Phenological trends among Australian alpine species: using herbarium records to identify climate-change indicators

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Abstract. Global temperatures are increasing at an unprecedented rate and the analysis of long-term phenological records has provided some of the most compelling evidence for the effect of these changes on species. In regions where systematically collected data on the timing of life-cycle events is scarce, such as Australia, researchers must seek alternative sources of information from which climate-change signals can be identified. In the present paper, we explore the limitations and strengths of using herbarium specimens to detect changes in flowering phenology, to select potential indicator species, and to pinpoint locations for potential monitoring schemes of native plants in Australia's subalpine and alpine zone. We selected 20 species on the basis of a range of selection criteria, including a flowering duration of 3 months or less and the number of herbarium records available in the areas above 1500 m. By the use of gridded temperature data within the study region, we identified an increase in mean annual temperature of 0.74°C between 1950 and 2007. We then matched the spatial locations of the herbarium specimens to these temperature data and, by using linear regression models, identified five species whose flowering response may be sensitive to temperature. Higher mean annual temperatures at the point of collection were negatively associated with earlier flowering in each of these species ($\alpha = 0.05$). We also found a significant ($P = 0.02$) negative relationship between year and flowering observation for Alpine groundsel, *Senecio pectinatus* var. *major*. This species is potentially a suitable candidate for monitoring responses of species to future climate change, owing to the accessibility of populations and its conspicuous flowers. It is also likely that with ongoing warming the other four species identified (*Colobanthus affinis*, *Ewartia nubigena*, *Prasophyllum tadgellianum* and *Wahlenbergia ceracea*) in the present study may show the same response.

Introduction

The Earth's climate is warming and life cycles of organisms that use seasonal changes in temperature to cue the initiation of phenophases are already being affected. These species are prime candidates on which to base monitoring programs to elucidate the effect of climate change on natural systems. The seasonal onset of warmer temperatures triggers a suite of physiological responses in plants, such as leaf bud-burst and the initiation of flowering. Advancement in the timing of these processes has been extensively reported across many plant taxa in recent years (Bradley *et al*. 1999; Fitter and Fitter 2002; Fosaa *et al*. 2004; Ahas and Aasa 2006; Donnelly *et al*. 2006; Cleland *et al*. 2007) from a broad range of biogeographic regions, including Asia (Lu *et al*. 2006; Tao *et al*. 2006), North America (Lavoie and Lachance 2006) and Europe (Sparks *et al*. 2000; Chmielewski and Rötzer 2001; Badeck *et al*. 2004; Dose and Menzel 2006; Høye *et al*. 2007).

There is a paucity of published evidence for climate-associated phenological trends from the southern hemisphere, owing to the lack of centralised phenological record keeping (for the few exceptions see Keatley *et al*. 2002). This shortage of robust, long-term datasets hinders our capacity to address questions about the impacts of climate change in southern continents such as Australia but has also encouraged researchers to seek alternative sources of data for analysis. In the present study, we

ask 'How can we use historical data to inform contemporary research into the response of species to climate change?'.

Historical records, such as herbarium specimens, capture information about species phenology that, if used with caution, can be used to detect changes in the timing of life-cycle events. In the northern hemisphere, data collated from natural history collections have been used extensively to investigate the impacts of climate change on plant species. Evidence for phenological changes has emerged from the analysis of herbarium voucher specimens (Borchert 1996; Primack *et al*. 2004; Bolmgren and Lonnberg 2005; Lavoie and Lachance 2006), photographic archives (Miller-Rushing *et al*. 2006) and agricultural records (Orlandi *et al*. 2005; Sadras and Monzon 2006). However, researchers in the southern hemisphere are yet to capitalise on these data sources.

The collections housed in Australian herbaria comprise about six million records dating back to the late 1700s. The main challenge in using herbarium data is detecting a signal above the 'noise' associated with data that have not been systematically collected for the purpose of phenological investigations. The use of rigorous selection criteria to filter historical collections for climate-change research, however, increases the likelihood of detecting this signal. For instance, records restricted to a particular locality for a species that exhibits a relatively short flowering season may constitute a meaningful record of changes in

phenology if collected over a sufficiently long time period (e.g. at least 20 years). In the present study, we explore the limitations and strengths of the use of historical data to detect phenological changes, select indicator species and pinpoint locations for potential monitoring schemes in Australia's subalpine and alpine zone.

Across Australia, mean annual temperatures have risen by 0.9°C since 1950 and are predicted to increase by 0.2–2.2°C by 2030 and 0.4–6.7°C by 2070 relative to 1990 (CSIRO/BoM 2007). Most of the warming experienced so far has occurred since the 1990s; in 2005, the annual mean temperature was 1.09°C higher than the 1961–1990 average, making it the warmest year since the recording began. Alpine ecosystems are particularly vulnerable to the effects of climate change (Pickering *et al.* 2008). On the Australian mainland, subalpine and alpine habitats are restricted to the south-eastern corner of the continent in the region broadly referred to as the Australian Alps (Fig. 1). There has been a 40% reduction in snow cover in this region since the 1960s (Green and Pickering 2002; Pickering *et al.* 2004). The area receiving at least 60 days of snow per year is predicted to decrease by between 18–60% by 2020, and by up to 96% by 2050 (Hennessy *et al.* 2008). Reduction in snow cover has been implicated in the colonisation of newly exposed areas by both native and introduced plants and the increased incidence of frost damage in some species (Scherrer and Pickering 2001; Inouye 2008). Trends in minimum and

maximum temperatures from June to September at four alpine sites indicate an increase of 0.02°C per year (~1962–2001) (Hennessy *et al.* 2008).

The Australian Alps represent a small fraction, ~0.09%, of Australia's land area. Much of its flora and fauna is endemic and of high conservation value (Pickering and Buckley 2003). Alpine species that are sensitive to subtle changes in their environment are expected to make excellent 'indicator species' owing to their reliance on seasonal changes in temperature to initiate flowering (Green and Pickering 2002; Hughes 2002; Pickering *et al.* 2004). Aside from being sensitive to abiotic factors in their environment, other desirable characteristics of an indicator species may include being conspicuous and easy to identify, and being associated with some form of long-term dataset that can be used as a baseline to compare new observations.

We addressed the following three specific questions:

(1) have mean annual temperatures increased in the period 1950–2007 in areas above 1500 m in the Australian alpine region;
(2) can we identify alpine plant species whose flowering response is sensitive to temperature, by using herbarium specimens; and
(3) is there a trend among these species to earlier flowering through time, consistent with any identified temperature changes?
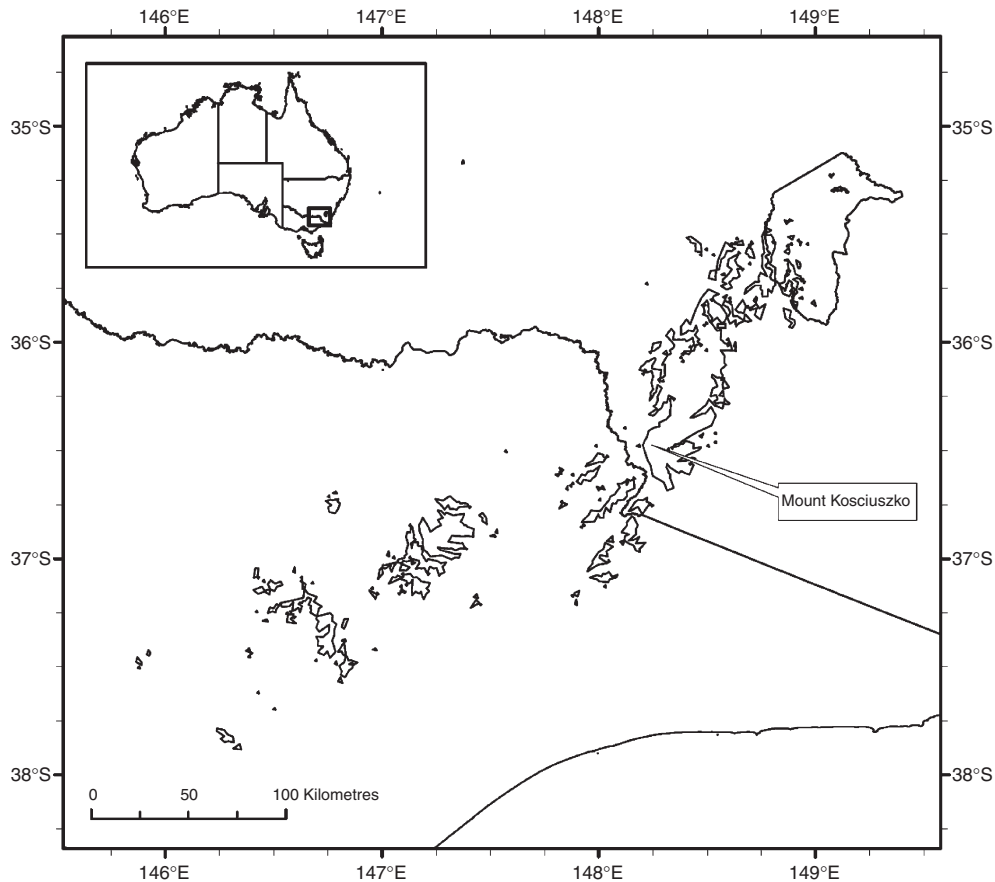

Fig. 1.   Study region. Areas above 1500 m in the alpine and subalpine regions of mainland Australia.

Materials and methods

Study area

The study region comprised subalpine and alpine areas on the Australian mainland at an altitude of 1500 m or above, up to Australia's highest peak, Mount Kosciuszko (2228 m) (Fig. 1). This altitudinal band encompasses both the 'true' alpine environment that lies between the tree-line and nival zones (1830 m and above) and the portion of subalpine environment that lies between 1500 m and the tree-line (Costin *et al*. 2000). We did not examine high-altitude areas that fell outside the alpine zone (such as the Atherton Tablelands), nor did we include the alpine areas of Tasmania.

Climate data

Gridded monthly maximum and minimum temperature data were obtained from the Bureau of Meteorology for the time period 1950–2007. These data represent average monthly values of temperature extremes across Australia at a grid resolution of $0.05° \times 0.05°$ (~5 km × 5 km). These files were imported into ArcGIS *v.* 9.2 (ESRI). We converted a polygon layer of areas above 1500 m to points at the same resolution as the gridded climate data. The Intersect Point Tool in the Hawth's Tools extension (http://www.spatialecology.com/htools/) was used to extract monthly climate data for the study area. This procedure was repeated for each maximum and minimum temperature file in the study area for each year between 1950 and 2007, with the use of the batch-processing tool in ArcGIS. From these data, average values of minimum, maximum and mean temperatures in areas above 1500 m in the alpine zone for each year were calculated.

The relationship between the timing of snowmelt and flowering plant phenology in alpine zones is well established (Inouye and McGuire 1991; Inouye *et al*. 2002; Molau *et al*. 2005; Venn and Morgan 2007). However, we were unable to include timing of snowmelt in the analysis because data at an adequate spatial resolution were not available within the study region. Data on snowmelt that approximated the time period of the study could only be acquired for Spencer's Creek, and this did not adequately represent the entire study region.

Species data

A preliminary list of 171 species found in the Kosciuszko alpine zone (36°27′S, 148°15′E) was compiled from *Kosciuszko Alpine Flora* (Costin *et al*. 2000). This publication is a comprehensive guide to native plant species found in Australia's largest contiguous alpine habitat. An estimated 90% of the 171 species on the list extend their ranges into the subalpine zone. Because of the inherent similarity in species composition between the flora of the Kosciuszko alpine area and the Victorian Alps (some 80% of species listed occur in both environments), we included herbarium records from both localities.

Collation of herbarium data

We obtained data in electronic format for all species in our preliminary list from three of Australia's major herbaria, including the National Herbarium of NSW, Botanic Gardens Trust, Sydney, the National Herbarium of Victoria in Melbourne and the Australian National Herbarium in Canberra. The data query was limited to specimen records that were flagged as flowering at the time of collection. We imposed a set of eight steps to refine the data acquired from the herbaria.

(1) Records that did not contain an exact date (day, month and year) of collection, and either a geo-referenced location or a detailed description of the collection location from which coordinates could be determined with a gazetteer, were removed (Geosciences Australia; http://www.ga.gov.au/map/names/).

(2) Duplicate records that arose from the sharing of herbarium specimens between the three institutions were also removed. The accession number from the donor herbarium was used to identify these records.

(3) In instances where there were multiple observations in the one year for a particular species, we used the date of the first collection made as the measure of first flowering. All other observations from that year were then eliminated from the dataset. The first observation in a year, as opposed to the median or mean date, was used because no spatial location exists for a mean or median observation derived from averaging an even number of observations. It was critical for subsequent analyses carried out in the present study that each observation corresponded to a set of coordinates within the study area. It is important to note that collection effort remained relatively consistent throughout the study period.

(4) The data were imported into a geographic information system (ArcView 9.1 ESRI) and records that clearly exhibited mistakes in geo-coding, such as points falling in bodies of water, were removed.

(5) Specimen point localities were intersected with an altitude layer with 3 arc-second (~90 m) resolution by using the point intersection tools in Hawths Tools (Beyer 2004) to obtain an estimate of the altitude at each collection site. The altitude layer used was downloaded from the NASA Shuttle Radar Topography Mission (SRTM) interface (http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html) and was assembled with the mosaic tool in ArcGIS. Specimen records with an estimated altitude of less than 1455 m were removed from the dataset. A value of 1455 m, as opposed to 1500 m, was used to eliminate records to account for possible variation related to the 90-m resolution of the altitude layer.

(6) The dataset was limited to specimen records falling between the years 1950 and 2007, to correspond with the time period of the temperature data used in the analysis. This also had the effect of limiting outlying observations associated with sporadic collecting of herbarium specimens in the earlier part of Australia's colonial history.

(7) The dataset was restricted to species for which records indicated a flowering season of less than 3 months. This was designed to reduce slight differences in flowering times across latitudes. A signal identifying variation in the timing of flowering over time is likely to be more recognisable in a species that exhibits a short and discrete flowering season.

(8) Only species with more than 10 independent specimen records (collections made in different years) were included in the final data analysis to conform to the assumptions of the statistical tests performed.

After imposing these limits on the raw data, a final list of 20 species from seven families was obtained (Table 1).

Table 1.   Least-squares linear regression models of flowering observation, with mean annual temperature (°C) in the year of collection

Model diagnostics (number of observation (n), F-test statistic, R^2 goodness of fit and P-value) are presented. Direction of the trend is indicated by β value where negative numbers represent earlier flowering, and positive numbers represent later flowering. Standard error of β is also provided as a measure of confidence in estimates of slope. The months in which the species is reported to be flowering are taken from the Flora of NSW (Harden 1993)

Species	n	R^2	F	P	β	s.e. of β	Flowering months
Asteraceae							
Brachyscome nivalis	13	<0.01	0.04	0.84	−1.29	6.19	Dec.–Feb.
Craspedia aurantia	17	0.02	0.23	0.64	−1.71	3.53	Dec.–Feb.
Craspedia costiniana	15	0.00	0.05	0.83	−1.54	6.93	Dec.–Feb.
Craspedia jamesii	11	0.24	2.81	0.13	−6.01	3.59	Dec.–Feb.
Craspedia lamicola	14	0.21	3.18	0.10	−8.53	4.79	Dec.–Feb.
Erigeron nitidus	12	0.01	0.12	0.74	−1.32	3.82	Jan.–Mar.
Ewartia nubigena	15	0.38	7.85	0.02**	−9.32	3.33	Jan.–Mar.
Podolepis robusta	23	0.02	0.46	0.51	2.38	3.51	Dec.–Feb.
Senecio gunnii	21	0.06	1.25	0.28	−4.71	4.21	Dec.–Feb.
Senecio pectinatus var. *major*	24	0.47	19.49	<0.001***	−8.44	1.91	Dec.–Feb.
Campanulaceae							
Wahlenbergia ceracea	26	0.15	8.08	0.05**	−4.35	2.40	Dec.–Feb.
Caryophyllaceae							
Colobanthus affinis	18	0.38	1.79	0.01**	−7.57	2.96	Dec.–Feb.
Fabaceae							
Hovea montana	26	0.07	0.32	0.18	−5.62	4.87	Nov.
Podolobium alpestre	16	0.00	1.52	0.88	0.68	3.93	Dec.–Feb.
Juncaceae							
Juncus falcatus	27	0.00	0.67	0.98	0.06	2.69	Dec.–Feb.
Luzula alpestris	15	0.25	0.01	0.06*	−11.97	4.09	Dec.–Feb.
Myrtaceae							
Baeckea gunniana	16	0.00	<0.01	0.81	0.79	3.49	Dec.–Feb.
Kunzea muelleri	18	0.21	0.70	0.06*	−5.74	3.06	Dec.–Feb.
Orchidaceae							
Prasophyllum suttonii	22	0.17	0.11	0.06*	3.73	2.15	Jan.–Mar.
Prasophyllum tadgellianum	22	0.63	0.98	<0.0001***	−8.99	2.23	Jan.–Mar.

*Marginally significant at α level of $P = 0.1$, **significant at α level of $P = 0.05$, ***highly significant at α level of $P < 0.01$.

Conversion of collection date to flowering observation

For each herbarium specimen record, we determined the day of the year on which the collection was made, where 1 = January 1 and 32 = February 1; henceforth known as the 'flowering observation'. When converting collection dates for this analysis a difficulty arose for those species with a spring–summer flowering season occurring during the turn of a year. For example, when converting two observations from, e.g. 31 December 2001 and 1 January 2002, we arrive at the days of the year 365 and 1, respectively, despite the fact that these two observations have a Euclidean distance of one. This problem is usually not encountered in the northern hemisphere where the predominant flowering season falls in the middle of the year. To circumvent this issue we performed a linear transformation by adding a constant ($x = 365$) to the portion of data that fell between 1 and 183 (the midpoint of the year). Following from the previous example, the observation 1 January is transformed to a flowering observation of 366, whereas the 31 December remains 365 and the Euclidean distance between the observations is preserved.

Matching climate data to species data

The locality information associated with each herbarium specimen was used to assign values of mean annual temperature in the year of collection from the climate data, with a script generated in MATLAB (Version 7.0). The large inter-annual variation in MAT in the study area was used to detect species that flower earlier in warmer years. This procedure was repeated with climate data for the season preceding the flowering period in the year of collection (e.g. mean spring temperatures for summer flowering species). Seasonal climate layers were created from monthly average minimum and maximum temperature grids, averaged to provide a mean seasonal temperature.

Statistical analysis

The association between temperature variables (seasonal and annual) and year was assessed with linear ordinary least-squares (OLS) regression models. The OLS technique was also used for species data to quantify the association between mean annual temperature in the year of collection and flowering observation, and between year of collection and flowering observation. We also tested for heterogeneity of slopes between OLS regression models fitted to minimum and maximum temperatures to investigate any differences in the rate of change between these two variables. All statistical tests were considered significant at $P < 0.05$. Statistical analyses were performed by using the bivariate line-fitting program SMATR

(v.2) (see Warton *et al*. 2006 for further discussion of bivariate line-fitting techniques).

Results

Climate data

Mean annual temperature (MAT) increased 0.74°C in the study area between 1950 and 2007 (Fig. 2). We identified a highly significant ($P < 0.001$) relationship between mean annual temperature and year corresponding to an average yearly increase in temperature of 0.014°C ($y = 0.014x - 19.76$). Minimum temperatures in the study area have increased on average by 0.011°C year^{-1} ($P = 0.001$) and maximum temperatures by 0.016°C year^{-1} ($P < 0.001$) (Fig. 2). There was no significant difference in the slopes of the regression lines for minimum or maximum temperatures against year ($F = 1.0$, $P = 0.34$, d.f. $= 1,2$).

Species data

Of the 20 species examined, five showed a significant negative relationship between flowering observation and MAT in the year of collection; i.e. warmer annual temperatures at the point of collection are associated with earlier flowering in these species (Table 1, Fig. 3). These species were *Colobanthus affinis* (Hook.) Hook.f., *Ewartia nubigena* (F.Muell.) Beauverd, *Prasophyllum tadgellianum* (R.S.Rogers) R.S.Rogers, *Senecio pectinatus* var. *major* F.Muell. ex Belcher and *Wahlenbergia ceracea* Lothian. A further two species, *Kunzea muelleri* and *Luzula alpestris*, showed marginally significant ($0.05 < P < 0.1$) negative associations between flowering observation and MAT in the year of collection. The orchid *Prasophyllum suttonii* was the only species for which the flowering time was positively correlated with MAT, although the association was weak (see Table 1). The results obtained from performing a similar analysis, with temperature in the preceding season as the response variable, were consistent with those for mean annual temperature and so are not reported here.

Of the eight species listed above, only *Senecio pectinatus* var. *major* showed a significant ($R^2 = 0.21$, $P = 0.02$) association between flowering observation and year (Fig. 4). Onset of flowering in this species is sensitive to temperature and appears to have tracked the temporal trend of increasing mean annual temperatures in the study region through time. Historical records of this species may, therefore, provide a baseline set of observations with which future observations can be compared.

Discussion

The present study has shown that mean annual temperatures have risen by 0.74°C in the Australian subalpine and alpine zone since 1950. We identified five plant species for which the time of flowering was negatively associated with temperature at the collection location; this sensitivity to temperature suggests that these species would make suitable indicators for monitoring species' responses to climate change.

Our analysis of temperature data in the study region revealed an average increase of 0.014°C each year between 1950 and 2007. The overall 0.74°C increase during the study period is slightly less than the average value across all of Australia of 0.9°C during the same period (CSIRO/BoM 2007). The increase we identified is
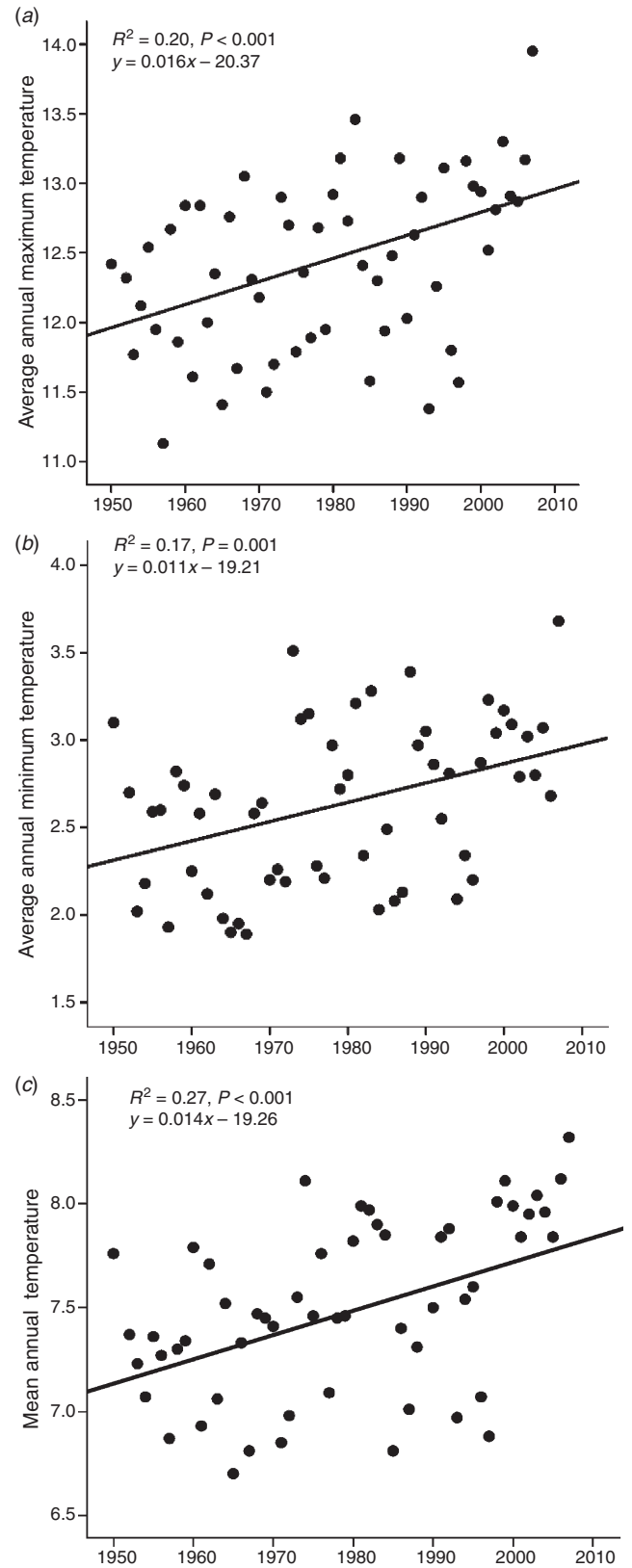

Fig. 2. Annual (*a*) maximum (*b*) minimum and (*c*) mean temperatures (°C) between 1950 and 2007 in areas above 1500 m in the Australian continental alpine zone.
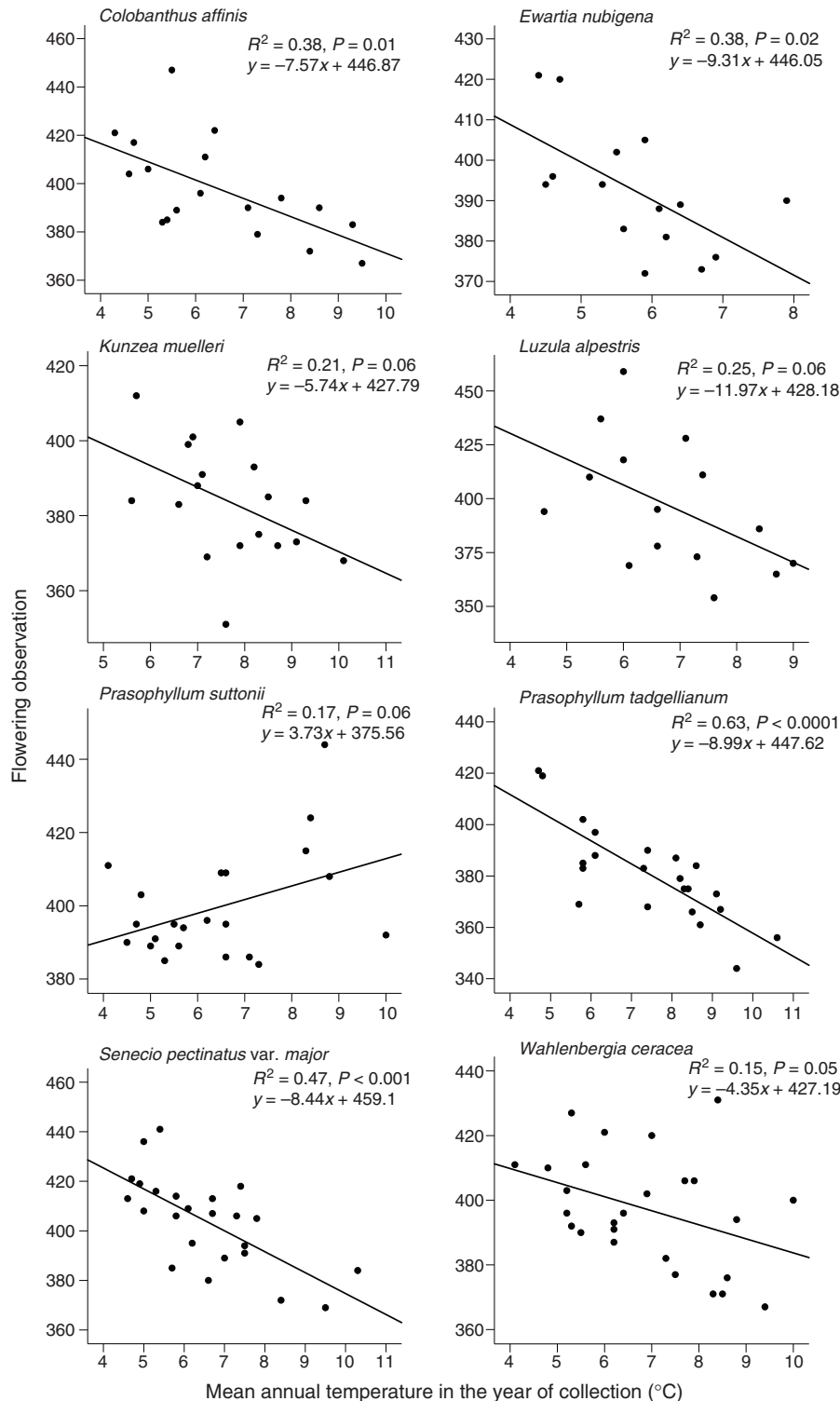
Fig. 3. Relationship between the day number that a flowering herbarium specimen was collected and mean annual temperature (°C) in the year of collection for eight species.

also slightly smaller than recently reported estimates of temperature increase in high latitude regions of south-eastern Australia of 0.02°C per year (~1962–2001) (Hennessy *et al.*

2008). The differences may arise from differences in the spatial and temporal scale of each study. There is a large amount of spatial variation in rates of temperature change

Senecio pectinatus var. *major*

$R^2 = 0.21$, $P = 0.02$
$y = -0.69x + 1763.79$

Fig. 4. Relationship between the day number that a flowering herbarium specimen was collected and year for *Senecio pectinatus* var. *major*.

across Australia reported for the same period; e.g. the north-west of Australia has undergone reductions in temperatures of about $-0.01°C$ $year^{-1}$, whereas in some inland areas temperatures have increased by up to $0.03°C$ $year^{-1}$ (CSIRO/BoM 2007). Our study also focussed on annual increases in temperature, rather than the temperature increases between the months of June and September in the alpine zone, as examined in Hennessy *et al.* (2008). This, in conjunction with the longer overall time period examined in our study (1950–2007), may explain the slight divergence in the estimate of warming indentified in the study of Hennessy *et al.* (2008).

It is possible that factors other than warmer mean annual temperatures have contributed to the results for flowering time. For example, as herbarium specimens are generally not systematically sampled either at the same time each year or throughout a species' entire flowering period, the date of the collection could occur at any time within the flowering period. Although we used the herbarium specimen with the earliest collection as the best possible substitute for date of first flowering, the data are nonetheless noisy and any signals towards earlier flowering would have to be very strong to be detected. Physical factors such as the timing of snowmelt or topographic location (e.g. north- compared with south-facing slope) may also play an important role in the timing of flowering events (Inouye and McGuire 1991; Inouye *et al.* 2002; Molau *et al.* 2005; Høye *et al.* 2007). Unfortunately, snowmelt data for the study period of interest in the Australian Alps are available for one site only (Spencer's Creek in NSW) and we were unable to include this factor in the analysis.

Despite the increase in temperature during the study period 1950–2007, and the relationships found between temperature and flowering observation for 5 of the 20 species, only one species, the alpine groundsel *Senecio pectinatus* var. *major*, was found to exhibit significantly earlier flowering through the years of the study period, consistent with this increase in MAT. This species

was sampled in 24 of the 57 years between 1950 and 2007 and linear modelling indicated that the timing of flowering observation advanced by 6.9 days per decade. A change of this magnitude is larger than other estimates of the advancement of spring phenology of 2.3–5.1 days per decade derived from global meta-analyses (Parmesan and Yohe 2003; Root *et al.* 2003). This suggests that this species may be useful as an indicator of the effect of climate change in the alpine area. The characteristic yellow button-shaped flowers of this species are conspicuous in the landscape, further suggesting its potential utility as a monitoring tool.

It is anticipated that establishing a monitoring program based on the species identified in the present paper will provide valuable evidence for the effect of climate change on Australian alpine plants. The earlier onset of flowering can have consequences not only for the individual plants and populations affected, but also to the maintenance of diversity at the community level. For example, earlier flowering may lead to the decoupling of plant–pollinator interactions. Asynchrony in this type of biotic interaction may be of particular importance where pollinator mutualism is highly specialised, such as in the family Orchidaceae. Therefore, understanding the response of primary producers within communities provides scope for investigating the effect of climate change on biotic interactions with species at other trophic levels. In addition, monitoring the species identified in the present study may quantify the rate at which species with different evolutionary histories respond to rising temperatures in the Australian alpine area. The five species identified as having flowering responses sensitive to temperature are drawn from a range of lineages and there is considerable variation in life-history strategies among these species.

Using herbarium specimens as baselines for monitoring

The present study has shown that herbarium specimens can be used to identify appropriate species for systematic monitoring studies of climate-change impacts in the Australian alpine zone. We propose that rather than constituting a compelling, stand-alone record of phenological trends across time, the real utility of herbarium specimens lies in providing a complementary historical baseline of data to which new field-based observational records may be compared. Herbarium specimens have been used in this way in several monitoring programs across a wide range of species and latitudes in the northern hemisphere (Borchert 1996; Bolmgren and Lonnberg 2005). The locality information that accompanies each herbarium specimen used in the present study would be a valuable source of information regarding the placement of permanent plots. In all, 12 of the 24 specimens of *Senecio pectinatus* var. *major* used in our analysis were collected from the vicinity of the summit of Mount Kosciuszko (~36°25′S, 148°15′E) (Fig. 5). The accessibility of this site from nearby Summit Road also makes it ideal for establishing a monitoring program.

Caveats

There are important caveats that need to be addressed when data from natural-history collections are used to answer contemporary research questions. Error may be introduced to analyses through unresolved taxonomic issues, misidentification or nomenclatural
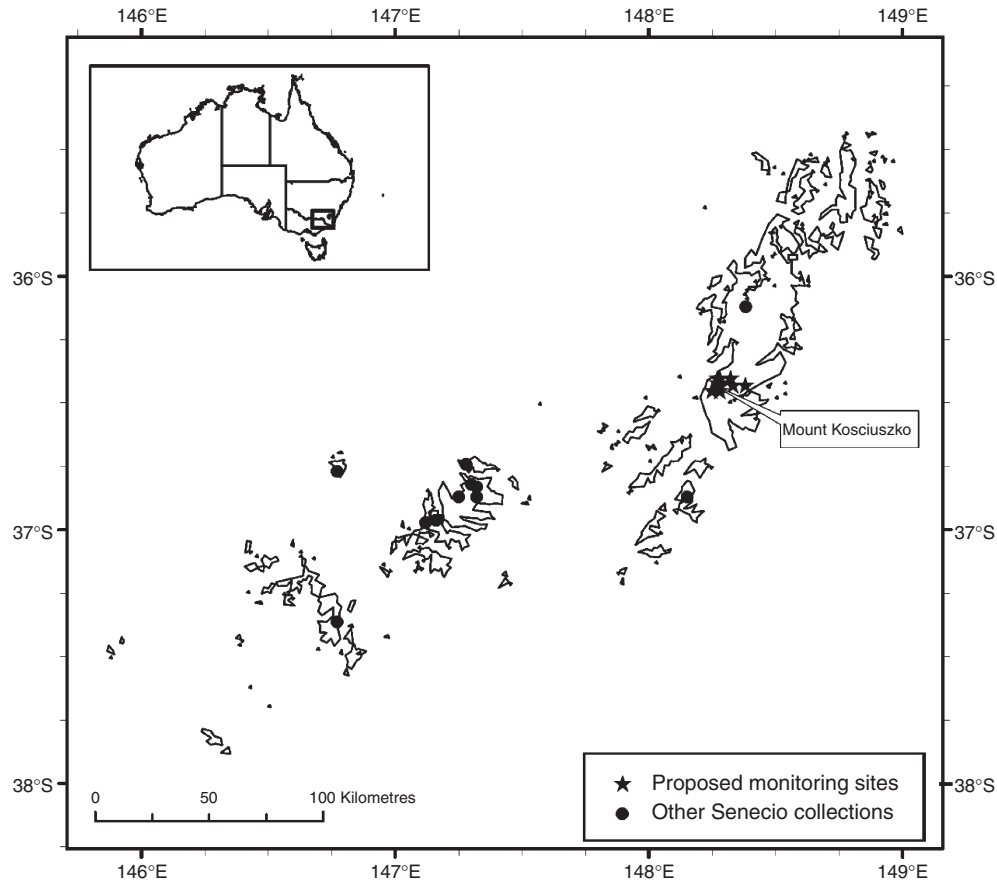
Fig. 5.   Proposed locations for the monitoring of *Senecio pectinatus* var. *major* in the study area.

inconsistencies between organisations. There may also be errors related to the spatial accuracy of coordinates resulting from misrepresentation of the original location of the collection, inconsistencies in the datum used to record collecting locations or mistakes with data entry (Graham *et al.* 2004). These drawbacks must be evaluated and appropriate precautions applied so that researchers can use the vast amount of information housed in natural-history collections worldwide with confidence.

Finding innovative ways to apply the information housed in natural-history collections to current research is also important for gaining on-going financial support for the institutions charged with housing them. An appreciable sum has been devoted to the digitisation of natural-history collections both in Australia and throughout the world during the last two decades, such as the Australian Virtual Herbarium and Global Biodiversity Information Facility, and this commitment has greatly increased the relevance and utility of such collections for contemporary research. It is now possible to access and collate data from herbaria with a minimal amount of specimen handling, which would previously have been prohibitive for the compilation of the dataset presented here. We are not discarding the hope that long-term phenological data will be located in Australia. The search for such data has been far from exhaustive, and such datasets and accompanying information about their provenance are likely to be held by enthusiastic naturalists unaware of their significance. When coupled with the considerable time and expense involved in the collection, identification and curation of herbarium collections, it is important that this type of historical data be treated as a valuable resource (Sparks *et al.* 2000).

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