8.2 SHIFTS IN THE DATE OF FLOWERING COMMENCEMENT IN SOME AUSTRALIAN PLANTS

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1. INTRODUCTION

Phenological datasets have been used to document the impacts of climate change on natural systems in many parts of the world (e.g. Europe, Asia and the Americas) (Fitter and Fitter 2002; Inouye et al. 2000; Menzel 2000; Root et al. 2003; Visser et al. 2003). These, and many other studies, show that there has been a change in phenology (e.g. an advancement in the commencement of leafing, flowering, an extension of the growing season, earlier arrival of migrating birds) as well as a change in plant and animal distribution (e.g. extension of the range of butterflies).

The studies which inform this conclusion are based primarily on northern hemisphere research, because of an apparent paucity of data in the southern hemisphere (Parmesan and Yohe 2003; Root et al. 2003). In Australia this is attributable to a rarity of natural data sets of the required length (20 years (Allen et al. 1994; Keatley et al. 2002; Sparks and Menzel 2002; Westoby 1991)) which can detect such trends. It does not reflect that such changes as observed in the northern hemisphere have not occurred, as changes in temperature, rainfall and other climate variables in Australia are similar to those observed globally (Howden et al. 2003).

A recent review (Hughes 2003) of the potential impacts of climate change on biodiversity highlighted the need for such studies. The review suggested that a change in the timing of reproductive activity may lead to major changes in ecosystem composition, and thus biodiversity of Australian ecosystems.

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Previous work on eucalypt flowering phenology, covering 1940 to 1971, has indicated that changes in temperature are likely to translate to changes in flowering commencement (Hudson et al. 2003; Keatley et al. 2002).

This paper uses a 20 year flowering record of four species to examine whether there has been a significant change over time in the commencement of flowering. It also examines whether there has been an increase in local temperature over time.

The study reports a statistically significant shift in the commencement of flowering in two of the plants examined.

2. DATA AND METHODS

Phenological data

The records used in this study come from the state of Victoria, in south-east Australia (Fig. 1) and have been collected by one observer between 1983 and the present. Observations were initially undertaken 3 times a week but since the late 1990s have been recorded weekly. Weekday recordings represent 64.2% of this dataset. Records currently available for examination cover the period from 1983 to 2002.

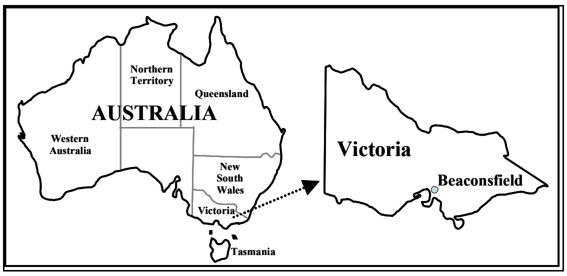

Fig. 1. Location of observations.

The dates of first flowering of 126 species from within one community have been recorded – approximately 45 species are presently suitable for examination (i.e. greater than 20 years of observation) (Menzel 2000).

Weather data

Weather data were obtained from the Bureau of Meteorology from the nearest weather station (approx. 22kms from the site), Scoresby (station number 086104). Data are available from 1965 until the present although the dataset is not complete. When only 1 day was missing, the average of the temperature either side of the missing date was used. If 2 or more days were not recorded, then the mean minimum or maximum temperature for that particular month was substituted. Data were missing between December 1989 and March 1990, October 1994 and August 1996. The weather data were examined (based on mean annual statistics for the daily mean, minimum and maximum temperatures), via simple linear regression, to determine whether there had been a change over time.

Methods

The date of flowering commencement for four species, arbitrarily chosen from the data set, were also examined by simple linear regression, to examine potential changes in flowering behaviour over the time of observation:

- *Glycine clandestina* J.C. Wendl [Twining glycine],
- *Thysanotus tuberosus* R. Br. [Tufted fringe lily],
- *Dichondra repens* J.R & G. Forst. [Kidney plant] and
- *Wahlenbergia stricta* (R. Br.) Sweet [Tall bluebell].

Lastly, as temperature is a major influence on phenological events such as flowering (Snyder et al. 2001) linear regression was also used to determine if flowering commencement date was related to either accumulated (daily) minimum, maximum or mean temperature in the period from September 1st to the mean flowering commencement date of each year.

3. RESULTS

The annual average of the mean and maximum daily temperature were found to have increased by 0.83ºC and 1.08ºC during the period from 1965 to 2002 (linear regression P < 0.001 and, P < 0.0001, respectively) (Fig. 2).

Over the period of observation of flowering (1983 to 2002), only the annual mean of maximum temperature exhibited a significant change (P < 0. 014), increasing by 0.89ºC (Fig. 2A box). During this period, linear trends in annual means of daily mean and minimum temperature were not significant (P > 0.30).

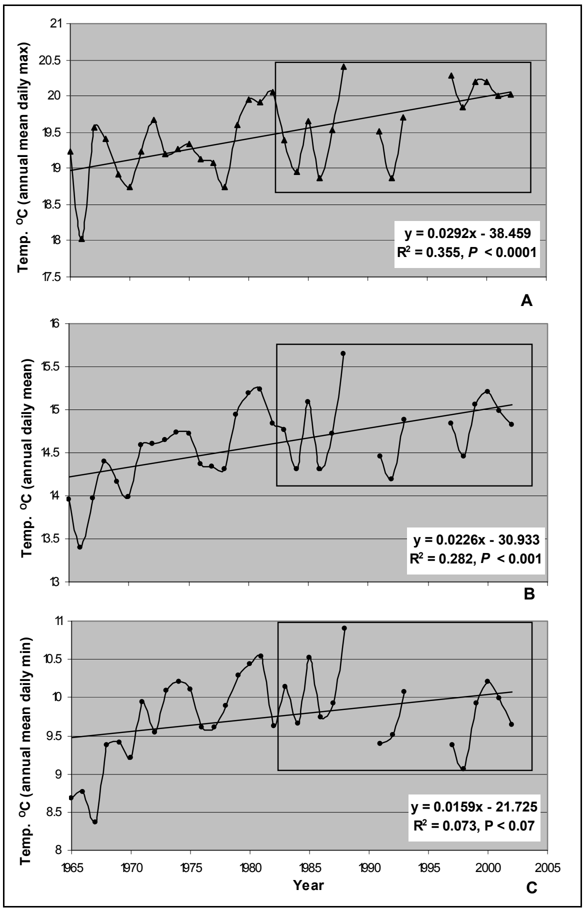

Fig. 2. Trends in annual temperature statistics at Scoresby weather station 1965 to 2002. A) Annual mean daily maximum temperature, B) annual mean daily temperature and C) annual mean daily minimum temperature.

Two of the observed species (*Glycine clandestina* [Twining glycine] and *Thysanotus tuberosus* [Tufted fringe lily]) have shown significant shifts (P < 0.001 and P = 0.044, respectively) in their date of first flowering (Fig. 3). This shift equates to 46 days later flowering commencement in twining glycine. The latest commencement of flowering was October 22nd (yearday 295) 2002 – in the last year of observations currently being examined.

Tufted fringe lily, however, has commenced flowering earlier (42 days); the earliest commencements of flowering were in 1985 and 2002, being on the 9th of October (yearday 282).

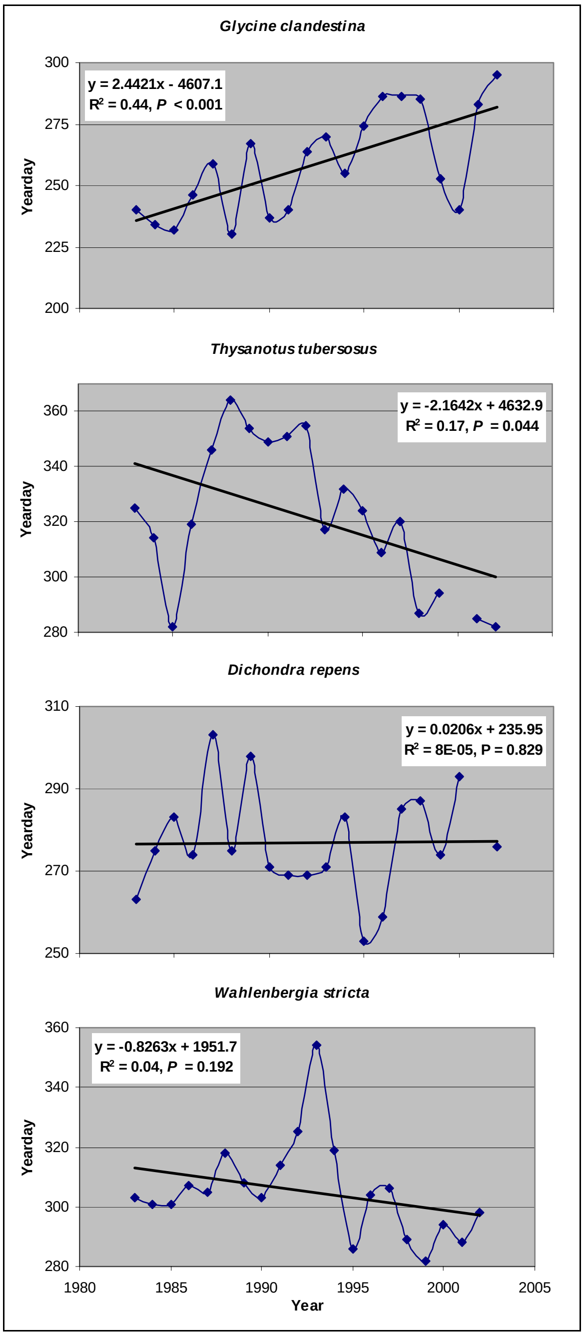

Fig. 3. Trends in flowering commencement dates of four plants.

The remaining two species (*Dichondra repens* [Kidney plant] and *Wahlenbergia stricta* [Tall bluebell]) have not had significant shifts in their dates of first flowering (P > 0.192). Kidney plant has basically remained unchanged (0.39 days over the 20 years). For Tall bluebell, although the shift is not significant, the negative trend would equate to flowering 15 days earlier.

An examination of the relationship between accumulated minimum, maximum or mean temperature in the period from September 1st to the mean flowering commencement date for each species found no significant relationship (P > 0.254) (Fig. 4).

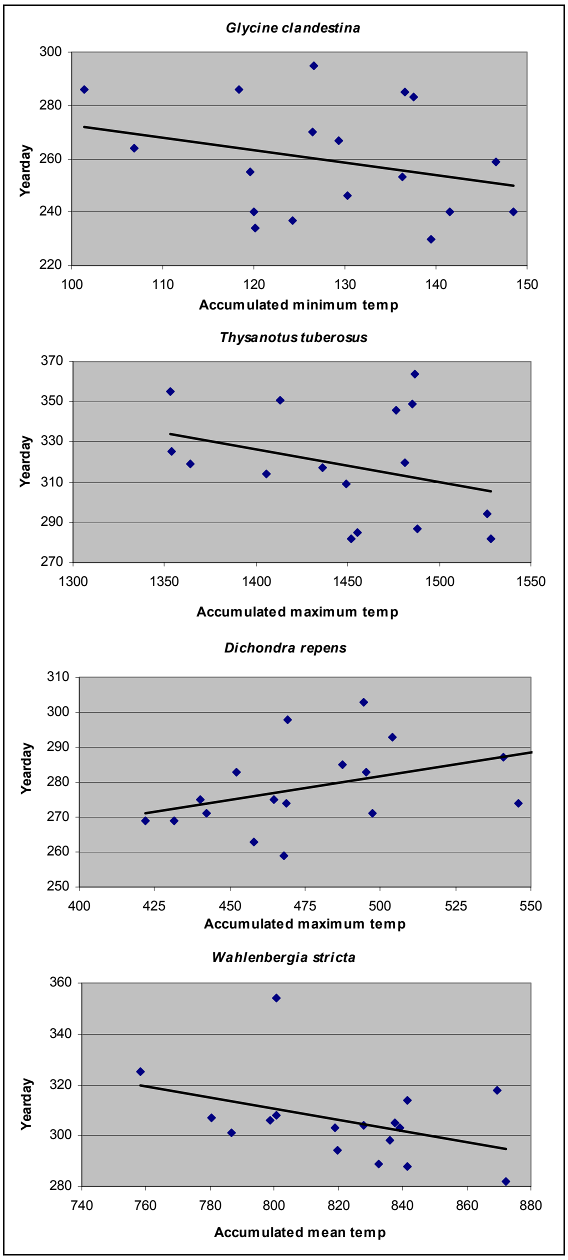

Fig. 4. Relationships between various accumulated temperatures and the flowering dates of the four species.

The temperature statistic with the most explanatory power for flowering commencement date varied between species (accumulated maximum temperature for *Thysanotus tuberosus* and *Dichondra repens*, accumulated mean temperature for *Wahlenbergia stricta*, and accumulated minimum temperature for *Glycine clandestina*).

4. DISCUSSION

Annual means of the daily average and daily maximum temperatures have increased significantly at the selected weather station over the last thirty-nine years. The increase in mean annual temperature over this period (0.82ºC) is in broad agreement with the reported increase in Australia's average temperature of 0.76ºC, although the latter occurred over longer period (from 1910 to 1999). The majority of this increase, however, has occurred since 1950. (Manins et al. 2001; Torok and Nicholls 1996). The increase in annual mean of the maximum daily temperature is much greater than the Australian average (1.08ºC compared to 0.56ºC) whereas the minimum has not increased as much (0.56ºC compared to 0.96ºC) (Manins et al. 2001). Such deviation from the mean, minimum and maximum temperature trends across Australia is within the observed range. For example, maximum temperature trends differ by -1.5 to 2ºC from the mean (Bureau of Meteorology 2003).

While the four species examined here have been arbitrarily chosen, they demonstrate a diversity of responses occurring in Australian plants, similar to those recorded in other studies (e.g. no trend, earlier and later phenology (Fitter and Fitter 2002; Parmesan and Yohe 2003; Sparks and Menzel 2002)). The shifts in flowering are only partly explained by the changes in the temperature. The temperature statistic with the most explanatory power for flowering commencement date varied between species. This suggests that the mechanism of temperature influence varies between species, and may explain why the shifts in flowering vary between species. However, the temperature variables examined here were not found to be significant (although at P = 0.10 the relationship between temperature and *Glycine clandestina* was tending towards significance).

For three of these species the relationship between temperature and flowering date was consistent with the observed shift in flowering date (*Thysanotus tuberosus, Dichondra repens* and *Wahlenbergia stricta*). The relationship suggested between *Glycine clandestina* and temperature, however, is inconsistent with observed changes in flowering (a negative relationship would suggest earlier flowering).

A threshold temperature of 0^{O}C was used in this study. This could, in part, account for the lack of significance. The effect of temperature on flowering is non linear (Hudson et al. 2003; Sparks et al. 2000). Future research therefore should focus on identifying the appropriate lower and upper threshold temperature. Examination of whether other climatic influences (e.g. precipitation prior to flowering) are important is also required (Freidel et al. 1993; Keatley and Hudson 2000; Kramer et al. 2000)). Further, there is a need to investigate different approaches of examining the data for example, bayesian methods, spectral analysis and treating phenological and climate records as multivariate time series, (Dose and Menzel 2004; Hudson et al. 2004; Hudson et al. 2003; Studer et al. 2003).

In general, changes in phenological phases have been found to be between 2.3 and 5.1 days earlier per decade (Parmesan and Yohe 2003; Root et al. 2003). Significant shifts indicated in this study are therefore at the extreme end (42 and 46 days over 2 decades). It is important to note, however, that the results may be somewhat influenced by the change in frequency of observation from 2 to 3 times a week to weekly. From the time from which weekly observations commenced, there was a potential maximum 'lag' in the period between flowering and its observation of 7 days (compared with 2-4 days for the period with observations 2-3 times per week). This potentially introduces an artificial shift in flowering (i.e. shift to later flowering). For the species where predictions are of changes to earlier flowering, this artificial lag may have acted to 'mask' the real shift, whilst for species with observed delay in flowering, the lag may have contributed to this observation.

One other recent Australian study (Keatley et al. 2002) which examined flowering phenology, predicted shifts of up to 71 days later and 44 days earlier for an increase of 1^{o}C. In that study of eucalypts the results were also confounded by the length of time between observations (1 month). There have been, however, some species with similar sized shifts reported ((*Lamium album* - 55 days earlier, *Cymbalaria muralis* - 35 days earlier, *Buddleja davidii* - 36 days later (Fitter and Fitter 2002), *Duchesnea* *indica* - 46 days earlier, *Cardamine hirsuta* – 42 days earlier, *Lamium purpureum* – 39 days earlier (Abu-Asab et al. 2001), *Alnus glutinosa* – 54 days earlier, *Rubus ulmifolius* – 42 days, *Spartium junceum* – 32 days (Peñuelas et al. 2002)). The time frames over which these shifts occurred are 10, 30 and 48 years, respectively.

Further examination of the full dataset (126 + species) is also required to determine whether these large changes in flowering commencement are typical. If so, then changes in this part of Australia would appear to be occurring at a greater rate than observed in the Northern hemisphere. Detecting any trend in a phenological series is influenced by when the series commences, finishes and also by its duration (Sparks and Menzel 2002). It must be borne in mind therefore that this dataset is relatively short and covers some of the warmest recorded years in Australia (11 of the observation years are amongst the 20 warmest years since 1910; based on departures from the 1961-1990 mean (Bureau of Meteorology 2004)). Therefore to make a sensible comparison between rate of change in the Northern hemisphere and Australia the same time period should be compared (Schaber 2002).

The simple findings presented in this study suggest that climate change is likely to have a significant impact on the reproductive behaviour of plant species in this area of south-eastern Australia.

The implications go beyond the species for which there is a significant change in flowering time predicted; species whose date of flowering commencement might not change will be impacted on by those species whose flowering has, due to changes in pollinator competition, for example. Many studies have already put forward the consequences of such changes (e.g. possible changes in reproductive success, production of hybrids, decoupling of previous synchronous events, changes in distribution etc (Fitter and Fitter 2002; Hughes 2000; Visser and Holleman 2001; Walther et al. 2002)).

Whether these same species would exhibit similar changes in other areas of their geographic distribution requires further examination as some species throughout Europe have been shown to have varying responses in relation to temperature (Ahas et al. 2002; Sparks and Menzel 2002).

To achieve this and a greater understanding of climate change impacts on its biodiversity, Australia needs to search out other historical phenological records, identify species which can act as biomonitors; this has already occurred in the United Kingdom and Ireland (Cannell et al. 1999; Sweeney et al. 2002) and commence long-term monitoring (Hughes 2003; Keatley et al. 2002). Additionally, greater collaboration should be encouraged between the climate-change and ecological modeling communities (Dunlop and Howden 2003).

5. CONCLUSIONS

This study indicates that there has been a significant change in local temperature over time and that the flowering phenology of some species has changed. Further analysis is required on alternate methods of examining the data, focused on better understanding the cause of these shifts in flowering, and the implications on Australian biodiversity.

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7. REFERENCES

Abu-Asab, M. S., P. M. Peterson, S. G. Shelter, and S. S. Orli, 2001: Earlier plant flowering in spring as a response to global warming in the Washington DC. area. *Biodivers. Conserv.*, **10,** 597-612.

Ahas, R., A. Aasa, A. Menzel, V. G. Fedotova, and H. Scheifinger, 2002: Changes in European spring phenology. *Int. J. Climatol.*, **22,** 1727-1738.

Allen, M. R., C. T. Mutlow, G. M. C. Blumberg, J. R. Christy, R. T. McNider, and D. T. Llewellyn-Jones, 1994: Global change detection. *Nature*, **370,** 24-25.

Bureau of Meteorology, 2003: *The Greenhouse effect and climate change*. Bureau of Meteorology, Melbourne.

——, cited 2004: Australian annual mean anomalies. [Available online from http://www.bom.gov.au/climate/change/amtemp.shtml.]

Cannell, M. G. R., J. P. Palutikof, and T. H. Sparks, Eds., 1999: *Indicators of climate change in the United Kingdom*. Dept. of

Transport, Local Government and the Regions, London.

Dose, V. and A. Menzel, 2004: Bayesian analysis of climate change impacts in phenology. *Glob. Change Biol.*

Dunlop, M. and M. Howden, 2003: Policy Discussion. *Climate Change Impacts on Biodiversity in Australia. Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October 2002*, M. Howden, L. Hughes, M. Dunlop, I. Zethoven, D. Hilbert, and C. Chilcott, Eds., Commonwealth of Australia, Canberra, 67-79.

Fitter, A. H. and R. S. R. Fitter, 2002: Rapid changes in flowering time in British plants. *Science*, **296,** 1689-1691.

Freidel, M. H., D. J. Nelson, A. D. Sparrow, J. E. Kinlock, and J. R. Maconochie, 1993: What induces central Australian arid zone trees and shrubs to flower and fruit? *Aust. J. Bot.*, **41,** 307-319.

Howden, M., L. Hughes, M. Dunlop, I. Zethoven, D. Hilbert, and C. Chilcott, Eds., 2003: *Climate Change Impacts on Biodiversity in Australia. Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October 2002*. Department of the Environment and Heritage, Canberra.

Hudson, I. L., K. Fukuda, and M. R. Keatley, 2004: Detecting underlying time series structures and change points within a phenological dataset using SSA [abstract]. *XXIInd International Biometric Conference*, Cairns: Australia.

Hudson, I. L., A. Barnett, M. R. Keatley, and P. K. Ades, 2003: Investigation into Drivers for Flowering in Eucalypts: Effects of Climate on Flowering. *18th International Workshop on Statistcal Modelling*, Katholieke Universiteit Leuven: Belgium.

Hughes, L., 2000: Biological consequences of global warming: Is the signal already apparent? *Trends Ecol. Evol.*, **15,** 56-61.

——, 2003: Climate change and Australia: Trends, projections and impacts. *Austral Ecol.*, **28,** 423-443.

Inouye, D. W., B. Barr, K. B. Armitage, and B. D. Inouye, 2000: Climate change is affecting altitudinal migrants and hibernating species. *Proc. Natl. Acad. Sci. USA*, **97,** 1630-1633.

Keatley, M. R. and I. L. Hudson, 2000: Influences on the flowering phenology of three eucalypts. *Biometeorology and Urban Climatology at the Turn of the Century. Selected Papers from the Conference ICB-ICUC' 99*, R. J. de Dear, J. D. Kalma, T. R. Oke, and A. Aucliems, Eds., World Meteorological Organisation,Geneva, Switzerland, 191-196.

Keatley, M. R., T. D. Fletcher, I. L. Hudson, and P. K. Ades, 2002: Phenological studies in Australia: Potential application in historical and future climate analysis. *Int. J. Climatol.*, **22,** 1769-1780.

Kramer, K., I. Leinonen, and D. Loustau, 2000: The importance of phenology for the evaluation of impact of climate change on growth of boreal, temperate and Mediterranean forests ecosystems: an overview. *Int. J. Biometeorology***,** 67-75.

Manins, P., R. Allan, T. Beer, P. Fraser, P. Holper, R. Suppiah, and K. Walsh, 2001: *Atmosphere, Australia State of the Environment Report (2001) Theme Report*. CSIRO Publishing on behalf of the Dept. of the Environment and Heritage, Canberra.

Menzel, A., 2000: Trends in phenological phases in Europe between 1951 and 1996. *Int. J. Biometeorol.*, **44,** 76-81.

Parmesan, C. and G. Yohe, 2003: A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421,** 37-42.

Peñuelas, J., I. Filella, and P. Comas, 2002: Changed plant and animal cycles from 1952 to 2000 in the Mediterranean region. *Glob. Change Biol.*, **8,** 531-544.

Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds, 2003: Fingerprints of global warming on wild animals and plants. *Nature*, **421,** 57-60.

Schaber, J., 2002: Phenology in Germany in the 20th Century: Methods, analyses and models, Doctor rerum naturalium, Dept. of Geoecology, University of Potsdam.

Snyder, R. L., D. Spano, P. Duce, and C. Cesaraccio, 2001: Temperature data for phenological models. *Int. J. Biometeorol.*, **45,** 178-183.

Sparks, T. H. and A. Menzel, 2002: Observed changes in seasons: an overview. *Int. J. Climatol.*, **22,** 1715-1725.

Sparks, T. H., E. P. Jeffree, and C. E. Jeffree, 2000: An examination of the relationship between flowering times and temperature at the national scale using long-term phenological records from the UK. *Int. J. Biometeorology*, **44,** 82-87.

Studer, S., C. Appenzeller, and C. Defila, 2003: Inter-annual variability and decadal trends in Alpine spring phenology - A multivariate approach. *Climate Change: Impacts on Terrestrial Ecosystems. 2nd International NCCR Climate Summer School*, Grindelwald, Switzerland, National Centre of Competence in Research: Swiss National Science Foundation.

Sweeney, J., D. Donnelly, L. McElwain, and M. Jones, 2002: Climate Change: Indicators for Ireland 2000-LS-5.2.2-M1, 54 pp.

Torok, S. J. and N. Nicholls, 1996: A historical annual temperature data set for Australia. *Aust. Meteor. Mag.*, **45,** 251-260.

Visser, M. E. and L. J. M. Holleman, 2001: Warmer springs disrupt the synchrony of oak and winter moth phenology. *Proc. R. Soc. London B*, **268,** 289-294.

Visser, M. E., F. Adriaensen, J. H. van Balen, J. Blondel, A. A. Dhondt, S. van Dongen, C. du Feu, E. V. Ivankina, A. B. Kerimov, J. de Laet, E. Matthysen, R. McCleery, M. Orell, and D. J. Thomson, 2003: Responses of Great and Blue Tits to Regional Warming. *Proc. Roy. Soc. London. B*, **270,** 367-372.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein, 2002: Ecological responses to recent climate change. *Nature*, **416,** 389-395.

Westoby, M., 1991: On long-term ecological research in Australia. *Long-term ecological research*, P. Risser, Ed., John Wiley and Sons, Chichester, 191-209.