Park and the National Botanical Gardens) sites. Projections utilising the temperature output from the 21 climate simulations at the locations of the four IPG sites were oextracted. All simulation weights were equal for this analysis. Projections were back cast and forecast with mean daily temperature from each simulation. The individual outputs from the 21 simulations were then averaged for each of the four sites.

### 4.2.3.4 *Mapping future bud burst of birch in Ireland*

As the DORMPHOT model was developed to draw simulations at the point level, the whole algorithm was restructured to calculate daily maps of the thresholds triggering each stage of dormancy in Ireland. The inputs are daily maps of photoperiod and temperature. Three decades (1991–2000, 2021–2030, 2051–2060) of the A1B scenario of C4IRCA3, HadCM3Q16_DM ENSEMBLE model were used. The spatial resolution of temperature maps is 15 minutes of arc degree, so that Ireland is fully covered with 245 pixels. This resolution was considered too coarse to catch the spatial variability in simulated bud burst date. As no downscaled temperature data were available, a regression downscaling algorithm was used on ENSEMBLE input data: daily stepwise regression was performed using position, elevation and distance from the sea as explanatory variables. Bilinear interpolation was used when no significant trend ($p\text{-value}<0.05$) with a minimum $R2=0.5$ was found. The Digital Elevation Model adopted was the SRTM v4: the original resolution of three seconds of arc degree (16439850 pixels) was re-sampled to one minute arc degree (43349 pixels) to decrease computation time while still retaining the morphological variability of the spatial domain. Photoperiod maps with the same resolution were calculated using the SOLPOS algorithm (US National Renewable Energy Laboratory; http://rredc.nrel.gov/solar/codesandalgorithms/solpos/).

### 4.2.3.5 *Calibration of the DORMPHOT model for birch flowering in natural populations*

The DORMPHOT model was previously calibrated on flowering of IPG birch, but in order to reflect the variability of flowering in natural populations and to simulate the future pollen season aerobiological data in Ireland and the UK were sought. The DORMPHOT model is currently being calibrated on flowering of natural birch population, using aerobiological data obtained from the National Pollen and Aerobiology Research Unit of the University of Worcester (Dr Matthew Smith), as no data of this type were available in Ireland. The data consist of the dates of beginning, end and peak of birch pollen at two sites in the UK

**Table 4.2. Performance of the four models on the validation datasets.***

| Site and no. of years with observations | ME |  |  |  | MAE |  |  |  | WI |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | LIN | DP | UF | UN | LIN | DP | UF | UN | LIN | DP | UF | UN |
| Johnstown (10) | 0.38 | 0.54 | 0.49 | 0.40 | 7.2 | 5.8 | 6.2 | 6.6 | 9.3 | 5.8 | 7.0 | 6.3 |
| JFK arboretum (22) | 0.04 | 0.24 | -0.17 | -0.17 | 5.0 | 4.7 | 6.4 | 6.0 | 2.00 | 2.90 | 9.70 | 4.60 |
| Wulfsdorf (24) | 0.29 | 0.38 | 0.11 | 0.41 | 6.9 | 5.8 | 6.3 | 5.5 | 8.30 | 7.60 | 7.30 | 10.70 |
| Freiburg (26) | 0.63 | 0.67 | 0.58 | 0.67 | 8.4 | 4.6 | 5.0 | 4.5 | 8.20 | 4.10 | 3.00 | 7.60 |
| Munchen (17) | 0.34 | 0.63 | 0.53 | 0.70 | 6.8 | 4.7 | 5.2 | 4.1 | 8.00 | 4.30 | 4.00 | 4.70 |
| Zurich (9) | 0.24 | 0.41 | -0.13 | 0.24 | 5.3 | 4.2 | 5.7 | 5.0 | 4.70 | 4.50 | 6.30 | 9.50 |
| Bergen (7) | 0.37 | 0.93 | 0.55 | 0.66 | 4.2 | 1.6 | 4.3 | 3.3 | 2.90 | 1.40 | 5.30 | 4.40 |
| Average | 0.33 | 0.54 | 0.28 | 0.42 | 6.3 | 4.5 | 5.6 | 5.0 | 6.2 | 4.4 | 6.1 | 6.8 |

*ME: Modelling efficiency; MAE: Mean Absolute Error; WI: Warm year Index. LIN: Linear regression model between bud burst date and the average temperature February-April; DP: DORMPHOT model; UF: UniForc model; UN: Unified Model.

(London and Worcester) over the period 1885–2010 (16 years); these dates are being used as indicators of beginning, end and peak of flowering.

### 4.2.4 *Results*

#### *4.2.4.1 The DORMPHOT model: calibration and validation*

Whereas the DORMPHOT model is built upon existing phenological models, it features two novel aspects: (a) the inclusion of dormancy induction through the combined effect of temperature and photoperiod and (b) the dynamic effect of photoperiod on forcing rate. Besides giving more biological realism to the model, these modifications improved its predicting performance. The model outperformed the unified model, the linear regression model, and the UniForc model (Table 4.2).

#### *4.2.4.2 Projections of bud burst under climate change scenarios*

Observed and projected dates of bud burst showed a large variation within the four IPG sites. The previously observed range in bud burst dates varied by 42 days (73–115 JD) at the John F. Kennedy site,

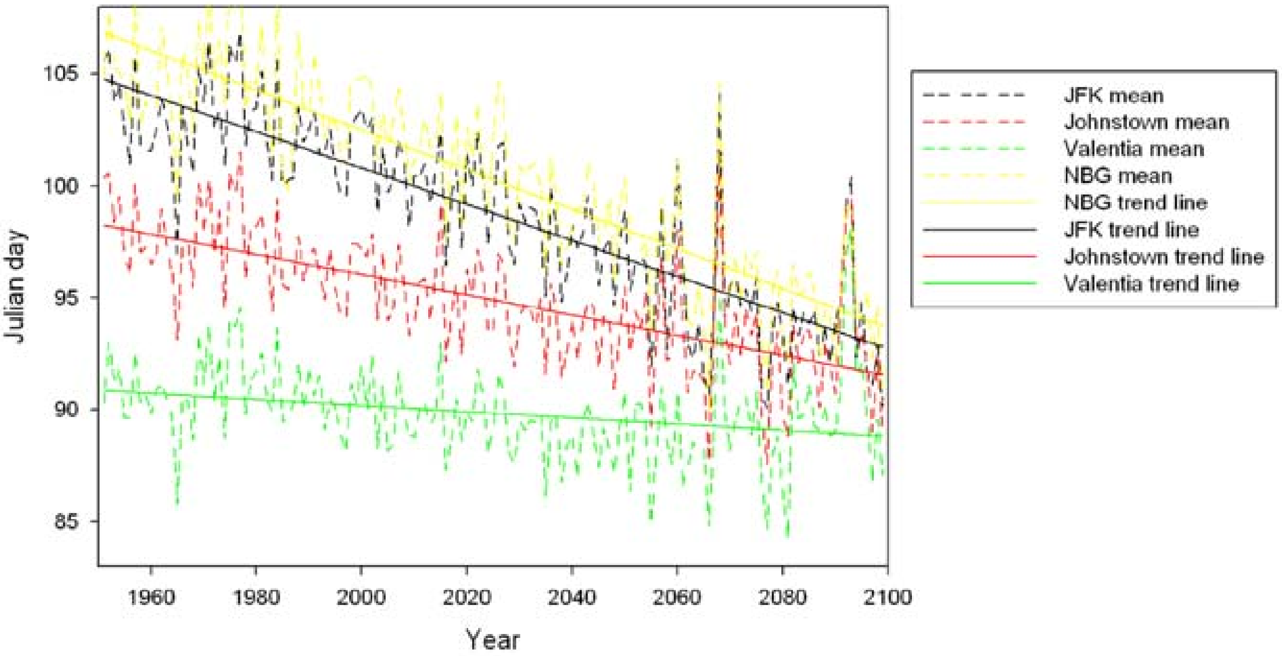

**Figure 4.4. Phenological model output for the timing of birch tree leafing at four stations (JFK – John F. Kennedy Arboretum, Co. Wexford, Johnstown – Johnstown Castle, Co. Wexford, Valentia – Valentia Observatory, Co. Kerry and NBG – National Botanic Garden, NBG, Glasnevin) in Ireland, 1950–2100.**

45 days (83–128 JD) at the Johnstown site and 48 days (71–119 JD) at the Valentia site. Modelled range in future bud burst dates was projected (utilising the temperature data from each of the 19 ENSEMBLES simulations) to vary by 63 days (68–130 JD) at the National Botanical Garden site, 62 days (68–129 JD) at the John F. Kennedy site, 64 days (66–129 JD) at the Johnstown site and 48 days (72–120 JD) at the Valentia site. Modelled date of bud burst was projected to advance by 15–20 days at the NBG site, 16–17 days at the John F. Kennedy site, 12–14 days at the Johnstown site and 4–14 days at the Valentia site over the course of the time period modelled (1950–2100) (Fig. 4.4).

#### *4.2.4.3 Mapping future bud burst of birch in Ireland*

Maps of projected bud burst showed, in accordance with currently observed bud burst patterns, a large inter-annual variability. As expected, bud burst date advanced from the 1990s to 2050s, as a consequence of the projected increase in temperature. However, this advance was not homogeneous and pronounced in all areas. This is likely due to the structure of the DORMPHOT model, in which chilling temperature and photoperiod act to stabilise the timing of bud burst, offsetting increasing temperatures. Currently, early zones, such as the south-west of Ireland showed the smallest advance, while late zones like the north-east showed the largest advance. In particular, when comparing the mean date of bud burst in the 2050s with the 1990s, the earliest date of bud burst advanced from 82 to 80 while the latest advanced from 102 to 94 (Fig. 4.5).

### *4.2.5 Discussion and Conclusions*

The high average modelling efficiency (54%) and better performance of the DORMPHOT model on validation datasets was notable, given the presence of additional relationships constraining the model structure and the restriction of parameter space during calibration. This suggests that the model structure was suited to the shape of the data and the noise in the series did not affect the parameter values. The consistently more accurate bud burst prediction output by the DORMPHOT model in warm years and the similarity between its average MAE and WI suggested that it is robust on extreme years and can be reliably applied to future climate change scenarios for the forecast of its impacts on tree phenology.

The results of the projections suggest that the trend towards earlier bud burst will continue at least into the near future and that the phenology of late bud burst zones like the north-east of Ireland will be impacted more significantly by climate change compared to currently early bud burst zones like the south-west.

## 4.3 Overall Conclusions

The use of experimental data has been proven useful to improve the predictive powers of current phenological models of bud burst and addition of a wider range of environmental conditions simulated, the more data will be available to further refine the models. The model predictions suggest that bud burst of birch will continue to advance at least until 2100 but the rate of advance will vary across the country with the north east showing the greatest advance.

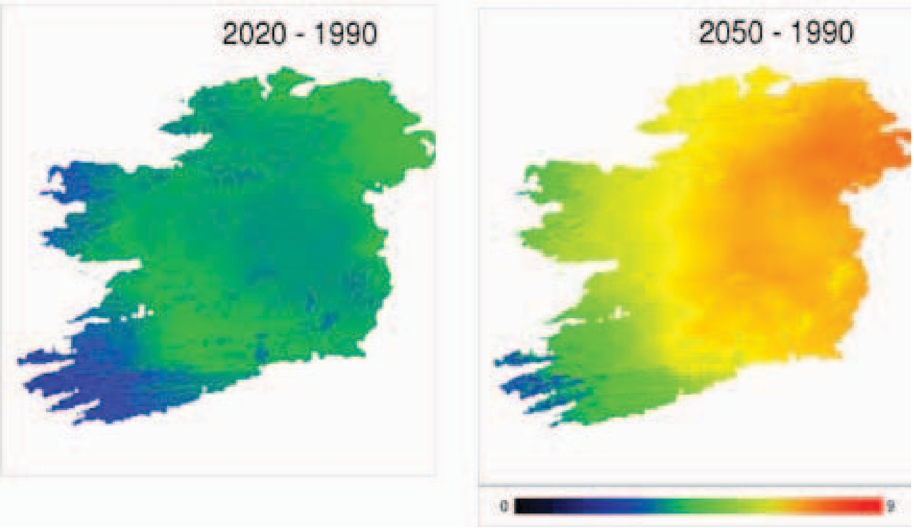

**Figure 4.5. Projected advances (days) in mean birch bud burst date between the 2020s and the 1990s (left) and the 2050s and 1990s (right).**

# 5 Investigation of Bud Burst at the Genetic Level across Europe

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## 5.1 Background

Because both survival and reproduction are affected by climate change, through the timing of bud burst and flowering, there are strong evolutionary pressures at play on these phenological traits (Hoffmann and Sgrò, 2011). The unique characteristics of trees such as wood formation, cold hardiness and leafing and flowering phenology cannot be studied using the annual herbaceous model plant Arabidopsis thaliana. Hence, a model system for forest trees was proposed, i.e. poplar (Populus spp.; Bradshaw et al., 2000).

Several common-garden studies have indicated that the genetic make-up of species and populations has a more important influence on bud burst than environmental factors. When trees from northern and southern populations are transplanted to a common environment, they mostly retain their phenotypic response of bud burst, showing that this trait is under strong genetic control and that the trees are locally adapted to their environment (Frewen et al., 2000; Howe et al., 2003). In order to study the underlying genetic variation in tree populations, candidate genes must be identified (Taiz and Zeiger, 2006).

Unknown genes may be identified and characterised through a combination of quantitative trait locus (QTL) analyses, gene expression studies, and genetic association mapping (Gailing et al., 2009). By comparing the genetic diversity between candidate genes and neutral markers, the level of local adaptation can be estimated. A number of candidate genes have been found for traits such as bud burst and dormancy release and these can be used to test for variations based on temperature clines.

## 5.2 Aims

The aims of this particular work were to quantify the genetic variation of genes involved in the release of dormancy both within and between natural populations of *Populus tremula* and to investigate if clinal genetic variation along latitudinal and longitudinal gradients in Europe exists. The traits of interest were spring phenological traits such as bud burst and reactivation of growth after dormancy; and the genes of interest were linked with temperature. This study sought to analyse single nucleotide polymorphisms (SNPs) and patterns of DNA sequence variation in candidate genes between the different European populations in order to test whether variation along a particular cline between the populations exists at the individual SNPs, which would suggest that an adaptive response to local conditions has occurred, and whether there is evidence for variation from expected low genetic differentiation of the populations.

## 5.3 Methods

The plant material for this study was collected between February 2009 and March 2010. A letter was sent in January 2009 to 464 botanic gardens across Europe, requesting twig samples from natural populations of poplar that contained at least four buds.

The candidate genes were chosen based on recent scientific literature of genetic studies on dormancy-related traits in trees and other woody species. The genes of interest were mainly linked with temperature responses rather than photoperiod, and also with spring phenological traits such as the breaking of dormancy and reactivation of growth. A search for selected gene regions of interest was performed in GenBank (NCBI; http://www.ncbi.nlm.nih.gov), and when *Populus* homologues of the candidate genes were found using BLAST (Basic Local Alignment Search Tool), the locations of the regions in the *Populus* genome were verified in specific databases such as PopGenIE

(*Populus* Genome Integrative Explorer; Sjödin et al. 2009), the JGI *Populus trichocarpa* v1.1 Genome Browser (Joint Genome Institute, Tuskan et al. 2006), and the more recent version JGI v2.2 of the *Populus* genome incorporated in Phytozome v7.0 (Joint Genome Institute, http://www.phytozome.net/poplar).

The candidate genes used in this study were ABI1B (ABAINSENSITIVE 1B) and GA20ox (GA20-OXIDASE) which are involved in hormonal pathways; and CYCB and CDKB (CYCLIN B and CYCLIN-DEPENDENT KINASE B) which are cell cycle regulators, while all others (CENL1 (CENTRORADIALIS LIKE 1), LFY (LEAFY), FT1 (FLOWERING LOCUS T1), MFT (MOTHER OF FT AND TFL1), FTL1 (FT/TFL1-LIKE1), FTL3 (FT/TFL1-LIKE3), SVP (SHORT VEGETATIVE PHASE), SOC1 (SUPPRESSOR OF OVEREXPRESSION OF CONSTANS 1), PTM5 (*P. tremuloides* MADS BOX 5) and FVE (MULTICOPY SUPPRESSOR OF IRA 4)) are involved in the floral regulatory pathway.

In order to design suitable primers for the PCR (polymerase chain reaction) of each gene region, a multiple alignment was made of the sequences resulting from the BLAST searches. From the consensus sequence of these alignments, conserved regions of +/-20 bp were chosen for the primers using Primer3 software (Rozen and Skaletsky, 2000). Polymerase chain reactions were used on the total DNA in order to amplify the selected regions. In order to verify the presence of total DNA after extraction and PCR product after amplification, all samples and controls were checked using gel electrophoresis. Positive, single-banded PCR products of which the controls were negative were purified for sequencing using SureClean Plus solution (Bioline). The sequencing was outsourced to Eurofins MWG Operon, Germany. After sequencing results returned, a BLAST search was performed with the results in order to verify that the correct genes had been sequenced.

The sequences of a particular region were assembled and aligned in contigs using Sequencer DNA Software 4.10.1 (Gene Codes Corporation), which also identifies polymorphic sites. All polymorphisms in the multiple sequence alignments were then manually verified using the chromatograms to exclude any scoring errors and the sequences were trimmed to the same size. The software package used for the analysis of nucleotide diversity was DnaSP 5.10.01 (Librado and Rozas, 2009). Both $\pi$ and $S$ are measures of genetic variation. Genetic diversity within and between the populations was calculated, including SNPs, indels and synonymous and non-synonymous mutations. The number of haplotypes, $H$ and the haplotypic diversity, $Hd$ (Nei, 1987) were also calculated using DnaSP. The nucleotide diversity patterns were tested for deviation from expectations under the neutral theory using DnaSP 5.10.01 (Librado and Rozas, 2009). From a variety of neutrality tests, Tajima's D statistic (Tajima, 1989) was selected for this study. $Fst$ (population differentiation index) is a measure for diversity of populations, or how the genetic variation is distributed between the populations (Weir and Cockerham, 1984). It has a value between zero and one, with values closer to zero indicating more gene flow between populations. $Fst$ was calculated as: $Fst = (Ht - Hs) / Ht$ where $Ht$ is the total heterozygosity and $Hs$ is the heterozygosity of the populations. $Fst$ was calculated for each SNP in all populations >3 individuals and averaged for the whole sequence. Allele frequencies were calculated for each SNP within populations of which three or more sequences of different individuals were available. The frequency of each allele ($p$ and $q$) is the frequency of its homozygote form ($f_{AA}$, $f_{aa}$), plus half the frequency for all heterozygotes in which it is present ($f_{Aa}$): $p=f_{AA} + \frac{1}{2} f_{Aa}$ and $q=f_{aa} + \frac{1}{2} f_{Aa}$ where $p + q=1.0$ (Page and Holmes, 1998). The frequencies $p$ and $q$ provide a simple description of the amount of genetic variation in a population. R 2.12.2 was used for linear regression and calculation of Pearson correlation coefficients in order to determine the importance of latitude, longitude and altitude on the genetic variation of the populations.

## 5.4 Results

### *5.4.1 Gene Regions and Primers*

After an extensive literature review a total of 14 gene regions were screened. Seven of the 14 fragments yielded successful sequences: PtABI1B, PtCDKB, PtFTL1, PTLF, PtMFT, PtSOC1 and PtSVP. The PtABI1B region was used for an initial trial but no polymorphism were observed in 500-550 bp of sequence from five individuals, so this was not used further. The six other gene regions did show some variation in the test sequencing and therefore more samples were selected for amplification and sequencing of these regions. Between 40 and 64 individual sequences were obtained from 13–16 populations, giving a total of 324 individual fragment sequences. The fragments were located on three different scaffolds: Scaffold 2 (PtSOC1 and PtSVP), Scaffold 5 (CDKB) and Scaffold 15 (PtFTL1, PTLF and PtMFT, with PtFTL1 and PTLF positioned relatively close to each other). For PtSOC1 and PtSVP, using BLAST in the P. trichocarpa database resulted in several hits with varying overlapping lengths and similarities. PtCDKB was made up of a series of five relatively short intron- and exon sections, while the other regions included one exon and one (PTLF), two (PtSOC1, PtSVP) or no introns (PtFTL1, PtMFT). The complete coding regions were sequenced for exons I–IV in PtCDKB and for the exons in PtSOC1 and PtSVP. Fragment lengths of the six gene regions ranged between 246 and 882 bp after alignment and trimming of the sequences, with a total of 3 kb sequenced. For PTLF, 20 base pairs were omitted from further analysis because the forward and reverse sequences did not fully overlap for many of the samples.

### 5.4.2 *Polymorphisms and Nucleotide Diversity*

Three indels were detected in total: one of 8bp in PtSVP, and two in PtSOC1 (4 bp and 2 bp long). The total number of SNPs found was 82 over all the gene fragments, with on average one SNP per 37 bp. Of the 3 kb sequenced, 1.8 kb were found in coding sequences and 1.2 kb were part of non-coding regions, in which most of the SNPs were found (52 non-coding SNPs out of 82 in total). Of the 30 SNPs in coding regions, 12 were synonymous and 18 were non-synonymous (Table 5.1). All segregating sites (equal to the number of SNPs in the six sequences) were parsimony informative. Estimates of total nucleotide diversity (πtot) ranged from 0.00376 (for PtFTL1) to 0.0127 (for PTLF) between the six gene fragments, with an overall average of 0.00636. Non-coding sections were more variable than coding regions: the average πsil was 0.0079 for silent sites (both non-coding and synonymous), compared to coding nucleotide diversities πsyn and πns (for synonymous and non-synonymous coding sites, respectively 0.0036 and 0.0019). This also shows that the level of diversity in coding sequences was higher for synonymous sites than for non-synonymous sites. High levels of non-synonymous nucleotide diversity were observed for PtFTL1 and PtMFT (πns: 0.0038 and 0.0075 respectively, compared to zero in the four other sequences). Between 10 (for PtFTL1) and 49 (for PtMFT) different haplotypes (H) were found in each of the gene regions, with haplotype diversity (Hd) ranging from 0.591 in PtFTL1 to 0.986 in PtMFT, with an average of 0.804.

**Table 5. 1. Summary of gene regions and polymorphisms detected in *P. tremula.* Indel sizes in parentheses.**

| Locus Name | Regional length analysed (bp) | | | | | Number of polymorphisms in region | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Coding SNPs | | | |
| | Total | Coding | Non-coding | Excons | Indels | SNPs | syn | non-Syn | Non coding SNPs | bp/SNP |
| PtCDKB | 882 | 354 | 528 | 5 | 0 | 18 | 2 | 0 | 16 | 49.0 |
| PtFTL 1 | 246 | 246 | 0 | 1 | 0 | 8 | 4 | 4 | 0 | 30.8 |
| PTLF | 398 | 73 | 325 | 1 | 0 | 19 | 0 | 0 | 19 | 20.9 |
| PtMFT | 783 | 783 | 0 | 1 | 0 | 18 | 4 | 14 | 0 | 43.5 |
| PtSOC 1 | 302 | 193 | 109 | 1 | 2 (4bp/2bp) | 7 | 2 | 0 | 5 | 43.1 |
| PtSVP | 427 | 176 | 251 | 1 | 1 (8bp) | 12 | 0 | 0 | 12 | 35.6 |
| Total | 3038 | 1825 | 1213 | 10 | 3 | 82 | 12 | 18 | 52 | 222.9 |
| Average | 506.3 | 304.2 | 202.2 | 1.7 | 0.3 | 13.7 | 2.0 | 3.0 | 8.7 | 37.2 |

### *5.4.3 Neutrality Test, Population Differentiation and Allele Frequencies and Clinal Variation*

Based on Tajima’s D neutrality test, there was no evidence found for departure from neutral evolution in any of the six gene regions. Positive values were obtained for the Tajima’s D estimate of PtCDKB, PTLF and PtMFT, which can be generated by sampling across different paralogues. One paralogue for PtCDKB was found in Scaffold 2, which was considerably shorter than the 882 bp of the PtCDKB consensus sequence; and for PTLF and PtMFT the search only yielded one copy of the sequence. Overall genetic differentiation was determined for populations with three or more individuals, giving a mean Fst of 0.0461 over all polymorphic sites. The lowest Fst value per locus was found for PtSVP (-0.0857). The highest differentiation of populations was located in the PtMFT region, with Fst value 0.1007. The low Fst value for PtSVP was due to negative values for all SNPs in this region except for SNP_419 (Fst 0.1133), which had a relatively high value. The SNPs showing a possibility for variation in allele frequencies along latitude were PtCDKB SNP_296 (r2=0.28; Fig. 5.1a) and PtSOC1 SNP_186 (r2=0.62; Fig. 5.1b). Along longitude, indications for variation were found in PTLF SNP_281 and SNP_318 (r2 =0.51 and 0.33 respectively; Fig. 5.1c) and in PtMFT SNP_778 (r2 =0.62; Fig. 5.1d).

## 5.5 Discussion and Conclusions

The level of nucleotide diversity discovered across the six candidate genes (mean πtot: 0.00636) lies within the previously reported range for poplar species. Since none of the Tajima’s D estimates were significant, neutrality could not be rejected for any of the gene regions in this study. This means that natural selection has had no significant influence on the variation observed and therefore the variation that is present was caused by gene flow or random mutations. A negative estimate of Tajima’s D was found for PtFTL1, PtSOC1 and PtSVP, indicating a large number of haplotypes and an excess of low-frequency variants. From the tree’s perspective, it can be an advantage if the genes involved in dormancy traits are not put under strong selective pressures, particularly in the scope of climate change. Since climate change has a known effect on plant phenology, the neutrality of the genes and the high gene flow levels will allow the trees to respond relatively easily to changes in environmental conditions.

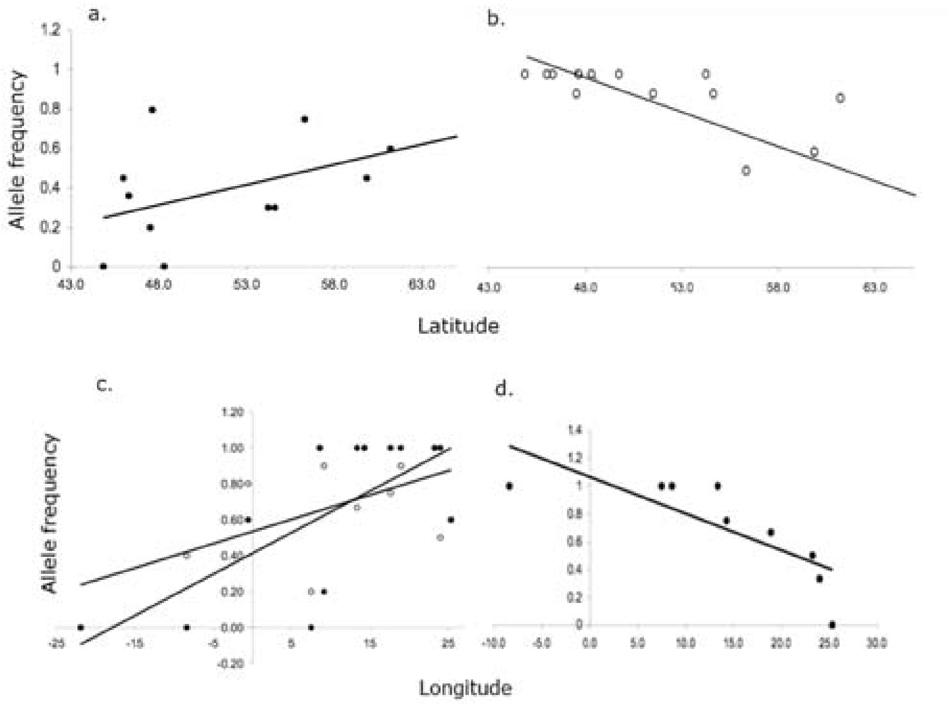

**Figure 5.1. Scatter plots of allele frequencies of some selected SNPs vs. environmental gradients latitude and longitude. (a). PtCDKB SNP_296 ($r^2$=0.28), (b) PtSOC1 SNP_186 ($r^2$=0.62), (c) PTLF SNP_281 ($r^2$=0.51, black dots) and SNP_318 ($r^2$=0.33, white dots), (d) PtMFT SNP_778 ($r^2$=0.62).**

In this study, the overall level of population differentiation, Fst, was established at 0.0461, with Fst values varying considerably between SNPs. Only the overall population differentiation was calculated here, as the small sample sizes per population made meaningful Fst calculations within populations impossible. The overall population differentiation was lower than, but close to 0.05, the value above which differentiation is considered to be moderately present (Wright, 1976). Fst values > 0.05 were found for gene regions PtCDKB, PtFTL1, PtMFT, and PtSVP, with highest values for SNPs in the PtMFT region (mean Fst 0.1). According to Wright's guidelines (1976), these regions showed moderate genetic differentiation for the populations. A certain amount of differentiation can be very valuable for plant populations, as it provides a possibility of intergroup selection: when evolutionary change is made possible on smaller groups it can happen more rapidly and more effectively. With rapid temperature increases due to climate change, this small amount of differentiation could be a determining factor for the survival of European aspen populations.

Allele frequencies deviated strongly in most cases from the Hardy-Weinberg equilibrium. Because neutrality could not be rejected from Tajima's D test, it is likely that the reason was the small population sample sizes in this study, rather than selection for a particular allele. The basic regression method used for assessing clinal variation resulted in five SNPs illustrating evidence for correlations with either latitudinal or longitudinal gradients. The Fst values of the five particular SNPs were very low, contrary to an expected differentiation at a locus showing signs of clinal variation: 0 for PtCDKB SNP_296, 0.104 for PtSOC1 SNP_186, 0 and 0.08 for PTLF SNP_281 and SNP_318 respectively and at PtMFT SNP_778 Fst was 0.05. Local adaptations resulting in clinal variations can be caused by admixture (De Carvalho et al., 2010) or by selection along an ecological gradient (Endler, 1977). Isolation by distance and genetic drift are not likely to play an important part as neutral markers generally have low differentiation among populations (Savolainen et al., 2007). The longitudinal correlations discovered in two genes in this study cannot be explained by temperature clines; however, they are uncommon in phenological studies on forest trees.

In conclusion, high nucleotide diversity was found for six genes involved in dormancy control in *P. tremula*. In addition, low to moderate population differentiation was detected for these genes amongst natural *P. tremula* populations across Europe. Both nucleotide diversity and population differentiation provide the raw material for adaptation of such populations to future climatic change. Indications for clinal variation were detected for a few genes across the geographical area examined. These genes deserve further investigation to assess their contribution to adaptive traits in natural populations. The results presented here show that the majority of diversity can be found on the scale of *P. tremula* natural populations, but certain alleles occur at different frequencies across the entire European range.

# 6 Establishment of a Web-based Facility for Recording Observations and presenting Phenological Data

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## 6.1 Background

There are a growing number of websites across the world that rely on nature lovers to contribute to scientific research. Throughout the USA, UK, Sweden and the Netherlands 'citizen scientists' record phenological events throughout the year. These collaborations are extremely valuable to teach the general public about the scientific process and involve them in large-scale studies with grateful scientists.

## 6.2 Ireland's National Phenology Network

Ireland's National Phenology Network (IE_NPN, see Appendix 2) is run by the Phenology Research Group at TCD. This project is helping to establish a sustainable phenological network in Ireland which will enable the monitoring and predicting of shifts in the timing of phenological phases in relation to climate change. In addition, it is conducting research into various aspects of both plant and animal phenology.

## 6.3 Aims

The aim of the *Nature Watch* website is to provide the general public with an opportunity to participate in phenological observations in Ireland. Their observations are invaluable for climate change research by the scientific community.

- The general public are asked to record the growing season of trees and other plants, birds and insects. This information can help show if events are happening earlier or later each year with changes in temperature and rainfall in Ireland.
- These observations are compared with those taken in other countries. This way, it is possible to see if the same changes that are occurring here are also occurring in the UK, or in mainland Europe. The more records obtained, the more reliable these studies will be.

Records that have already been taken and deposited with the NBDC are also used to ascertain what changes have occurred in Ireland over time

## 6.4 Methods

The *Nature Watch* website for public recording of phenological observations was developed in conjunction with the NBDC. Members of the TCD Phenology Research Group met colleagues from the NBDC to discuss building a website for recording phenological observations of the public. The NBDC had developed an observational mapping system for their own website, and were eager to collaborate with biological monitoring organisations in Ireland and the UK on other websites. The name *Nature Watch* was agreed upon for the site, and an initial storyboard of the various pages on the site was developed. The NBDC agreed to host the website and build the basic framework. An initial list of 20 species was drawn up for monitoring in Ireland: 10 plants, 5 insects, and 5 birds (see Box 6.1). The original species list designated for Nature Watch observation was made up of these species:

While the chosen insect species were acceptable, there were a few problems with the plant species and many problems with the chosen bird species. European spindle was thought to have flowers that were too hard to notice for first flowering, and was replaced on the website by common hawthorn (*Crataegus monogyna*). For the birds, only barn swallow was thought to be a good choice for monitoring migratory phenology. European robins are year-round residents and do not migrate. Whooper swans, razorbills and black-legged kittiwakes are migratory, but not widespread enough across the country. They were replaced on the website

**Box 6.1. Original species list designated for *Nature Watch* observation.**

**Birds**

- Black-legged Kittiwake (*Rissa tridactyla*)
- Razorbill (*Alca torda*)
- European Robin (*Erithacus rubecula*)
- Barn Swallow (*Hirundo rustica*)
- Whooper Swan (*Cygnus cygnus*)

**Insects**

- Buff-Tailed Bumble Bee (*Bombus terrestris*)
- Cinnabar Moth (*Tyria jacobaeae*)
- Clouded Yellow (*Colias crocea*)
- Common Darter (*Sympetrum striolatum*)
- Common Green Grasshopper (*Omocestus viridulus*)

**Plants**

- European Ash (*Fraxinus excelsior*)
- Downy Birch (*Betula pubescens*)
- Bluebell (*Hyacinthoides non-scripta*)
- Coltsfoot (*Tussilago farfara*)
- Daisy (*Bellis perennis*)
- Elder (*Sambucus nigra*)
- Common Hazel (*Corylus avellana*)
- Snowdrop (*Galanthus nivalis*)
- European Spindle (*Euonymus europaeus*)
- Wood Anemone (*Anemone nemorosa*)

by northern wheatear (*Oenanthe oenanthe),* common cuckoo (*Cuculus canorus*), common house martin (*Delichon urbica*) and willow warbler (*Phylloscopus trochilus).*

The website is made up of a number of connected pages: a homepage with a brief welcome (Fig. 6.1); a latest news page; an introduction section with a page introducing phenology; a page introducing the IPN and why phenology is important to monitor; a page on how to make observations; and a page talking more about the phenology research group at TCD. There is also a section on the species people should observe, divided into birds, insects and plants. Each page has species common and scientific names, species taxonomy, common habitat, distribution across Ireland, size, appearance (adult and young), food, life history, how

Nature Watch

Welcome to Nature Watch! Nature Watch is a phenology monitoring website for Ireland created by the Irish Phenology Network (IPN). A place where you can report when you see the first leaves in Spring, the first bumble bee in your garden, hear the first cuckoo or see the last leaf fall from your birch tree in Autumn. Click on the pages above to find out more about phenology, why it is important to monitor and how you can become a part of Nature Watch.

The business of climate change http://t.co/1EasiCX 3 days ago

Help translate ancient Greek texts, no Greek knowledge needed http://t.co/C0C4E8i 3 days ago

**Figure 6.1. Screen-shot of *Nature Watch* homepage.**

to identify the species, when during the year they should expect to see the species, what phenophases to monitor, fun facts, notes of special circumstances and photographs of species and phenophases if available.

There is a section on the phenophases people should observe divided into phenophases for birds, insects and plants. The phenophase to observe for birds and insects is first sighting in the spring. For plants the phenophases to observe are beginning of leaf unfolding, beginning of flowering, first ripe fruit, autumn colour and leaf fall. Each page has a description of the phenophase and photographs illustrating phenophases when available. And finally there is a records submission page where the observer enters date of observation, species observed, phenophase observed, address of observation (not observer), town of observation, county of observation, weather conditions, environmental conditions (local environment of sighting), other relevant information (time of day, mowing, etc.), recorder name and recorder email so that they may be contacted with questions if necessary.

### 6.4.1 Getting Started: Monitoring Phenology

Users are encouraged to pick one location that they want to monitor. It could be around their house, their school, their work or a local natural area or park. It is preferable if they just record observations in this one area instead of travelling around recording the first time they see one of the phenophases. This way it is easier to keep track of how phenology is changing in their location. They are then asked to check the pages on the website for the species the group would most like them to keep track of, and the phenological events they should be looking out for. They are advised to make sure they are comfortable being able to identify these species and these phenophases.

### 6.4.2 Recording Phenology

Users are asked to keep a list or diary of the first time each year they see the phenophases listed on this site for these 5 species of birds, 5 species of insects and the 10 species of plants. They should take notes of when and where they saw this phenophase, what the weather was like and what the environment was like. For example, was their bird sighting in a field or a woodland? Was someone watering or mowing around their plant when they saw the first flower? They are asked to enter the information online from their observation. They are encouraged to enter the information online as soon as they can so they won't forget or lose their list. If they think they might have missed a phenophase, they are told to just skip it and record when they see the next one.

### 6.4.3 Results

*Nature Watch* (http://phenology.biodiversityireland.ie/) was launched on 20 April 2010. This launch coincided with a press release from TCD. The press release was picked up and articles were published by the *Irish Daily Mirror*, *Laois Nationalist*, *Kildare Nationalist*, *Carlow Nationalist* and *The Irish Times*. Maintenance of the website and monitoring of records submitted is ongoing. The NBDC will be adding an observational mapping system. Collaboration was established with Greenwave (http://www.greenwave.ie/), a phenological monitoring site for primary schools in Ireland, to share phenological data and to help analyse the data they have already collected. A newsletter for current observers is in development.

A Twitter account was created for the project (#Nature_Watch), and a Facebook account for the Irish Phenological Network was also created. Short articles for the NBDC (*Biodiversity Ireland*, autumn 2010 iss. 6) and the Irish Meteorological Society (Autumn–Winter 2010 newsletter) websites and newsletters were written and published to help draw in more observers. These updates were also circulated among garden and wildlife viewing groups online. A short update was also published in *The Irish Garden* magazine, vol. 19, no. 8, Oct/Nov 2010. A brochure about *Nature Watch* was produced with Heritage Council funding and provided to all of the participants at the annual meeting of the Irish Meteorological Society. This brochure is also available to the general public at the NBDC offices.

### 6.4.4 Discussion and Conclusions

The *Nature Watch* website was developed in collaboration with the NBDC. This website (http://phenology.biodiversityireland.ie/) invites members of the general public to participate in a national search for phenological data. This Citizen Science project requests interested parties to record the date on which they see the first bird, the first insect, leaf fall and other phenological events in their surrounding environment throughout the year. In the long term, the results of this research will give a national view of when the seasons are occurring, and over the years will enable the determination of advances in seasonal events between interdependent organisms, such as birds and their insect food resources, are remaining in sync.

While the *Nature Watch* website and larger online presence of Ireland's IPN is growing, acceptance by the public has been slow. Recorded observations have been limited to the spring, with only one summer observation at this point. These bursts in spring observations have typically followed publications about *Nature Watch* in either the popular press or targeted newsletters. Additional publicity in the summer and autumn should help to boost observation numbers, particularly on radio and television programmes.

Another issue influencing public acceptance is the recent proliferation of Irish monitoring websites and programs. *Nature Watch,* Greenwave.ie, Biology.ie and even the NBDC are all asking members of the public to record nature sightings and to add them to the organisations' databases. Members of the public do not want to enter in observations multiple times, and so choose one organisation to support. While *Nature Watch* is hosted by the NBDC, its databases are not linked with the IPN, requiring observers to input their information twice. Linking these databases might result in increased data for both organisations. Recent collaborations with Greenwave.ie and Biology.ie will allow the pooling of data for research purposes, but will not simplify the observation submission process for the general public. Further divisions of the 'market' may be most useful for this issue. Greenwave.ie already focuses on primary schools while *Nature Watch* and Biology.ie concentrate on secondary schools. Further focus on specific sections of the general public by either *Nature Watch* or Biology.ie should help boost observer numbers.

Of the 20 species observed for *Nature Watch*, the bird species have proved the most popular with the public. Herbaceous plants have proven to be more eye catching than shrubs or trees, but species of Lepidoptera (normally quite visible) have been ignored. Adding more species of bees, particularly other bumble bee species, and additional spring wildflowers may boost number of species being actively observed. These changes in species to observe may shift *Nature Watch* to a solely spring phenology platform. This would help to focus promotion on spring events and capture the general public's attention after dreary winters, but would ignore potential changes to the length of the growth season induced by climate change.

In general, the first year of *Nature Watch* has resulted in a fair amount of data and increased public interest in phenology. With increased promotion, collaboration and selection of additional species to monitor, this programme should increase in size and popularity.

# 7 Recommendations

## 7.1 Phenological Network

- Identify indicator plants specific to the Irish climate in order to substantiate the influence of climate change on the Irish growing season.
- Develop a website which would enable the participants of the gardens network to discuss observations as they happen. A blog or twitter account may be suitable.
- Establish a centralised group of gardens within the Irish International Phenological Gardens (IPG) network who would oversee the annual observations and report directly to the IPG and a national co-ordinator.

## 7.2 Pollen Release

- The study on Ireland’s pollen season could be further expanded to include grass which is the most virulent plant source causing allergenic rhinitis globally.

## 7.3 Strategic Plan

- Implement the findings of the Strategic Plan.
- Facilitate propagation of both IPG and native species between site participants.
- Continue to raise awareness of the importance of phenology among both the scientific community and the general public through publishing research findings and providing information leaflets, public talks and media interviews.

## 7.4 Herbarium Records

- Digitisation of herbarium specimens would be useful on a global scale.
- Conduct further research on the potential for trophic level asynchrony in herbarium collections.
- Include additional species that are available in herbaria.

## 7.5 Bird Migration

- Carry out further studies on bird wintering populations.
- Broaden the range of temperature variables in order to continue to develop understanding of how climate change is impacting bird migration.
- Examine arrival dates of northern species to determine if arrival is getting later over time.

## 7.6 Moth Phenology

- Locate and analyse datasets from additional trophic partners (e.g. bats or herbaceous plants) for moths for potential future mismatches.
- Analyse moth phenology in relation to changes in precipitation in addition to temperature.
- Establish a more uniform network of moth observers across the country, similar to the IPG network for future observations.

## 7.7 Remote Sensing

- Assess the feasibility of obtaining and using higher spatial resolution vegetation measures over Ireland from the European Space Agency for continued SOS monitoring. There are considerable opportunities with the replacement of the MERIS mission with the Sentinel-3 satellite sensor in 2013 and the development of a new high resolution land monitoring sensor, Sentinel-2, which will provide vegetation measures at very high spatial resolutions (<60m).
- Further explore and define the land covers underlying the seasonality clusters.
- Assess the potential of the land cover clustering method to aid national-scale mapping of land-use practices such as intensive grassland agriculture for more precise carbon budget accounting under the Kyoto Protocol.

## 7.8 Photoperiod Experiments

- The effect of forcing temperature and photoperiod on the timing and progress of bud burst could not be investigated due to mechanical failure of growth chambers. Investigate the detailed response of bud burst to forcing temperatures and the interactions with other environmental factors is complicated further.
- Clones were used in this experiment to rule out intra-specific variability as a factor of bud burst variation. However, in order to generalise our findings for forest ecosystems studies, evaluate more species and different genotypes per species.
- As vegetative tree buds go through several phases of dormancy release, invisible to the naked eye but happening on a microscopic or molecular level, carry out bud developmental studies to fully understand the influence of environmental factors on dormancy release. These observations would greatly improve phenological models.

## 7.9 Phenological Modelling

- Project flowering phenology of birch using the ENSEMBLEs scenarios in order to simulate the impact of climate change on the timing and duration of the allergy season for birch pollen.
- Improve the computational efficiency of the spatialised DORMPHOT algorithm in order to use all the ensemble scenarios available and create an efficient and user-friendly tool for the spatialisation of phenology in Ireland.
- Conduct experiments under controlled conditions to explore how the spread in the timing of bud burst /leaf unfolding of tree species is affected by the main drivers of this phenophase (temperature and photoperiod) and include in phenological models of bud burst /leaf unfolding the environmental control over the variance of these phenophases.

## 7.10 Bud Burst Genetics

- Larger sample sizes should be obtained for the individual sites examined for the *P. tremula* genetic research.
- Examine a wider range of species and genes.

## 7.11 Citizen Science Website

- Add mapping software to the *Nature Watch* system so observers may look at where phenophases are occurring across the country at any time.
- Create individual accounts for *Nature Watch* observers so personal details need not be entered for each observation.
- Distribute biannual newsletters with information about phenology, timing of events each season, and the first recording of each event, with space for users' photographs to be printed.

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# Acronyms and Annotations

| | |
|---|---|
| BB | Bud burst |
| BBD | Days to bud burst |
| BGS | Beginning of the growing season |
| BLAST | Basic Local Alignment Search Tool |
| C | Chilling duration |
| CLC | CORINE Land Cover |
| DWD | Deutsche Wetterdienst |
| ECAD | European Climate Assessment and Dataset |
| GAMs | Generalised additive models |
| IE-NPN | National Phenology Network |
| IPG | International Phenological Gardens |
| JD | Julian Day |
| JM | Jeffries-Mathusita |
| JRC | Joint Research Centre |
| KW | Kruskal-Wallis |
| LGS | Length of the growing season |
| LRT | Long Range Transport |
| LSP | Land Surface Phenology |
| MAE | Mean Absolute Error |
| ME | Modelling Efficiency |
| Mgvi | MERIS Global Vegetation Index |
| NAO | North Atlantic Oscillation |
| NBDC | National Biodiversity Data Centre |
| NUI Galway | National University of Ireland, Galway |
| P | Photoperiod |
| PCR | Polymerase chain reaction |
| QTL | Quantitative trait locus |
| SNPs | Single nucleotide polymorphisms |
| SOS | Start of Season |
| TCD | Trinity College Dublin |
| UCC | University College Cork |
| USA-NPN VI | USA National Phenology Network Vegetation Index |
| WI | Warm year Index |

# Appendices

## Appendix 1: Project outputs

### *PhDs*

Annelies Pletsers 'Tree phenology under climate change conditions in Ireland and Europe'. Submitted 30 September 2011 to Trinity College Dublin.

Brian O'Connor 'Monitoring the vegetation Start of Season (SOS) across the island of Ireland using the MERIS Global Vegetation Index'. Submitted September 2011 to University College Cork (part supported by CCIP).

### *MScs*

Rebecca Stirnemann 'What mechanisms are driving responses of migratory bird phenology to changing environmental conditions?' Completed July 2011.

Hazel Proctor 'Phenology of birch pollen in Ireland'. Submitted 30 September 2011 to Trinity College Dublin.

Heather Ann Geyer 'The impact of spring arrival phenology of migratory non-passerine birds to the east coast of Ireland' Submitted 23 September 2011 to Trinity College Dublin.

### *Book Chapters*

Alison Donnelly, Amelia Caffarra, Eileen Diskin, C. T. Kelleher, Annelies Pletsers, Hazel Proctor, Rebecca Stirnemann, Mike Jones, John O'Halloran, Bridget F. O'Neill, Josep Peñuelas, and Tim Sparks. Climate warming results in phenotypic and evolutionary changes in spring events – A mini-review. In T. Hodkinson and J.A.N. Parnell (eds) *Systematics, Ecology and Climate Change*. 2011.

Alison Donnelly, James Robinson, John O'Halloran and Richard Nairn (2011) Climate change and bird conservation in Ireland. In: eds. J. O'Halloran anDr Nairn, Birds in Ireland.

### *Conferences*

Phenology 2010 – 14-17 June, 2010, Trinity College Dublin, Ireland.

### *Media Interviews*

Newstalk interview of Alison Donnelly with Sean Montcrief, 1 September, 2008.

Interview of Alison Donnelly for TG4 and Nuacht as gaeilge, 1 September, 2008.

Interview of Alison Donnelly with John Hennessy – *Newstalk*, 21 October, 2009.

Interview of Alison Donnelly Timpeall Orainn on Raidio na Life, April 28, 2010.

Interview of Alison Donnelly for *Science Spin* June 15, 2010, 11.30 am

Interview of Hazel Proctor, *Irish Times*. 'Why the hay fever drugs don't always work' and was published on Thursday April 28, 2011. It can be read at: http://www.irishtimes.com/newspaper/sciencetoday/2011/0428/1224295611910.html

### *Popular Press Publications*

Nature Watch featured in the *Irish Daily Mirror*, 21 April, 2010.

Nature Watch featured in the Laois Nationalist, the Kildare Nationalist and the Carlow Nationalist, 27 April, 2010.

*Nature Watch* featured in the *Irish Times Weekend* Review, 1 May, 2010.

Timing is Everything, by Alison Donnelly, *Biodiversity Ireland* **6**, autumn 2010, Pp 6–7.

Newsletter article for British Aerobiology Federation, 4 November, 2010

Newsletter article for International Aerobiology Association, 4 November, 2010

A short update on *Nature Watch*, published in *Biodiversity Ireland* **6**, autumn 2010, pg. 16

A short update on *Nature Watch*, published in *The Irish Garden*, Oct/Nov 2010, **19, no. 8**, pg. 78.

A short update on *Nature Watch* published in the Irish Meteorological Society's Autumn/Winter 2010 newsletter.

Timing is everything, April 2011 Irish Meteorological Society Newsletter

### *Reports*

Donnelly, A. and Moran, E. (2008) History of phenology in Ireland. In: Nekovář, J. (ed) *The history and current status of plant phenology in Europe*. COST Office.

Proctor, H. and Donnelly, A. I*reland phenology network 2009: New and existing phenological gardens in Ireland.*

Donnelly, A. and Proctor, H. *Ireland's National Phenology Network.*

Donnelly, A. *Ireland's National Phenology Network – Strategic Plan.*

## *Scientific Publications*

### *Published*

Amelia Caffarra and Alison Donnelly. 2011. The ecological significance of phenology in four different tree species: effects of light and temperature on bud burst. *International Journal of Biometeorology*. DOI 10.1007/s00484-011-0426-5.

Amelia Caffarra, Alison Donnelly and Isabelle Chuine. 2011. Modelling the timing of *Betula pubescens* bud burst . I. Temperature and photoperiod: a conceptual model. *Climate Research*. **46**, 147–57.

Amelia Caffarra, Alison Donnelly and Isabelle Chuine. 2011. Modelling the timing of *Betula pubescens* bud burst . II. Integrating complex effects of photoperiod into process-based models. *Climate Research* **46**, 159–70.

Elisabeth Carroll, Tim Sparks, Alison Donnelly and Tom Cooney. 2009. Irish phenological observations from the early 20th century reveal a strong response to temperature. *Biology and Environment, Proceedings of the Royal Irish Academy* **109B(2)**, 115–26.

Alison Donnelly, Tom Cooney, Eleanor Jennings, Erika Buscardo and Mike Jones. May, 2009. Response of birds to climatic variability; evidence from the western fringe of Europe. *International Journal of Biometeorology* **53(3)**, 211–20.

Alison Donnelly, Amelia Caffarra and Bridget F. O'Neill. 2011. A review of climate-driven mismatches between interdependent phenophases in terrestrial and aquatic ecosystems. *International Journal of Biometeorology*. DOI:10.1007/s00484-011-0426-5.

### *Submitted*

Diskin, E., Proctor, H. and Donnelly, A. *Rubus spp*. phenology in Ireland: an exploration using herbarium specimens. Submitted to *International Journal of Biometeorology*, accepted with revisions.

Donnelly, A., Caffarra, A., Diskin, E., Kelleher, C.T., Pletsers, A., Proctor, H., Stirnemann, R., O'Halloran, J., O'Neill, B.F., Peñuelas, J. and Sparks, T. Surviving in a warmer world: environmental and genetic responses. *Climate Research*.

Gleeson, E. O'Neill, B. Donnelly, A., Semmler, T., McGrath, R. and ní Bhroin, A. A Comparison of Spring Phenology and Meteorological Parameters. *Biology and Environment, Proceedings of the Royal Irish Academy*.

O'Connor, B., Dwyer, N., Cawkwell, F. and Eklundh, L. Spatio-temporal trends in the start of season across the island of Ireland using the MERIS Global Vegetation Index. *Journal of the International Society of Photogrammetry and Remote Sensing* (ISPRS), accepted with revisions.

O'Connor, B., Dwyer, N. and Cawkwell, F. The implications of cloud cover for vegetation seasonality monitoring in Ireland. *Journal of Irish Geography*, accepted with revisions.

O'Neill, B., Bond, K., Tyner, A., ShepparDr Bryant, T., Chapman, J., Bell, J. and Donnelly, A. Climatic warming advancing phenology of moth species in Ireland. *Entomologia Experimentalis et Applicata*.

Stirnemann, R., O'Halloran, J. and Donnelly, A. Climatic driven changes in the winter phenology of the whooper swan in Ireland. Submitted to Ibis, accepted with minor revisions.

### *In Preparation*

Geyer, H.A. and Donnelly, A. The impact of spring arrival phenology of migratory non-passerine birds to the east coast of Ireland Biology and Environment; Proceedings of the Royal Irish Academy

O'Neill, B., Gleeson, E., Semmier, T., McGrath, R. and Donnelly, A. Modelling future plant phenology using climatic projections: climate change influences on Irish phenology.

Pletsers, A., Caffarra, A. and Donnelly, A. Effects of photoperiod and temperature on budset and bud burst in birch (*Betula pubescens*).

Pletsers, A., Caffarra, A., Kelleher, C. and Donnelly, A. Genetic variation of bud burst -related traits in European aspen (*Populus tremula*).

Pletsers, A., Caffarra, A. and Donnelly, A. Modelling future trends for tree phenology in Ireland.

Scarrott, R., O'Connor, B., Dwyer, N. and Cawkwell F. Enhancing Irish landcover classifications with satellite-derived seasonality information.

Scarrott, R. Exploring spatio-temporal patterns in Irish landcover, using a time-series of MODIS EVI. Sensed, the RSPSoc magazine.

Stirnemann, R. How are changing environmental conditions driving migratory bird phenology?

*Special Issue of the International Journal of Biometeorology*

14 scientific papers (1 of which from Donnelly, A., Caffarra, A. and O'Neill, B.F.) 1 preface (Donnelly, A., Caffarra, A., O'Neill, B.F. and Schwartz, M.) Editors - Donnelly, A., Caffarra, A., O'Neill, B.F. and Schwartz, M.

*Scientific Statement of the Royal Irish Academy*

Donnelly, A. The impact of rising spring temperature on trees, insects and birds in Ireland

### *Websites*

Nature Watch launched 20 April, 2010.

## Appendix 2: Phenology Project Timeline

| Date | Event | Location | People Involved |
|---|---|---|---|
| 27 July, 2007 | Proposal submitted | Trinity College Dublin (TCD) | Alison Donnelly |
| 17 October, 2007 | Confirmation from EPA of funding. Budget to be reduced and reviewers' comments to be addressed. | Dublin | Frank McGovern |
| 23 October, 2007 | Resubmitted proposal with modified budget and reviewers comments addressed. Sent hard copy of proposal and covering letter to Frank Mc Govern. | Trinity College Dublin | Alison Donnelly |
| 12–13 November, 2007 | COST 725 WG2 Workshop. | Ljubljana, Slovenia | Alison Donnelly |
| 7 December, 2007 | Information meeting with Head of School, Director of Research, Head of Discipline, Director of Centre for Environment and PI. | Trinity College Dublin | Alison Donnelly |
| 7 February, 2008 | Phenology workshop | Alnarp, Sweden | Alison Donnelly |
| 10 March, 2008 | Workshop in TCD, Phenology in UK, past present and future | Trinity College Dublin | Tim Sparks & Lizzy Carroll |
| 1 April, 2008 | Research Assistant takes up post. PhD students begin. | Trinity College Dublin | Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann |
| April, 2008 | Partnership agreement with University College Cork and Teagasc |  | Prof John O'Halloran and Dr Daire Ó hUallacháin |
| April, 2008 | Climate change impacts on Irish birds. CCIP. Lecture to MSc environmental science students. | Trinity College Dublin | Tom Cooney |
| 23 April, 2008 | Progress report sent to COST |  | Alison Donnelly |
| 5–7 May, 2008 | COST Management Committee Meeting,<br>Presentation to WG3 | Bucharest, Romania. | Alison Donnelly |
| 14 May, 2008 | Field trip to Ireland's Eye (reverted to Howth Head – sea too rough). |  | Tom Cooney, Alison Donnelly, Hazel Proctor. Rebecca Stirnemann & Annelies Pletsers |
| 1 June, 2008 | Post-doc researcher begins | Trinity College Dublin | Dr Munang Tingem |
| 5 June, 2008 | Meeting to discuss website and biology.ie | Trinity College Dublin | Hazel Proctor, Alison Donnelly and Paul Whelan |
| June, 2008 | Field trip to Wicklow |  | Alison Donnelly, Hazel Proctor. Rebecca Stirnemann & Annelies Pletsers |
| 17 June, 2008 | Climate Change Research Adaptation Workshop.<br>Organised by EPA | Gresham Hotel, Dublin. | Alison Donnelly, Munang Tingem, Hazel Proctor, Rebecca Stirnemann, Annelies Pletsers and Amelia Caffarra |
| 18 June, 2008 | Kick-off project meeting. | Centre for Environment, Trinity College Dublin | In attendance: Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann, Munang Tingem, Mike B Jones, Daire, Ned Dwyer, Brian O'Connor, Amelia Caffara, Phillip O'Brien and Tom Cooney. |
| 20 June, 08 | Meeting with National Botanic Gardens. Discussed genetics and phenology. | TCD | Dr Colin Kelleher, Alison Donnelly, Amelia Caffarra and Annelies Pletsers |
| 6 August, 2008 | Group progress meeting | TCD | Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann |
| 18–21 August, 2008 | Visit to Johnstown Castle and JFK Arboretum Phenological gardens. Visited CMRC and UCC in Cork. Visit to Valentia Observatory. |  | Rebecca Stirnemann, Hazel Proctor, Annelies Pletsers and Alison Donnelly |

| Date | Event | Location | People Involved |
|---|---|---|---|
| 1 September, 2008 | Interview, in Irish with RTE and TG4 | | Alison Donnelly |
| 1 September, 2008 | Launch of Royal Irish Academy’s 6th Scientific Statement from the Irish Committee on Climate Change on Impacts of climate change on biodiversity. | | Mike Jones and Alison Donnelly. |
| 1–3 September, 2008 | Climate Change and Systematics Conference | Arts Building Trinity College | Rebecca Stirnemann, Hazel Proctor, Annelies Pletsers and Alison Donnelly |
| 8 September, 2008 | Interview on Newstalk at 2.45pm Sean Moncrief | | Alison Donnelly |
| 10 September, 2008 | Ecology Group Forum, presentation entitled Birds – patterns of change. | Zoology Building, TCD | Rebecca Stirnemann |
| 10–12 September, 2008 | PlantNetwork Conference, Climate change and planting for the future | Royal Agricultural College, Cirencester with Westonbirt National Arboretum | Annelies Pletsers and Alison Donnelly |
| 1 October, 2008 | blackberry records review. | National Botanic Garden, Dublin | Matthew Jebb, Eileen Diskin |
| 1 October, 2008 | research assistant started | | Eileen Diskin |
| 10 October, 2008 | Group meeting | TCD | Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann, Eileen Diskin |
| 15 October, 2008 | Guest speaker | Armagh Museum | Alison Donnelly |
| 23 October, 2008 | Interviewed Post-doc | TCD | Alison Donnelly, Bridget O’Neill |
| 4 November, 2008 | Group meeting | TCD | Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann, Eileen Diskin |
| 7 November, 2008 | Guest lecture | Dundalk Institute of Technology | Alison Donnelly |
| 11 November, 2008 | Meeting with Colin Kelleher | National Botanic Gardens | Annelies Pletsers |
| 17–19 November, 2008 | COST WG2 Meeting, Final report of WG2 | Zurich, Switzerland | Alison Donnelly |
| 20 November, 2008 | Ecology Group Forum | TCD | Annelies Pletsers |
| 26 November, 2008 | Group meeting | TCD | Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann, Eileen Diskin |
| 28 November, 2008 | Web design office | TCD | Alison Donnelly |
| 8 December, 2008 | Group meeting | TCD | Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann, Eileen Diskin |
| 9 December, 2008 | First Steering Committee Meeting | Gresham Hotel, Dublin | Alison Donnelly, Hazel Proctor, Annelies Pletsers, Rebecca Stirnemann, Eileen Diskin, Tom Cooney, Brian O’Connor, Ned Dwyer, Amelia Caffarra |
| 27–28 January, 2009 | COST meeting, WG2 | Vienna, Austria | Alison Donnelly |
| 1 February, 2009 | Post-doctoral researcher starts | | Bridget O’Neill |
| 4 February, 2009 | Project Website goes live | | |
| 5 February, 2009 | Meet Liam Lysaght | | Alison Donnelly |
| 10 February, 2009 | Contacted Aidan Kinch, DoEHLG | | Alison Donnelly |
| 11 February, 2009 | Contacted Noel Casserly, COMHAR | | Alison Donnelly |
| 11 February, 2009 | Conference call | | Rebecca Stirnemann, Alison Donnelly, John O’Halloran |
| 9 March, 2009 | Final COST725 management committee meeting | Geisenheim, Germany | Alison Donnelly |

| Date | Event | Location | People Involved |
|---|---|---|---|
| 10–12 March, 2009 | International conference on 'Scope and current limits of linking phenology and climatology' | Geisenheim, Germany | Alison Donnelly, Annelies Pletsers, Amelia Caffarra, Hazel Proctor, Bridget O'Neill, Eileen Diskin, Brian O'Connor |
| 19 March, 2009 | IPSAM | TCD | Annelies Pletsers, Alison Donnelly |
| 26 March, 2009 | Progress meeting for Rebecca's PhD | Botany Library, TCD | John O'Halloran, Rebecca Stirnemann and Alison Donnelly |
| 31 March, 2009 | Progress meeting with Brian O'Connor | Centre for the Environment, TCD | Brian O'Connor, Alison Donnelly and Ned Dwyer |
| 7 April, 2009 | Meeting to discuss TPR | in EPA | Margaret Desmond and Alison Donnelly |
| 21 April, 2009 | Eileen granted funding from IRCSET for PhD | | Eileen Diskin |
| 15 May, 2009 | Trinity Week. Round table discussion on EPA funded projects. | Ed Burke theatre, TCD | Alison Donnelly |
| 18 May, 2009 | Meeting with Ray McGrath and Tito Semmier to discuss climate scenarios | Met Eireann | Alison Donnelly, Bridget O'Neill, Rebecca Stirnemann, Eileen Diskin, Hazel Proctor, Annelies Pletsers |
| 21 May, 2009 | Spoke to Ilaria Nardello, Marine Institute with view to collaboration on marine phenology. | | Alison Donnelly |
| 27 May, 2009 | Meeting to discuss available datasets | National Biodiversity Data Centre in Waterford | Alison Donnelly, Bridget O'Neill, Rebecca Stirnemann, Eileen Diskin, Hazel Proctor, Annelies Pletsers, Dr Eugenie Regan and Director Dr Liam Lysaght |
| 24 June, 2009 | Meeting with Emily Gleeson, Met Eireann to show us sample dataset. | Centre for Environment, TCD | Bridget O'Neill, Alison Donnelly |
| 2–3 June, 2009 | Site visits to Glenveagh National Park and Armagh Observatory | | Alison Donnelly, Bridget O'Neill, Rebecca Stirnemann, Eileen Diskin, Hazel Proctor, Annelies Pletsers |
| 28 June, 2009 | TPR submitted | | Alison Donnelly, Bridget O'Neill |
| 29 June, 2009 | Site visit to NBDC | | Bridget O'Neill, Hazel Proctor, Alison Donnelly |
| 30 June, 2009 | Announced Phenology 2010 | | Alison Donnelly, Bridget O'Neill |
| 28 August, 2009 | Submitted funding proposal to EPA for phenology 2010 conference | | Alison Donnelly |
| 9 September, 2009 | Meeting re collaboration and ENSEMBLES | Met Eireann | Alison Donnelly, Bridget O'Neill, Rebecca Stirnemann, Eileen Diskin, Hazel Proctor, Annelies Pletsers |
| 26 September, 2009 | invited to be on the Royal Irish Academy's Climate Change Sciences Committee | | Alison Donnelly |
| 1 October, 2009 | Eileen begins PhD funded by IRCSET<br>Hazel begins MSc on the phenology project researching pollen | | Eileen Diskin, Hazel Proctor |
| 14 October, 2009 | Meeting in Cork with John O'Halloran | | Alison Donnelly, Rebecca Stirnemann |
| 21 October, 2009 | Interview with John Hennessy - Newstalk | | Alison Donnelly |
| 22 October, 2009 | Meeting in Met Eireann | | Ray McGrath, Bridget O'Neill, Alison Donnelly |

| Date | Event | Location | People Involved |
|---|---|---|---|
| 27–29 October, 2009 | Steering committee meeting – National Botanic Gardens | | Alison Donnelly, Bridget O'Neill, Rebecca Stirnemann, Annelies Pletsers, Hazel Proctor, Eileen Diskin, Amelia Caffarra, Tom Cooney, Ned, Brian, Tim, Esa, Matthew & Margaret |
| 12 November, 2009 | Guest lecture | Dundalk Institute of Technology | Alison Donnelly |
| 20 November, 2009 | Received funding from USGS for Phenology 2010 | | Alison Donnelly |
| 3 December, 2009 | Confirmation of funding from Trinity Visual Arts fund for Phenology 2010 | | Alison Donnelly |
| 6 December, 2009 | Newstalk programme 7am | | Alison Donnelly |
| 8 December, 2009 | Meeting with Dr Gary Lanigan and Dr Daire Dr Daire Ó hUallacháin to set up pollen trap | Johnstown Castle | Alison Donnelly, Hazel Proctor |
| December, 2009 | Phenology 2010 advertised in the Irish Meteorological Societies Newsletter | | Alison Donnelly, Bridget O'Neill |
| 11 January, 2010 | Letter from Minister for the Environment confirming he will open Phenology 2010 | | Alison Donnelly |
| 1 March, 2010 | Conference call with Eugenie Regan at NBDC to discuss Nature Watch press release. | | Alison Donnelly, Bridget O'Neill |
| 4 March, 2010 | Invited speaker at forest monitoring workshop, organised by UCD. 4-5 March 2010 | | Alison Donnelly |
| 10 March, 2010 | Phenology workshop presentation on uses and applications of phenological data. | National Botanic Gardens | Alison Donnelly, Annelies Pletsers, Rebecca Stirnemann, Eileen Diskin, Hazel Proctor, Bridget O'Neill |
| 24 March, 2010 | discuss Whooper paper and MSc thesis | | Rebecca, Alison and John O'Halloran |
| 27 March, 2010 | Attended Irish Meteorological Society Conference | National Botanic Garden | Alison Donnelly, Bridget O'Neill, Annelies Pletsers, Rebecca Stirnemann |
| 7–10 April, 2010 | Attended International Conference on Phenology: plant ecology and diversity | Edinburgh, Scotland | Annelies Pletsers |
| 10 April, 2010 | Article in Irish Times (Michael Viney) http://www.irishtimes.com/newspaper/weekend/2010/0410/1224268016012.html | | |
| 20 April, 2010 | Interview on 4FM radio 18.45 with Tom McGurk | | Alison Donnelly |
| 20 April, 2010 | Nature Watch launched with a press release from Trinity College | | |
| 21 April, 2010 | Article in Mirror | | |
| 23 April, 2010 | Invited speaker at Transforming Ireland<br>Mobilising Innovation and Enterprise to Become a Prosperous Low Carbon Society, Mont Clare Hotel, Friday 12.30pm. Climate Change in Ireland - what's likely to happen? 23rd April 2010, Buds and Birds. | UCD Earth Sciences Institute | Alison Donnelly |
| 26 April, 2010 | Article in Irish Times | | |

| Date | Event | Location | People Involved |
|---|---|---|---|
| 27 April, 2010 | Nationalist - Carlow PRESS Nature reacts to rising heat 27-Apr-2010 2<br>Kildare Nationalist PRESS Nature reacts to rising heat 27-Apr-2010 3<br>Laois Nationalist PRESS Nature reacts to rising heat 27-Apr-2010 4<br>Irish Daily Mirror PRESS WILDLIFE WARNING 21-Apr-2010 5 | | |
| 28 April, 2010 | Timpeall Orainn on Raidio na Life | | Alison Donnelly |
| 1 May, 2010 | Article in IT (http://www.irishtimes.com/newspaper/weekend/2010/0501/1224269451391.html) | | Alison Donnelly |
| 2 May, 2010 | Meeting in Met Eireann, – to discuss finalising phenology paper. | | Alison Bridget, Emily and Ray McGrath |
| 3 May, 2010 | Evidence of both phenological and range shifts in birds in response to increasing temperature in Ireland | European Geosciences Union, Vienna | Alison Donnelly and Bridget O’Neill |
| 20 May, 2010 | Meeting in UCC with David Healy, David O’Connor and John Sodeau. Hazel and Alison gave presentations, discussed collaboration and strategy for pollen analyses. | | Hazel Proctor, Alison Donnelly |
| 2 June, 2010 | Meeting at Met Eireann with Emily Gleeson and Ray McGrath to discuss future collaboration possibilities | | Alison Donnelly, Bridget O’Neill |
| 14–18 June, 2010 | Phenology 2010; climate change impacts and adaptations. | TCD | Alison Donnelly, Amelia Caffarra, Eileen Diskin, Annelies Pletsers, Hazel Proctor, Brian O’Connor, Bridget O’Neill |
| 15 June, 2010 | Interview for Science Spin 11.30 am | | Alison Donnelly |
| 17 June, 2010 | Latest Science Spin podcast, broadcast on 103.2 Dublin City FM, on 17th June 2010. What’s it all about?: The science of phenology. http://sciencespin.podOmatic.com/entry/2010-06-21T08_25_35-07_00 | | Alison Donnelly |
| 18 June, 2010 | An international workshop the validation for satellite-based land surface phenology products. A workshop of the Committee on Earth Observing Satellites: Land Product Validation subgroup. Sponsored by TCD, USGS and USANPA | TCD USANPN and USGS | Alison Donnelly, Amelia Caffarra, Eileen Diskin, Annelies Pletsers, Hazel Proctor, Brian O’Connor, Bridget O’Neill |
| 14–16 June, 2010 | CIRCLE-2 ERA Net Kick off meeting - (www.circle-era.net) | Alexander Hotel, Dublin | Alison Donnelly |
| 21 June, 2010 | Meeting with Marie Russell Keatley and Lynda Chambers to discuss potential Australian involvement and collaborations with the National Phenology Network and Nature Watch. | TCD | Bridget O’Neill, Hazel Proctor |
| 28 June, 2010 | Attended European Space Agency (ESA) Living Planet Symposium. | Bergen, Norway | Brian O’Connor |
| 30 June, 2010 | Report on Phenology 2010 conference to EPA Climate Change Conference | Aviva Stadium | Alison Donnelly |
| 26 July, 2010 | Phenology network on LinkedIn | | |
| 11 August, 2010 | Meeting with Rory Scarrott, Ned Dwyer and Fiona Cakwell from UCC to report on progress to date on the remote sensing work. | TCD | Alison Donnelly, Bridget O’Neill, Hazel Proctor, Annelies Pletsers and Eileen Diskin |

| Date | Event | Location | People Involved |
|---|---|---|---|
| 25 August, 2010 | Meeting with Gerald Fleming, Met Eireann to discuss pollen project and forecasting | Centre for Environment, TCD | Hazel Proctor, Alison Donnelly |
| 7 September, 2010 | Agri-environment conference hosted by Teagasc | Ballykisteen, Co. Tipperary | Alison Donnelly |
| 23 September, 2010 | Phenology in a changing world: exploring rhythms in nature. | Instituto Agrario di San Micele, Trento, Italy | Alison Donnelly, Bridget O’Neill, Hazel Proctor, Eileen Diskin, Annelies Pletsers, Amelia Caffarra, Rory Scarrott |
| 4 November, 2010 | Newsletter article for British Aerobiology Federation | | Hazel Proctor |
| 4 November, 2010 | Newsletter article for International Aerobiology Association | | Hazel Proctor |
| 5 November, 2010 | Invited speaker - Phenology: what it is and why it’s important.<br>Establish a phenology garden. | NUI Galway | Alison Donnelly, Hazel Proctor |
| 11 November, 2010 | Attended EPA post-graduate seminar in Convention Centre | | Alison Donnelly, Hazel Proctor, Brian O’Connor, Annelies Pletsers, Bridget O’Neill |
| 11 November, 2010 | Pollen meeting – David Dodd, Dave O’Connor and John Sodeau | | Alison Donnelly, Hazel Proctor |
| 14–25 February, 2011 | Annelies spent time in Instituto Agrario di San Michele to do modelling | | Annelies Pletsers, Amelia Caffarra |
| 16-18 February, 2011 | AD went to meeting in Trento with AP and AC | | Alison Donnelly, Amelia Caffarra, Annelies Pletsers |
| 2 March, 2011 | Final Steering Committee Meeting | | Alison Donnelly, Bridget O’Neill, Annelies Pletsers, Hazel Proctor, Emily, Colin, Matthew, Esa and Tim, Ned, Rory |
| 26 March, 2011 | Irish Met Society Climate Change Conference | | Alison Donnelly and Hazel Proctor |
| 1 April, 2011 | Timing is everything; phenology as an indicator of climate change | Met Eireann | Alison Donnelly |
| April, 2011 | Timing is everything Article in IMS newsletter | | |
| 4–8 April, 2011 | EGU 2011, Vienna Austria | | Alison Donnelly, Bridget O’Neill, Hazel Proctor, Amelia Caffarra |
| 6 April, 2011 | PEP meeting, Vienna, Austria | | Alison Donnelly, Bridget O’Neill, Amelia Caffarra |
| 11 May, 2011 | Guest lecture in University of Nottingham - Timing is everything; phenology as an indicator of climate change | | Alison Donnelly |
| 6–13 July, 2011 | Aerobiology course, Copenhagen, Denmark | | Hazel Proctor |
| 20 July, 2011 | Meeting with NBDC, Waterford | | Alison Donnelly, Bridget O’Neill, Eugenie Regan |

## Appendix 3: Presentations

| Title | Location | Authors | Date | Oral | Poster |
|---|---|---|---|---|---|
| CCIP (Climate Change Impacts on Phenology; implications for terrestrial ecosystems) | COST 725, WG2 Workshop in Ljubljana, Slovenia | Alison Donnelly | 12–13 November, 2007 | X | |
| How to build a platform for a national phenological network. Experience from Ireland. | Phenology workshop, Alnarp, Sweden | Alison Donnelly | 7 February, 2008 | X | |
| CCIP (Climate Change Impacts on Phenology; implications for terrestrial ecosystems) | Management Committee Meeting of COST 725, Bucharest, Romania. | Alison Donnelly | 6–7 May, 2008 | X | |
| Climate change impacts on phenology: implications for terrestrial ecosystems | Systematics and Climate Change Conference, TCD | Annelies Pletsers, Rebecca Stirnemann, Alison Donnelly, Hazel Proctor | 1–3 September, 2008 | | X |
| Birds – patterns of change | Ecology Group Forum, TCD | Rebecca Stirnemann | 10 September, 2008 | X | |
| Climate change impacts on terrestrial ecosystems in Ireland | Climate Change and Planting for the Future Conference PlantNetwork, Royal Agricultural College, Cirencester, UK | Alison Donnelly | 10–12 September, 2008 | X | |
| Climate Change impacts on phenology: implications for terrestrial ecosystems | Climate Change and Planting for the Future Conference PlantNetwork, Royal Agricultural College, Cirencester, UK | Annelies Pletsers, Alison Donnelly | 10-12 September, 2008 | | X |
| Detecting Climate Change | Dundalk Institute of Technology, Dundalk, Ireland | Alison Donnelly | 7 October, 2008 | X | |
| Detecting Climate Change in our Environment | Armagh Museum, Armagh, UK | Alison Donnelly | 15 October, 2008 | X | |
| Climate change impacts on phenology: implications for terrestrial ecosystems | 5th Ornithological Conference University College Cork, Ireland | Rebecca Stirnemann | 15–16 November, 2008 | | X |
| Trees, Phenology and Climate Change | Ecology Group Forum, TCD | Annelies Pletsers, Alison Donnelly | 20 November, 2008 | X | |
| Blackberry (*Rubus spp.*) Phenology in Ireland: An Exploration Using Herbarium Specimens | Scope and current limits of linking phenology and climatology in Geisenheim, Germany | Eileen Diskin, Hazel Proctor, Matthew Jebb and Alison Donnelly | 10–12 March, 2009 | X | |
| Assessing the Genetic Variation of Dormancy-Related Traits in European Trees | Scope and current limits of linking phenology and climatology in Geisenheim, Germany | Annelies Pletsers, Colin Kelleher, Mike Jones and Alison Donnelly | 10–12 March, 2009 | X | |
| Satellite Observations of Seasonal Trends in Irish Vegetation | Scope and current limits of linking phenology and climatology in Geisenheim, Germany | Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 10–12 March, 2009 | X | |
| Expansion of the Phenological Gardens Network in Ireland | Scope and current limits of linking phenology and climatology in Geisenheim, Germany | Hazel Proctor and Alison Donnelly | 10–12 March, 2009 | | X |
| Assessing the Genetic Variation of Dormancy-Related Traits in European Trees | Irish Plant Scientists' Association meeting at TCD | Annelies Pletsers, Colin Kelleher, Mike Jones and Alison Donnelly | 19–20 March, 2009 | X | |

| Title | Location | Authors | Date | Oral | Poster |
|---|---|---|---|---|---|
| On a Methodology to Extract Measures of Seasonality from Satellite Data to Characterise Seasonal Trends in Irish Vegetation | Conference of Irish Geographers, University College Cork | Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 15–16 May, 2009 | X | |
| Impact of Climate Warming on Whopper Swan Wintering Phenology in Ireland | European Ornithologist's Union conference in Zurich | Rebecca Stirnemann, John O'Halloran and Alison Donnelly | 21–26 August, 2009 | | X |
| On a Methodology to Extract Measures of Seasonality from Satellite Data to Characterise Seasonal Trends in Irish Vegetation | Remote Sensing and Photogrammetry Society (RSPSoc) conference in Leicester, UK | Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 8–11 September, 2009 | X | |
| Detecting Climate Change | Dundalk Institute of Technology, Dundalk, Ireland | Alison Donnelly | 12 November, 2009 | X | |
| On a Methodology to Extract Measures of Seasonality from Satellite Data to Characterise Seasonal Trends in Irish Vegetation | 3rd Annual Irish Earth Observation Symposium, Geological Survey of Ireland in Dublin, Ireland | Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 12–13 November, 2009 | X | |
| The Use of Climate Projections in Phenological Modelling | ENSEMBLES symposium in Exeter, UK | Bridget O'Neill, Amelia Caffarra, Emily Gleeson, Tido Semmler, Ray McGrath and Alison Donnelly | 17–19 November, 2009 | | X |
| The Use of Climate Projections in Phenological Modelling | Irish Meteorological Society Conference at National Botanic Garden, Dublin, Ireland | Bridget O'Neill, Amelia Caffarra, Emily Gleeson, Tido Semmler, Ray McGrath and Alison Donnelly | 27 March, 2010 | | X |
| Impact of Climate Warming on Whopper Swan Wintering Phenology in Ireland | Irish Meteorological Society Conference at National Botanic Garden, Dublin, Ireland | Rebecca Stirnemann, John O'Halloran and Alison Donnelly | 27 March, 2010 | | X |
| Investigating Temperature-Related Genotypic and Phenotypic Variation in European Aspen (*Populus tremula* L.) | Irish Meteorological Society Conference at National Botanic Garden, Dublin, Ireland | Annelies Pletsers, Colin Kelleher, Amelia Caffarra and Alison Donnelly | 27 March, 2010 | | X |
| Investigating Temperature-Related Genotypic and Phenotypic Variation in European Aspen (*Populus tremula* L.) | International Conference on Phenology: plant ecology and diversity in Edinburgh, Scotland | Annelies Pletsers, Colin Kelleher, Amelia Caffarra and Alison Donnelly | 7–9 April, 2010 | | X |
| Evidence of both phenological and range shifts in birds in response to increasing temperature in Ireland | European Geosciences Union, Grand Assembly in Vienna, Austria | **Alison Donnelly**, Tom Cooney, Rebecca Stirnemann, and John O'Halloran | 2–7 May, 2010 | X | |
| The Use of Climate Projections in Phenological Modelling | European Geosciences Union, Grand Assembly in Vienna, Austria | Bridget O'Neill, Amelia Caffarra, Emily Gleeson, Tido Semmler, Ray McGrath and Alison Donnelly | 2–7 May, 2010 | | X |
| Multiple Applications of Phenological Data | Phenology 2010, TCD, Ireland | Alison Donnelly | 14–17 June, 2010 | X | |

| **Title** | **Location** | **Authors** | **Date** | **Oral** | **Poster** |
|---|---|---|---|---|---|
| Modelling Plant Phenology in a Warming Climate | Phenology 2010, TCD, Ireland | Amelia Caffarra, Isabelle Chuine, Alison Donnelly, Eccel Emanuele, Ilaria Pertot, Bridget O'Neill and Monica Rinaldi | 14–17 June, 2010 | X | |
| *Rubus spp*. Phenology in Ireland in Response to Climate Warming: an Exploration Using Herbarium Specimens | Phenology 2010, TCD, Ireland | Eileen Diskin, Hazel Proctor, Matthew Jebb, Tim Sparks and Alison Donnelly | 14–17 June, 2010 | X | |
| Investigating Temperature-Related Genotypic and Phenotypic Variation in European Aspen (*Populus tremula* L.) | Phenology 2010, TCD, Ireland | Annelies Pletsers, Colin T. Kelleher, Amelia Caffarra and Alison Donnelly | 14–17 June, 2010 | X | |
| Potential Impacts of Climate Variables on the Pollen Season of Birch (*Betula spp*.) and Related Species in Ireland | Phenology 2010, TCD, Ireland | Hazel Proctor, Paul Dowding and Alison Donnelly | 14–17 June, 2010 | X | |
| Spatio-Temporal Trends in Season Timing Across the Island of Ireland According to Landcover Type | Phenology 2010, TCD, Ireland | Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 14–17 June, 2010 | X | |
| Effect of Climatic Warming on the Flight Periods of Irish Moth Species | Phenology 2010, TCD, Ireland | Bridget O'Neill, Angus Tyner, Ken Bond, Ralph Sheppard, Tony Bryant and Alison Donnelly | 14–17 June, 2010 | | X |
| Nature Watch: The Irish National Phenology Network's New Citizen Science Website | Phenology 2010, TCD, Ireland | Bridget O'Neill, Hazel Proctor, Eugenie Regan, Liam Lysaght and Alison Donnelly | 14–17 June, 2010 | | X |
| Expansion of the Phenological Gardens Network in Ireland | Phenology 2010, TCD, Ireland | Hazel Proctor and Alison Donnelly | 14–17 June, 2010 | | X |
| The use of METEOSAT cloud mask data as a verification of MGVI clear sky value | RSPSoc2010 Annual Conference, University College Cork, Ireland | Brian O' Connor, Ned Dwyer and Fiona Cawkwell | 1–3 September, 2010 | X | |
| Characterisation of Irish land cover based on smoothed time-series of the MODIS Enhanced Vegetation Index | RSPSoc2010 Annual Conference, University College Cork, Ireland | Rory Scarrott, Brian O' Connor, Ned Dwyer and Fiona Cawkwell | 1–3 September, 2010 | | X |
| Phenology: trends in recurring natural cycles | Agri-environment conference | Alison Donnelly | 7 September, 2010 | X | |
| Multiple Applications of Phenological Data | Phenology in a Changing World: Exploring Rhythms in Nature Symposium, Aula Convitto, San Michele all'Adige, Italy | Alison Donnelly, Bridget O'Neill, Hazel Proctor and Eugenie Regan | 23 September, 2010 | X | |
| Potential Impacts of Climate Variables on the Pollen Season of Birch (*Betula spp*.) and Related Species in Ireland. | Phenology in a Changing World: Exploring Rhythms in Nature Symposium, Aula Convitto, San Michele all'Adige, Italy | Hazel Proctor, Paul Dowding and Alison Donnelly | 23 September, 2010 | X | |
| Investigating Temperature-Related Genotypic and Phenotypic Variation in European Aspen (*Populus tremula* L.) | Phenology in a Changing World: Exploring Rhythms in Nature Symposium, Aula Convitto, San Michele all'Adige, Italy | Annelies Pletsers, Colin T. Kelleher, Amelia Caffarra and Alison Donnelly | 23 September, 2010 | X | |

| Title | Location | Authors | Date | Oral | Poster |
|---|---|---|---|---|---|
| *Rubus spp*. Phenology in Ireland in Response to Climate Warming: an Exploration Using Herbarium Specimens | Phenology in a Changing World: Exploring Rhythms in Nature Symposium, Aula Convitto, San Michele all'Adige, Italy | Eileen Diskin, Hazel Proctor, Matthew Jebb, Tim Sparks and Alison Donnelly | 23 September, 2010 | X | |
| Effect of Climatic Warming on the Flight Periods of Irish Moth Species | Phenology in a Changing World: Exploring Rhythms in Nature Symposium, Aula Convitto, San Michele all'Adige, Italy | Bridget O'Neill, Angus Tyner, Ken Bond, Ralph Sheppard, Tony Bryant and Alison Donnelly | 23 September, 2010 | X | |
| Applying Earth Observation to Vegetation Seasonality Research in Ireland | Phenology in a Changing World: Exploring Rhythms in Nature Symposium, Aula Convitto, San Michele all'Adige, Italy | Rory Scarrott, Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 23 September, 2010 | X | |
| On a Methodology to Extract Measures of Seasonality from MERIS Reduced Resolution Data to Characterise Seasonal Trends in Irish Vegetation | EPA Strive Symposium, Dublin, Ireland | Brian O' Connor, Ned Dwyer and Fiona Cawkwell | 11 November, 2010 | X | |
| Monitoring Vegetation Seasonality in Ireland from Envisat MERIS | EPA Strive Symposium, Dublin, Ireland | Brian O' Connor, Ned Dwyer and Fiona Cawkwell | 11 November, 2010 | | X |
| Investigating Temperature-Related Genotypic and Phenotypic Variation in European Aspen (*Populus tremula* L.) | EPA Strive Symposium, Dublin, Ireland | Annelies Pletsers, Colin T. Kelleher, Amelia Caffarra and Alison Donnelly | 11 November, 2010 | | X |
| Potential Impacts of Climate Variables on the Pollen Season of Birch (*Betula spp*.) and Related Species in Ireland. | EPA Strive Symposium, Dublin, Ireland | Hazel Proctor, Paul Dowding and Alison Donnelly | 11 November, 2010 | | X |
| Effect of Climatic Warming on the Flight Periods of Irish Moth Species | Entomological Society of America's annual meeting, San Diego, USA | Bridget O'Neill, Angus Tyner, Ken Bond, Ralph Sheppard, Tony Bryant and Alison Donnelly | 12–15 December, 2010 | | X |
| Potential Impacts of Climate Variables on the Pollen Season of Birch (*Betula spp*.) and Related Species in Ireland | Irish Meteorological Society Conference, 'Ireland's Weather Past, Present and Future', NUI Maynooth, Co. Kildare | Hazel Proctor, Paul Dowding and Alison Donnelly | 26 March, 2011 | | X |
| Timing is everything; phenology as an indicator of climate change | Met Eireann | Alison Donnelly | 1 April, 2011 | X | |
| Potential Impacts of Climate Variables on the Pollen Season of Birch (*Betula spp*.) and Related Species in Ireland | European Geosciences Union annual conference in Vienna, Austria | Hazel Proctor, Paul Dowding and Alison Donnelly | 4–5 April, 2011 | | X |
| Land Cover and Vegetation Seasonality – Lessons from time-series satellite data analysis | European Geosciences Union annual conference in Vienna, Austria | Brian O' Connor, Rory Scarrott, Ned Dwyer and Fiona Cawkwell | 4–5 April, 2011 | | X |
| Effect of Climatic Warming on the Flight Periods of Irish Moth Species | European Geosciences Union annual conference in Vienna, Austria | Bridget O'Neill, Angus Tyner, Ken Bond, Ralph Sheppard, Tony Bryant and Alison Donnelly | 4–5 April, 2011 | | X |

| Title | Location | Authors | Date | Oral | Poster |
|---|---|---|---|---|---|
| Effect of Climatic Warming on the Flight Periods of Irish Moth Species | Pan European Phenology meeting in Vienna, Austria | Bridget O'Neill, Angus Tyner, Ken Bond, Ralph Sheppard, Tony Bryant and Alison Donnelly | 6 April, 2011 | X | |
| Characterising land cover using vegetation seasonality profiles determined from satellite imagery | ENVIRON 2011 conference, UCC, Cork, Ireland | Rory Scarrott, Brian O'Connor, Ned Dwyer and Fiona Cawkwell | 6–8 April, 2011 | X | |
| Timing is everything; phenology as an indicator of climate change | University of Nottingham | Alison Donnelly | 11 May, 2011 | X | |

# An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomhnithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

## ÁR bhFREAGRACHTAÍ

### CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

### FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

### MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

### RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

### TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

### MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

### PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

### BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

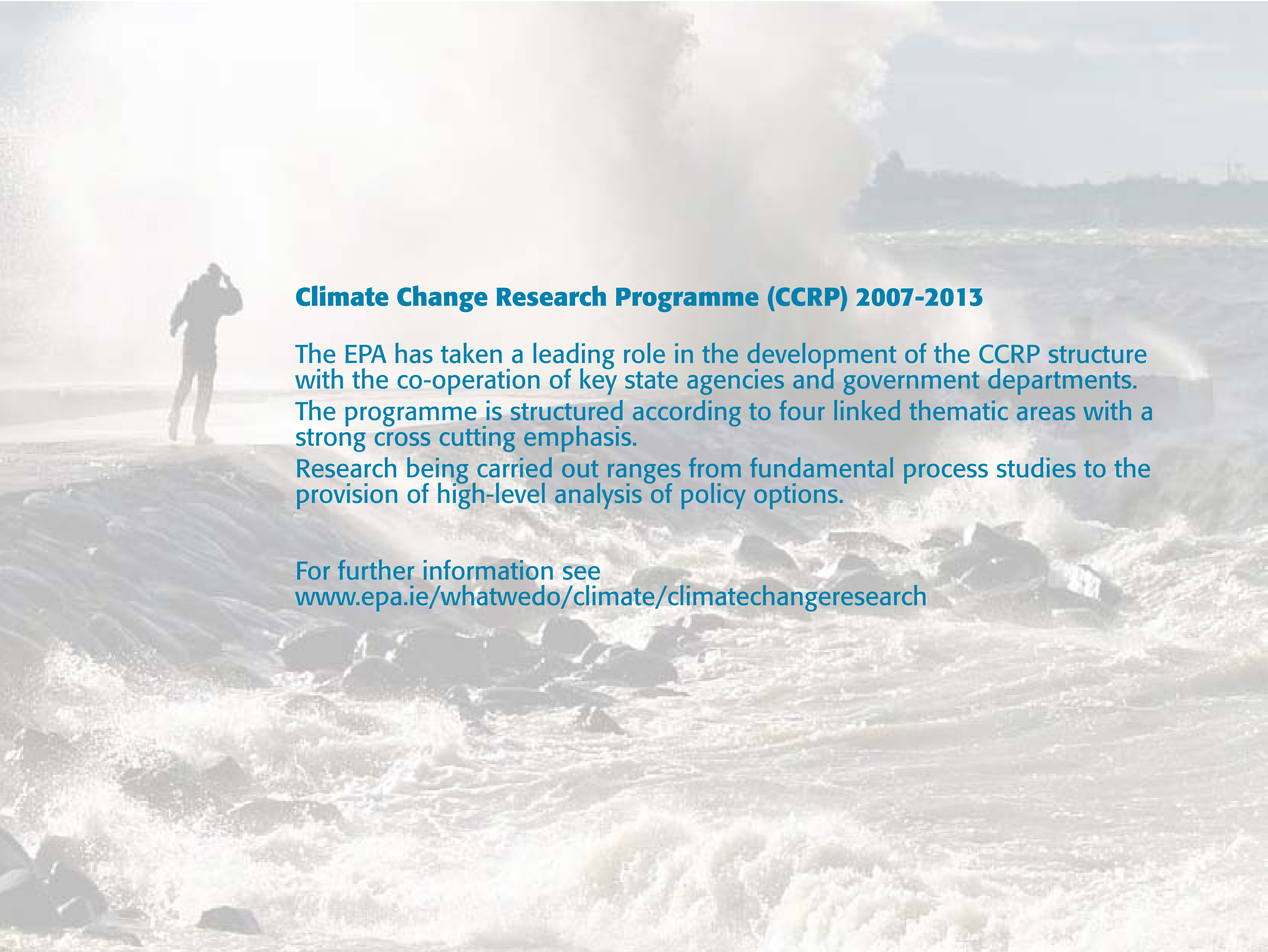
### STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.



## Climate Change Research Programme (CCRP) 2007-2013

The EPA has taken a leading role in the development of the CCRP structure with the co-operation of key state agencies and government departments.
The programme is structured according to four linked thematic areas with a strong cross cutting emphasis.
Research being carried out ranges from fundamental process studies to the provision of high-level analysis of policy options.

For further information see
www.epa.ie/whatwedo/climate/climatechangeresearch

Environmental Protection Agency
*An Ghníomhaireacht um Chaomhnú Comhshaoil*

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e info@epa.ie  w http://www.epa.ie

SSTI
Strategy for Science, Technology and Innovation

**Comhshaol, Pobal agus Rialtas Áitiúil**
Environment, Community and Local Government