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ORIGINAL ARTICLE

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Flowering plant phenology and weather in Alberta, Canada

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Abstract Plant phenology can be used for biomonitoring climate change. The flowering of certain temperate zone plant species occurs in response to accumulated heat. Networks of observers presently provide data on the timing of the growth of native and crop plants to Agro-meteorological Departments in Europe and the United States. In Alberta, a phenological survey which began in 1987 records flowering times for 15 native plants, with about 200 volunteers contributing observations annually. Six years of data have been summarized and correlated with temperature measurements. The Alberta phenological data can provide a key to sound decision-making in two ways: by providing proxy data on key variables to which vegetation responds, and by providing a model for transforming simple weather data into biologically meaningful zones.

Key words Spring flower phenology · Alberta · Canada Biomonitoring · International phenology program

Introduction

Phenology, defined as the study of the seasonal timing of life cycle events, is potentially a powerful tool for monitoring the biotic response to climate change. In the world's temperate zone, the onset of plant development in the first half of the year is primarily due to temperature accumulation above a threshold level (Larcher 1983). In particular, spring flowering of woody species as well as some perennial herbs occurs in response to heat (Rathcke and Lacey 1985; Lindsey and Newman 1956; Castonguay and Dubé 1985). A trend to earlier flowering should be observable, as global warming increases due to the human-enhanced greenhouse effect (Canadian Climate Program Board 1991).

Once the phenological behaviour of certain key indicator plants is known for an area, and the physical factors responsible for their flowering have been deduced, then a reversible system to describe environmental conditions can be exploited. Long-term weather records can provide information on past phenological variability. Also, past and present phenological data can provide models for deducing climatic conditions at sites where no historical or current meteorological records are available. The advantage of using plants as proxy weather instruments is that they are widespread and can provide an inexpensive way to increase the coverage of climatological observations. Moreover, herbaceous plants reflect conditions close to the ground, where the frost-free period can be a month shorter than at the height of a standard instrument shelter (Hopp et al. 1964).

Historical background

Unlike proxy data such as those from tree rings or pollen layers, phenology as an indicator of historic climate is not self-recording over periods of years. However written records have been provided by networks of volunteer phenological observers, and these studies have a long history. Thousands of years ago, in Rome and China, records were kept of plant development for the production of agricultural calendars. In Europe, networks of observers have recorded phenophases (easily observed growth phases) of wild and crop plants for up to 200 years, in extensive surveys coordinated by Agrometeorological Departments (Hopp 1974). These data have been used in biozonation, to indicate the relative warmth of growth zones (Ellenberg and Ellenberg 1974). In Poland, phenological data have enabled even the mountainous areas to be divided into pheno-climat-

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ic zones and have supplemented weather records in areas where they are missing (Obrebska-Starklowa 1981). Also, rapid reporting networks of observers can track the progress of the current growing season, permitting accurate prediction to farmers for the optimal timing of pest control. In Europe, international phenological gardens use cloned plants as indicators, providing more precision by removing the effects of genotype variation (Schnelle and Volkert 1974; Lieth and Scharrer 1992).

In North America, two extensive surveys began in the 1950s, using common purple lilac (*Syringa vulgaris*) and two cultivars of honeysuckle (*Lonicera*) as indicator plants (Hopp 1974). Just retired as head of the western lilac network, Dr. Joseph Caprio has noted earlier flowering through much of the 1980s (J.M. Caprio personal communication). Dr. Mark Schwartz (University of Wisconsin, Milwaukee) is responsible for the eastern network. These surveys have provided information for biozonation or climate mapping (Caprio 1966; Dubé and Chevrette 1978), for predictions of crop yields and crop protection (Hopp 1978) and in remote sensing (Dethier et al. 1975). Schwartz and Marotz (1988) used 20 years of first leaf data to demonstrate the effect of synoptic events on the arrival of the spring "green wave". There is still much untapped potential for using these historic phenology databases in an analysis of climate change.

In Canada, the Royal Society of Canada launched a phenological study, which was carried out by the Botanical Club from the 1890s to the 1920s. Since then the only large-scale study has been the involvement of the eastern provinces in the lilac/honeysuckle surveys of the eastern USA. In Alberta, few long-term studies have been conducted. Useful prairie studies include Budd and Campbell (1959) for Swift Current, Saskatchewan; Criddle (1927) for southern Manitoba; and Russell (1962) for Winnipeg, Saskatoon and Edmonton. Moss (1960) and Beaubien (1991) describe Edmonton species (aspen parkland). There are also few boreal phenology studies (Erskine 1985).

The first extensive study was carried out 1973–1983 by Alberta volunteers who recorded the flowering of native species (Bird 1983). This was revived and revised for the present study in 1987 (Beaubien 1991), where volunteers record three flowering dates for up to 15 native perennial plant species. This is the only extensive survey presently in Canada, and its goal is to assist decision-making in agriculture, forestry, biometeorology, and medicine. An analysis of the first 6 years (1987–1992) is presented here, including a summary of average flowering times, and growing degree-days to the onset of phenophases.

Various heat-summation methods have been used in correlation analyses with flowering times (Lindsey and Newman 1956; Anderson 1974; White 1979). Caprio (1993) and Caprio et al. (1974) found that adding solar radiation to temperature reduced variation between sites. Lilacs grown in Montana, the west coast of the United States, and Norway all required 380 000 solar-thermal units to flower (Caprio et al. 1974). However, White (1979) found that adding solar radiation to temperature did not account for any more variation in the flowering of 53 range plants.

Materials and methods

Data collection

Observers in Alberta recorded flowering times for up to 15 native plant species. These key indicator species have the four important qualities necessary for a public phenology survey: ease of recognition, wide distribution, relatively short and consistent flowering period, and lack of subspecies. Recruitment of observers has been done through the media, and through government agencies such as the federal Atmospheric Environment Service and provincial Alberta Forest Service.

The three flowering phenophases used in this survey were: first flowering (10% of flower buds open), mid-flowering (50%), and full flowering (90%; Kreeb 1977). This sequence of development dates was requested to ensure that the plants would be observed over a period of time, thus increasing the accuracy of phenophase estimation. A 22-page colour booklet entitled "Alberta wildflowers – a flowering date survey" provided colour photos and information on how to recognize plants, how to observe flowering, and how to select areas and plants for observation.

Data analysis

The yearly data sets for 1987–1992 were analyzed using SAS. Beginning January 1 of each year, total degree-days were calculated using a technique which fits a cosine function to the daily maximum and minimum temperatures, finds the areas above the lower threshold (0° C), and sums this value for each day up to the flowering date. Weather data were used from the closest Atmospheric Environment Service weather station within 5 km of the flowering observation locations. For each phenology observation, the latitude and longitude were determined, and the weather file searched for the closest station. This produced a smaller subset of observations which had a weather station within 5 km. The averaged results for plant species and flowering phases during 1987–1990 are reported.

Results and discussion

Observers (about 200 volunteers annually) provided a total of 15 450 flowering dates in the 6 years, 1987 to 1992. The locations and data are stored in a geographic information system at the Lethbridge Research Station. The observers were distributed over the southern two-thirds of Alberta with many clustered between Calgary and Edmonton, as shown by the 1992 map (Fig. 1). The density of observations is greatest from Red Deer north to Athabasca and east almost to the Saskatchewan border. More observers are needed in the southeast, the foothills and in northern Alberta.

All years were averaged for each of the 15 plant species for first and full bloom (Table 1). The sequence in which species reach 10% and 90% flowering are the same with the exception of crocus and poplar. Poplar has a shorter development time, and thus, on average, reaches full bloom before crocus, though poplar starts

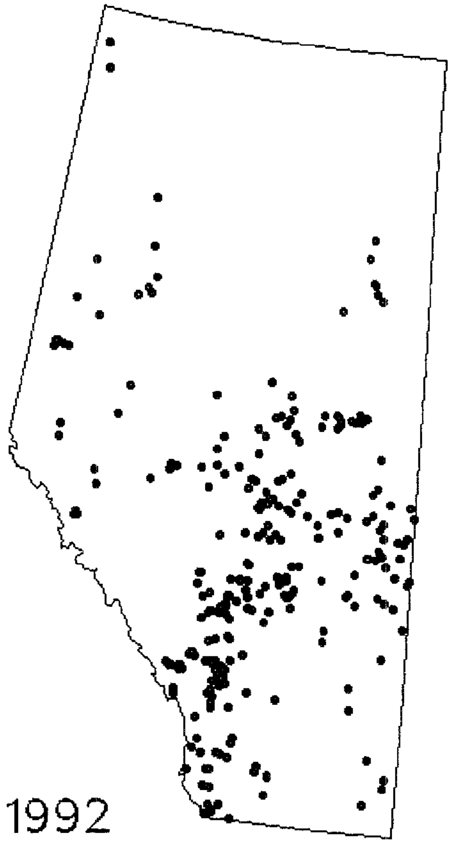

Fig. 1 Typical locations of phenology observations in Alberta (data for 1992)

Table 1 Alberta phenology survey species

		10%	90%
Anemone patens L. var wolfgangiana (Bess) Koch	Prairie crocus	04/10	04/23
**Populus tremuloides* Michx.	Aspen poplar	04/11	04/19
Thermopsis rhombifolia (Nutt.) Richards.	Golden bean	05/05	05/17
Viola adunca J.E. Smith	Early blue violet	05/06	05/18
**Amelanchier alnifolia* Nutt.	Saskatoon	05/12	05/20
**Prunus virginiana* L. var. melanocarpa (A. Nels.) Sarg.	Choke cherry	05/22	05/30
Smilacina stellate (L.) Desf.	Star-flowered Solomon's-seal	05/25	06/04
**Elaeagnus commutata* Bernh. ex Rydb.	Wolf willow	06/01	06/10
Lathyrus ochroleucus Hook.	Yellow pea vine	06/02	06/15
Galium boreale L.	Nothern bedstraw	06/15	06/27
Linnaea borealis L.	Twinflower	06/19	06/28
Lilium philadelphicum L. var. andinum (Nutt.) Ker.	Western wood lily	06/21	06/30
Achillea millefolium L.	Common yarrow	06/21	07/05
Gaillardia aristata Pursh	Brown-eyed susan	06/21	07/05
Epilobium angustifolium L.	Fireweed	07/03	07/20

All species are perennial. Woody species are marked with an asterisk. Six-year averages (1987–1992) for Alberta flowering dates are given, (month/day) for first (10%) and full (90%) flowering

flowering later. Crocus and poplar are consistently the first species to flower and the only ones in April.

Species with short flowering periods, which took less than 10 days to progress from first to full bloom, were: poplar, saskatoon, Solomon's-seal, cherry, wolf willow and wood lily. This fast sequence of flowering means there is less chance for observer error in the estimation of flowering dates, making these species more valuable for a phenology survey. The best-reported species (those with over 950 observations) were crocus, violet, saskatoon, bedstraw, yarrow and fireweed. Species with least data (under 700 observations) included wolf willow, brown-eyed susan and twinflower. Now that the data have been summarized for the whole province on an annual basis, the next step will be to subdivide the data to do regional comparisons between years, and to produce a unified model of flowering date as a function of species, weather, altitude and geographical position.

As temperature is considered the major factor influencing flowering time for many spring-flowering species, it was expected that these plants, especially the earlier ones in the sequence, would show a fairly consistent number of degree-days to reach each flowering phase. Figure 2 shows the heat accumulation and its variability for first and full bloom. Note that the length of the flowering period and variability increase through the sequence from *Anemone patens* to *Epilobium angustifolium*. The sequence of first flowering for the species in Table 1 does not exactly match the degree-day accumulation sequence. This is due to the fact that degree-days were calculated on a smaller subset of the total data.

Possible sources of variability include: (a) the observers, (b) the plants, (c) the observation sites, and (d) the weather.

a. The variability due to an observer's skill and experience is difficult to quantify. This survey will work towards providing better instructions for recognition of phenophases and also expanding the volunteer network. With large numbers of observations the unreliable data should average out, assuming the dates are not biased by consistently late or early records.

b. Concerning plant response, the effect of genotype (of variable genetics within a species) also needs to be investigated. Clausen et al. (1940) found using garden experiments that plants from high elevations flowered earlier than those from low elevations. Caprio (1966) describes ecotypic responses in phenology: plants growing in the north do not bloom early despite periods of warmth, and thus avoid frost. They then develop faster and mature before the fall. The extent of ecotypic variation in the 15 indicator plants used in this project could be determined by using garden experiments. As well as using native plants in phenology, a system of Canadian phenological gardens using cloned (genetically identi-

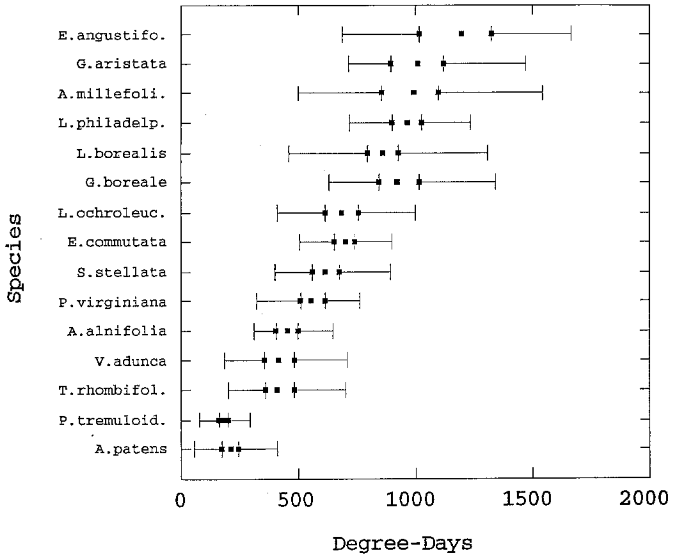

Fig. 2 Average degree-days for 1987–1990, for the 15 plant species of the Alberta phenology survey. *Squares* represent the flowering phases: 10% (first), 50% (mid), and 90% (full) flowering (from left to right). *Horizontal bars* represent twice the standard deviations for the 10% and 90% phases

cal) plants as biological weather instruments would provide additional precision.

c. Site variability includes differences in aspect, slope, altitude, latitude (which affects photoperiod) and longitude.

d. While temperature was accumulated beginning January 1, conditions beginning the previous fall may also be important through chilling effects. Adding solar radiation to temperature may also help. Differences between temperatures at plant height and at instrument shelter height could be important. Lastly, while a base temperature of 0° C was used for all species, it is likely that the threshold varies between species.

The method of using weather stations within 5 km may be too coarse, as there could be major microclimatic differences caused by the presence of a town or water body between weather station and observed plants. One way to reduce variability (in future refinements) will be to restrict the analysis to flowering dates from observers who are also Atmospheric Environment Service observers, so that plant and weather data are from identical sites. Precipitation may affect the accumulation of degree-days. In years of deep snow, heat will be consumed in the melting of snow before the plants can react to warmth. Soil moisture effects also need to be evaluated, and research to model this variable is underway.

The effects of climate warming on vegetation should also be considered. Species-specific information on phenology and physiological tolerances for heat, light and CO_2 would help us predict biogeographical changes resulting from future climate warming. This warming has some potentially negative effects on early-developing plant species, such as greater risks of frost damage. Higher temperatures over the period from fall to spring can result in midwinter bud-burst on trees and subsequent exposure to severe cold will damage buds (Hänninen 1991). In the Edmonton area, early flowering of poplar in the spring of 1992 resulted in major reproductive loss. The previous winter was very mild, due to an El Niño event. Climate warming could result in major timing shifts for first bloom for the earliest-flowering species.

By participating in this phenology survey, observers can learn first-hand about the relationships between plants and climate, while "taking action at home" as part of a climate change detection network. Both adults and children gain observation skills and a heightened awareness of the environment. Long-term goals for this project are to continue the analysis as years of data are added, to fine-tune correlations of flowering times with abiotic parameters and develop models of their effects on flowering of the 15 key species. Phenological data must now be analyzed on a regional basis, permitting biozonation and comparison between ecoregions. Correlation of these data with past Canadian phenological data sets for evidence of climate change and the effects of El Nino is needed. Studies of the phenology of crops, weeds and insect pests (farming and forestry) will precede the establishment of a rapid-reporting network of observers. Current funding is from agriculture, to investigate correlations with the development of crop pests. This survey is being expanded across the prairies, and would be very useful on a national basis.

Conclusion

Compilation of these Alberta phenology records for the 6 years from 1987 to 1992 has provided a measurement of the average phenological sequence for these 15 key plant indicator species. More than 15 000 flowering dates were reported. Knowledge of flowering periods, and which species and phases are best reported, allows selection of better indicator plants and simplification of the survey. A preliminary analysis of the amount of heat required to induce flowering for these species has been done. Comparisons can now be made with historic databases for clues to climate change.

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