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ORIGINAL ARTICLE

Plant phenology networks of citizen scientists: recommendations from two decades of experience in Canada

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Abstract Plant phenology networks of citizen scientists have a long history and have recently contributed to our understanding of climate change effects on ecosystems. This paper describes the development of the Alberta and Canada PlantWatch programs, which coordinate networks of citizen scientists who track spring development timing for common plants. Tracking spring phenology is highly suited to volunteers and, with effective volunteer management, observers will stay loyal to a phenology program for many years. Over two decades beginning in 1987, Alberta PlantWatch volunteers reported 47,000 records, the majority contributed by observers who participated for more than 9 years. We present a quantitative analysis of factors that determine the quality of this phenological data and explore sources of variation. Our goal is to help those who wish to initiate new observer networks with an analysis of the effectiveness of program protocols including selected plant species and bloom stages.

Keywords Citizen science · Climate change · Phenology · Flowering · Canada

Introduction

Many parts of the world are experiencing rapid climate change, and biological data are needed to understand how ecosystems are responding. We have previously shown trends to earlier spring bloom times over the last century in response to increased winter and spring temperatures (Beaubien and Freeland 2000; Beaubien and Hamann 2011). This paper tells the story of harnessing the energy of citizen scientists to track the effects of climate change across Canada. Specifically, we describe the development of the Alberta and Canada PlantWatch programs, and we provide a quantitative analysis of factors that determine data quality. This analysis is based on the Alberta PlantWatch program, the longest-running plant phenology network in Canada for recent decades, drawing on 47,000 records reported between 1987 and 2006. Data quality is an important consideration for volunteer citizen science programs (Bonney et al. 2009; Delaney et al. 2008) and our analysis of program protocols is presented to help those planning new networks. Since the paper is written for scientists who wish to recruit citizens for a plant phenology network, we offer some additional information on program development in the form of an extended introduction below.

History of Canadian phenology networks

The first large-scale Canadian phenology observer network started in Alberta in 1973. This decade-long survey of bloom dates of wild plants was initiated through the Federation of Alberta Naturalists (Bird 1983) and was revived as the Alberta Wildflower Survey in 1987 (Beaubien and Johnson 1994). This program has continued since that time, renamed Alberta PlantWatch in 2002. This project began as part of an MSc (Beaubien 1991) supervised by ecologist Dr. Walter Moser, with the goal of exploring the potential for phenology in Alberta. By 1995, E. Beaubien had added to the Alberta program a web-based program called Prairie PlantWatch. In 1997, it was renamed Canada PlantWatch with more indicator plant species added to gather data from Canada's west coast, eastern provinces, and Arctic

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(Schwartz and Beaubien 2003; Beaubien and Hall-Beyer 2003). In 2000, the federal Environmental Monitoring and Assessment Network, led by Tom Brydges of Environment Canada, added PlantWatch to their other NatureWatch citizen science activities (www.naturewatch.ca). Coordinators were found for all 13 provinces and territories.

Since 2002, the Canada PlantWatch program has been the umbrella organization for several regional programs in Canada's provinces and territories. The position of national coordinator has been a full-time position paid for by Environment Canada, in charge of four citizen science programs including PlantWatch. The coordinator has a budget to develop promotional materials and maintain the website (www.plantwatch.ca). In recent years, a small portion of the budget was provided to regional coordinators to cover the annual costs of promotion and mailing to observers. Promotional materials and program protocols were developed in conjunction with regional coordinators, who met annually during the initial development of the program to coordinate their efforts and exchange ideas. Regional coordinators are not paid specifically for their contributions to the PlantWatch program, but they typically hold positions at universities, botanic gardens, or non-profit nature organizations where PlantWatch-related work fits under the institutions' general mandate.

The main goal for this Canadian program is to better understand both temporal and geographic patterns of how vegetation is responding to climate warming. Some of the results from this program are now appearing in the scientific literature (Beaubien and Hamann 2011; Kross et al. 2011; Vasseur et al. 2001).

Program promotion and volunteer recruitment

In 1988, an illustrated booklet describing the Alberta Wildflower Survey and 15 selected native plants was distributed to potential observers. Over the period 1987–1990, promotion included articles in all major Alberta newspapers and 14 society or government newsletters, as well as 13 talks, 2 radio interviews and 4 posters at conferences (Beaubien 1991, appendix 5). A diverse group of volunteer observers was engaged, including people who recorded weather variables for Environment Canada, and fire tower staff from northern forests (Koch 2010). Other promotional efforts included the publication of a pocket-size booklet *PlantWatch: Canada in Bloom* in 2002, with an updated edition released in 2010, which supports identification and provides reporting instructions for 39 species.

Other important means of communication are websites and on-line tools. Alberta observers who wish to learn about Plantwatch, or report their data electronically, can choose from two sites: our Alberta website (www.plantwatch.fanweb.ca) or the Environment Canada website (www.plantwatch.ca). Observers can determine location information of their observations with on-line tools, report bloom or leafing data including photos, and edit their past data. New Alberta observers receive a mailed package with booklet, extra 'how to' information, and a paper data sheet. The majority of Alberta observers report data on paper or emailed data sheets rather than online. Reported phenology observations are also downloadable for research on the Environment Canada website.

Volunteer motivation and retention

We have made an effort to retain PlantWatch observers for many years to build their knowledge of plant identification and spring development stages, thus increasing the likelihood of accurate reporting. For example, a new observer may need several weeks in late winter and spring to learn to distinguish male from female trees in a complex species such as the aspen poplar tree *Populus tremuloides*. To be able to effectively reward and retain volunteers, coordinators need to know why observers join PlantWatch. A study of motives for long-term participation by 150 volunteers in an 'Adopt-a-Stream' program revealed the following as most important: enjoying learning, helping the environment, feeling needed, having time for reflection, and benefitting from a well-organized program with good leadership (Ryan et al. 2001). No specific studies of PlantWatch volunteers' motivations have yet been published.

In Alberta, PlantWatch participants receive regular communication by mail and email with thanks or reminders to send data. Newsletters summarize interesting comments from observers about the relative earliness of the season, abundance of flowers or berries, effects of spring snow or frost, and insect activities. In some years, results of data analysis were provided. Personal notes were added if needed, to request details on locations or dates submitted and to answer observers' questions. Believing that it is better to keep a known observer for as long as possible rather than to find and train new people, we sent observers reminder newsletters for up to 4 years after they stopped submitting data. Departing volunteers were sent a thank you letter and a certificate.

We try to make the PlantWatch volunteer experience as enjoyable and flexible as possible to maintain interest in the program. Observers can collect data near their homes at times that suit them, and report on just one plant if their time is limited. Participants gain awareness of the natural world around them; this field-based knowledge builds science skills and benefits society as it creates the commitment needed for true stewardship and conservation of wild habitats. PlantWatch encourages youth to make observations outdoors on a regular basis in spring. There is now a 'nature deficit disorder' among children, whose increasing use of electronic devices coincides with reduced contact with nature (Louv 2008). To encourage teachers, a PlantWatch Teacher Guide was posted on the Alberta website in 2001 and then updated in 2009 in English and French (www.plantwatch.ca). A wallchart helps maintain program visibility in schools and parks during the busy spring season (www.plantwatch.fanweb.ca).

Relying on volunteers with a long-term commitment to the program allows for the gathering of quality data from a wide area at a manageable cost. The advantages of using volunteers over paid technicians are that they are committed, often more careful, mature, and will participate for many years (Droege 2007).

Goals for this paper

The following analysis focuses on the findings of Alberta PlantWatch for the years 1987–2006. We use these data to provide a quantitative analysis of factors that determine data quality to aid the development of program protocols and species selection. We ask: How do the observed plant species differ in both timing and variability of bloom date, and how suitable is each for volunteer observation? How do the observed bloom phases differ in variability? How long did observers stay involved with Alberta PlantWatch, and how did this affect the quantity and quality of data reported?

Materials and methods

Species selection

The main criteria for including a plant species for observation by volunteers are wide distribution, abundance in suitable habitat, and ease of recognition. Plant species must be perennial (not annual), so that the timing of bloom does not depend on the seeding or germination time. The species should preferably be monoecious (having both male and female flower parts on the same plant). In dioecious species such as poplar trees, male plants should be observed rather than female plants for which exact bloom times are often hard to observe. Species complexes with many species or subspecies of similar appearance that may have different flowering times should be avoided. Since the primary objective is to track climate variability and climate change, plants which bloom at the start of spring are preferred. Their bloom timing is usually more closely linked to temperature accumulation than plants which bloom later in the season (Fitter and Fitter 2002).

Flowers of selected species should bloom for a short period and ideally stay open once bloom begins so that first bloom can be clearly identified. The degree of herbivory is important; selected plants should have flower buds which are not attractive to caterpillars, rabbits, deer, etc. It can be both useful and problematic to select native plants which have horticultural cultivars that look similar and are hard to distinguish from a wild specimen, because the genetics and phenology of cultivars may vary from those of wild populations. Cultivars of the plant could be distributed to observers as cloned plants which are identical genetically, thus removing this source of variation in bloom date. However, if cultivars exist for a plant species, it is necessary to ask observers to report whether a garden plant or a wild plant was observed. For an extensive discussion of how to select organisms for phenology studies, see Leopold and Jones (1947).

There are obviously few species that fit all these criteria well. The larger the geographic area of the observer network, the more difficult it is to find species that are, for example, abundant everywhere and without similar-looking related taxa. Some subjective judgment needs to be applied. Alberta PlantWatch species fulfill most of the selection criteria (Table 1).

Observer protocols

Observers were instructed to report the calendar date for bloom phases. First bloom was defined as “the first flowers open in three different places on a woody shrub or tree”, or “first flowers open in a patch of herbaceous plants”. Mid-bloom was defined as “50% of flower buds open” and full bloom was defined as “90% of flower buds open”. Observation of full bloom ended in 2002, when protocols were adjusted to better match those used in Europe. The purpose of reporting at least two bloom stages was to increase the accuracy of the data, as observers would need to revisit the plants over a period of time.

Secondly, observers were asked to report the location of their plants. Most rural observers used an Alberta coordinate system of township, range, section, and quarter section, a system which represents geographic locations to the nearest 400 m. Since the web-based program began in 1995, observers have been asked to georeference their data with exact geographic coordinates using web-based maps or a global positioning system (GPS). On the PlantWatch websites, observers now zoom in to their observed plant’s location on a map and that latitude/longitude is automatically added to their data report.

Thirdly, observers were also encouraged to tag individual shrubs or trees, or patches of small plants, and to re-visit those plants every year. The recommended frequency of spring visits was at least every 2 days to ensure that first bloom was accurately observed. Ideally, observed plants should be located on a flat area and away from heat sources such as buildings. To deal with habitat variation, we asked observers to add environmental details to indicate whether the plant was in a sunny or shady location, on a flat area or on a slope, and in what proximity to buildings.

Table 1 Species included in the Alberta PlantWatch program and characteristics that affect species' suitability for phenology citizen science networks

Species	Type	Distribution	Abundance	Similar taxa	Herbivory
Achillea millefolium L.	Herb	Throughout AB	High	One introduced	No
Amelanchier alnifolia Nutt.	Shrub	Throughout AB	High	None	Occas.
Anemone patens L.	Herb	Throughout AB	High	None	Yes
Artostaphylos uva ursi (L.) Spreng.	Shrub	Throughout AB	High	One frequent	No
Cornus canadensis L.	Herb	Forested AB	High	None	No
Dryas integrifolia M. Vahl, *D. octopetala* L.	Shrub	Alpine	High	Two included	No
Elaeagnus commutata Bernh. *ex* Rydb.	Shrub	Forested AB	Medium	None	No
Epilobium angustifolium L.	Herb	Throughout AB	High	None	Yes
Fragaria virginiana Duchesne, *F. vesca* L.	Herb	Throughout AB	High	Two included	No
Gaillardia aristata Pursh	Herb	Southern AB	Medium	None	No
Galium boreale L.	Herb	Throughout AB	High	None	No
Larix laricina (Du Roi) K. Koch	Tree	Forested AB	High	One introduced	No
Lathyrus ochroleucus Hook.	Herb	Throughout AB	High	None	Yes
Ledum groenlandicum Oeder	Shrub	Forested AB	High	None	No
Lilium philadelphicum L.	Herb	Throughout AB	Low	None	Yes
Linnaea borealis L.	Shrub	Throughout AB	Medium	None	No
Pinus contorta Loudon	Tree	Western AB	Medium	One frequent	No
Populus tremuloides (Michx.)	Tree	Throughout AB	High	One frequent	No
Prunus virginiana L.	Shrub	Throughout AB	High	One frequent	No
Saxifraga oppositifolia L.	Shrub	Alpine	Medium	None	No
*Smilacina stellata (*L). Desf.	Herb	Throughout AB	High	None	No
Syringa vulgaris L.	Shrub	Introduced	Medium	Many cultivars	No
Taraxacum officinale Weber	Herb	Introduced	High	None	No
Thermopsis rhombifolia (Nutt.) Richards.	Herb	Southern AB	Medium	None	No
Viola adunca J.E. Smith	Herb	Throughout AB	High	One rare	No

Analysis

For statistical analyses, we calculated least squares means (lsmeans) for day of year for phenology observations by species, bloom phase, year, and ecosystem using the general linear model procedure PROC GLM of the SAS statistical software package (SAS Institute 2008). Ecosystems were based on the Alberta Natural Region and Subregion system (Natural Regions Committee 2006) and we used this system to account generally for phenological differences between regions of Alberta. We further calculated variance components to attribute the total variance in the phenological dataset to various possible causes. Variance components were estimated with the restricted maximum likelihood method implemented with PROC VARCOMP (SAS Institute 2008). For this analysis, we worked with a reduced dataset including only the 15 species that were part of the program since the beginning in 1987. Because environmental data on plant shading and exposure were transcribed only for the years 1996–2002, 2005 and 2006, these 9 years were used. The main effects and treatment levels that we included for the variance partitioning were years (9 years of data), species (15 species), phase (first bloom, mid bloom and full bloom), location (20 natural subregions), shading (sunny, half shade, full shade), and exposure (nine treatment levels). The nine treatment levels were a combination of slope and aspect. We distinguished two slope levels that were reported as flat, versus gentle or steep slope. Aspect was summarized for analysis as south-facing (S, SE, SW), north-facing (N, NE, NW), west- or east-facing. Summary statistics and variance components were visualized with histograms, box plots, and area charts using the R programming environment (R Development Core Team 2008).

Results and discussion

Location and number of observations

The reported observations of the Alberta PlantWatch program between 1987 and 2006 are shown in Fig. 1, broken down by natural subregion. Most of the observations were reported from the Central Parklands region of Alberta and the Dry Mixedwood region 2, immediately

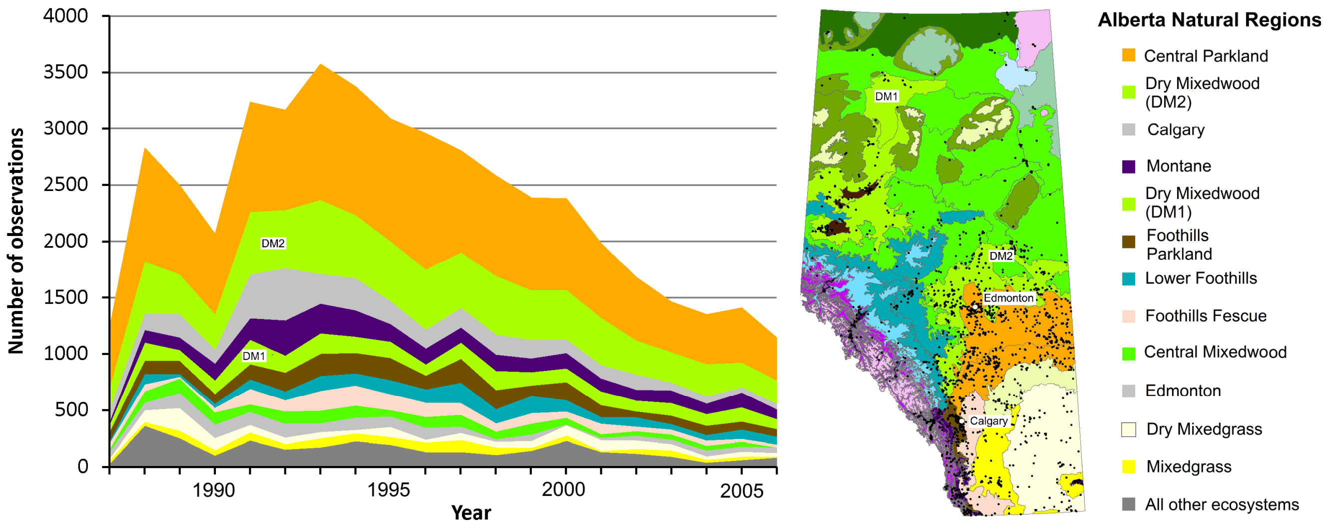

Fig. 1 Locations and number of observations over the course of the Alberta PlantWatch program from 1987 to 2006. Observer locations are shown as *black dots* on the map. Colors of natural regions in *chart* and *legend* are ordered in the same sequence from top to bottom

north of the Central Parklands. The area of next most abundant observations is the city of Calgary. This reflects the human population distribution of Alberta and much of the agriculturally productive zones of the province. It may also reflect the area of most promotional effort at the beginning of the program. The chart of numbers of observers over the years (not shown) has a very similar shape to Fig. 1.

At the start in 1987 and1988, the Alberta PlantWatch program built on the success and popularity of the Federation of Alberta Naturalists program which had run in the previous decade. About 200 naturalists including previous observers were contacted and 3,000 copies of a 22-page illustrated booklet describing the Alberta Wildflower Survey were distributed to potential observers at the beginning of the program. The early promotion resulted in a rapid recruitment and a peak of more than 2,500 observations in the second year (Fig. 1). Interestingly, there was a steady decline after the initial promotional effort, and again after a second peak. This pattern reflects the time commitment of the program coordinator (E. Beaubien), who was engaged with graduate research until 1991. After completion of her thesis, she was again able to devote a major portion of her time to engaging and communicating with observers. This increased observations to a peak of 3,500 observations in 1993. These intensive promotional efforts decreased after the program was firmly established and energy was diverted to establishing a national web-based PlantWatch.

The number of observations in Alberta did not increase either after Canada PlantWatch was established or after on-line reporting became available in 1995. The numbers actually decreased steadily from the 1993 peak (Fig. 1). It is therefore quite apparent that the success of a volunteer network relies considerably on the efforts of local coordinators to communicate with potential and existing observers. Though considerable promotional energy was devoted to engaging school classes over the two decades in Alberta, little data resulted. Teachers were initially enthusiastic, with students tagging plants and many observing dates in spring, but the step of actually reporting data was often missed. This could be remedied in future by regular spring reminder emails or incentive programs.

Even though the efforts of regional leaders are key to the success of a volunteer network, it is useful to have a national umbrella organization. For Canada, PlantWatch was organized regionally by province and territory, but it could potentially involve finer divisions, where local champions of the program can better maintain personal contact with the volunteers. In our experience, the regional coordinators were very effective in giving promotional talks and handling questions from the public. On the other hand, national coordination provided essential cohesiveness to the program and helped to minimize costs of promotional materials and website development and maintenance. The national coordinator found new regional coordinators, gathered their program suggestions, hosted conference calls, and supervised updates of website and promotional materials. Meetings at coordinator workshops helped regional coordinators share ideas for projects such as teacher guides, posters, and brochures and initiate applications for funding. This work resulted in numerous grants for at least the northern coordinators to promote involvement of citizens in tracking data needed to reveal the effect of climate change.

Variability of observations by species and phase

To quantify the variability in phenology records that are due to the observer as opposed to being caused by climate, we use a variance partitioning approach. Figure 2 shows the residual variation of phenology observations, after effects of year and location (but not species and bloom phase) have been accounted for as least squares means in the general linear model. Figure 2 includes plant species observed since the beginning of the program and which have the largest amount of data. In addition, we report number of observations, the median bloom date, and the inter-quartile range (25% of observations above and below the median) of bloom date for all species (Table 2). We followed the scientific nomenclature of Moss (1983). We found that the least variable species (smallest values of inter-quartile range) were *Amelanchier alnifolia* (saskatoon or serviceberry), *Elaeagnus commutata* (wolf willow), *Lilium philadelphicum* (western wood lily) and *Prunus virginiana* (chokecherry). These are species that bloom quickly, and are thus better phenology 'indicator' plants (Leopold and Jones 1947). Other useful species were

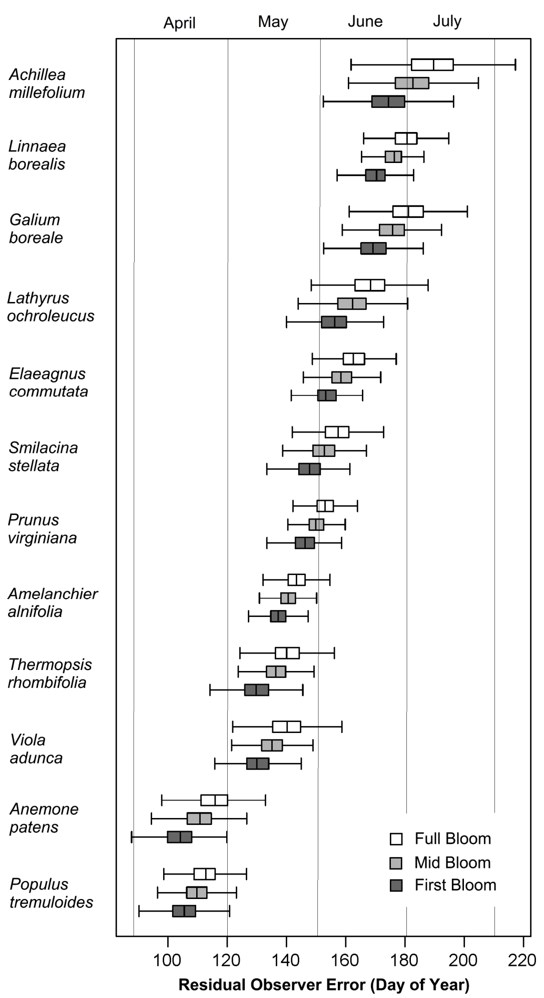

Fig. 2 Residual observer error in bloom date (as day of year) for three bloom phases, after interannual variation and variation due to location has been removed through variance partitioning. The *center* of the *boxplots* represents the median bloom date and the *box* encompasses the central 50% of observations

Anemone patens (prairie crocus) and *Populus tremuloides* (aspen poplar), because they bloom early, are widespread and the bloom dates show reasonably low variation (Fig. 2; Table 2).

Interestingly, the variability in bloom phases was only moderately increased for the full bloom phase with average inter-quartile ranges of 7.6, 7.4, and 8.9 days for first, mid-, and full bloom across all species, respectively. A paired t test revealed that there was no statistical difference between first and mid-bloom, but the full-bloom inter-quartile range differed significantly from the earlier phases with p values <0.001. We conclude, somewhat to our own surprise since first bloom is generally easier to recognize, that first and mid-bloom observations are equally accurate in this provincial data compilation. In future, they could possibly be combined using a species-specific adjustment. If the total number of observations is low, and standard errors of the estimates could be improved by increasing n, a more accurate first-bloom estimate for *Achillea millefolium* (as an example) may be obtained by including mid-bloom values minus the difference calculated from median values in Table 2 (183–174=9 days). If the data are normally distributed, all calculations could be done using means.

Variance partitioning

Next, we ask if the residual variation shown as boxplots in Fig. 2 can be attributed to causes other than species, phase, year, and location. Results from partitioning of variance components are shown in Table 3. Additional factors included were environmental details for observed plants including exposure to sun or shade, position on flat land or slope with a directional aspect, and proximity to buildings. However, none of these additional factors contributed very much to the overall variation in the entire dataset. This does not necessarily mean that some of these factors were not important for at least some species in some locations. The effects of micro-climate due to slope and aspect clearly would have an effect on bloom times in steep ravines (Jackson 1966) or in mountainous regions. However, none of these effects could be generalized to be important for studies at a provincial scale.

After all reported species, phase, year, location, and environmental factors have been accounted for, we still have an 8.4% residual variance (Table 3). Potential explanations for this residual variation include unknown microsite effects, natural genetic variation in plant populations, or erroneous reporting of flowering dates. While this is difficult to quantify, we made an attempt to reveal residual variance that is caused by observer error. The expectation would be that long-term program participants, who often rely on familiar tagged plants, should report less

Table 2 Observation and phenology statistics for species included in the Alberta PlantWatch program. For both median bloom date and interquartile range (which is a measure of variation in bloom dates) variation due to year and location has been removed through variance partitioning

Species	Number of obs.	Years of observations	Median bloom date			Inter-quartile range		
			First	Mid	Full	First	Mid	Full
Achillea millefolium L.	3,516	1987–2006	174	183	190	11.0	11.3	14.1
Amelanchier alnifolia Nutt.	4,889	1987–2006	137	141	143	5.0	4.9	5.7
Anemone patens L.	3,600	1987–2006	104	111	116	8.1	8.1	9.0
Artostaphylos uva ursi (L.) Spreng.	134	2002–2006	137	145				
Cornus canadensis L.	196	2002–2006	160	168				
Dryas integrifolia M. Vahl, and *D. octopetala* L.	34	2002–2006	160					
Elaeagnus commutata Bernh. *ex* Rydb.	2,112	1987–2006	153	158	163	6.1	6.6	7.2
Epilobium angustifolium L.	2,955	1987–2005	188	196	204	8.6	9.1	12.3
Fragaria virginiana Duchesne, *F. vesca* L.	504	2002–2006	141	149				
Gaillardia aristata Pursh	1,941	1987–2005	177	184	191	8.9	8.7	11.2
Galium boreale L.	3,426	1987–2006	169	176	181	8.4	8.4	10.2
Larix laricina (Du Roi) K. Koch	64	2002–2006	128	134				
Lathyrus ochroleucus Hook.	2,451	1987–2004	156	162	168	8.4	9.5	10.0
Ledum groenlandicum Oeder	93	2002–2006	160	168				
Lilium philadelphicum L.	2,182	1987–2004	175	180	185	5.9	6.4	8.0
Linnaea borealis L.	1,287	1987–2006	170	176	181	6.5	5.4	7.4
Pinus contorta Loudon	47	2002–2006	151					
Populus tremuloides (Michx.)	2,836	1987–2006	106	110	113	7.7	6.8	7.1
Prunus virginiana L.	3,204	1987–2006	146	150	153	6.4	4.9	5.5
Saxifraga oppositifolia L.	8	2002–2005	184					
*Smilacina stellata (*L). Desf.	2,992	1987–2006	148	153	157	7.2	7.3	7.9
Syringa vulgaris L.	541	1997–2006	150	155				
Taraxacum officinale Weber	617	2002–2006	128	140				
Thermopsis rhombifolia (Nutt.) Richards.	3,166	1987–2006	130	136	140	8.0	6.4	8.1
Viola adunca J.E. Smith	3,965	1987–2006	130	135	140	7.4	7.1	9.4

variable data than one-time observers who may not correctly identify a plant or bloom stage. We therefore grouped our data into log-2 classes of the number of years an observer has been a participant in the Alberta PlantWatch program (Fig. 3a). While we have many observers who reported only for 1 or 2 years, more than half of our data originate from observers who have stayed with the program for a decade or more (Fig. 3b). It is interesting to note that their observations are just slightly less variable than data submitted by short-term observers (Fig. 3c).

Table 3 Variance in bloom date explained by different species, locations, bloom phases, and environmental factors; variance components estimated with restricted maximum likelihood method

Effect (treatment levels)	Variance component (%)
Species (15 species)	72.7
Phase (first, mid, full)	9.6
Year (1996–2002, 2005, 2006)	5.5
Location (20 subregions)	3.7
Shading (sunny, half shade, full shade)	0.1
Exposure (N, E, S, W and slope)	0.1
Near building (yes, no)	0.0
Residual variance	8.4

We think that it is essential for observers to be properly trained in recognition of species and phases, and that many years of experience observing plants contributes to better data. Also, long-term observers usually report on multiple species over many years (Fig. 3b, class 9–16 years), contributing disproportionally to the amount of data. However, the residual variance for different observer groups in Fig. 3c suggests that even data from one-time reporters are largely unbiased (i.e. not over- or underestimating the mean bloom dates), and almost as temporally precise as data provided by long-term observers. This would suggest that observer networks could focus on obtaining large numbers of observations regardless of how long individual

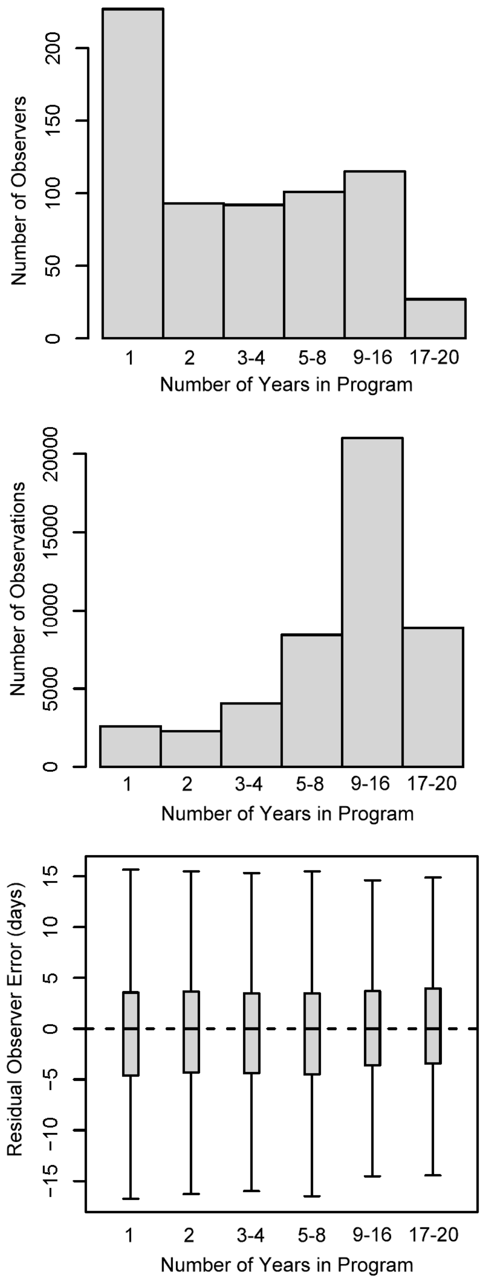

Fig. 3 Amount and quality of data as a function of length of participation of observers in the program. Histogram of observers by the duration of their participation (**a**). Total number of data points reported by observers grouped by the duration of their participation (**b**). Quality of the observation as a function of the duration of their participation, with residual observer error after the effects of year, species, phase, and location (ecosystem) have been removed through variance partitioning (**c**)

observers stay with the program, without compromising data quality.

Our findings support other research that suggest that networks of citizen scientists can gather high-quality data for scientific research. An evaluation of 395 European monitoring projects of flora and fauna concluded that volunteer-based projects provide relatively reliable data and unbiased results (Schmeller et al. 2009). Bonney et al. (2009) report that "citizen science projects have been remarkably successful in advancing scientific knowledge". A study by Delaney et al. (2008) suggests that even data collected by primary school students can provide quality biological data. We should note that other researchers report a more pronounced 'learning effect' where new participants in volunteer-based monitoring programs are the source for most of the variation in observer ability, with improvements in data collection over time (Dickinson et al. 2010).

Conclusions and recommendations

With respect to selecting suitable species for plant-watch programs, we can recommend a number of species that fit one or more of the desirable attributes of blooming early, over a relatively short period, with low variability, and which are easily identifiable: *Amelanchier alnifolia* (saskatoon), *Elaeagnus commutata* (wolf willow), *Prunus virginiana* (chokecherry), *Anemone patens* (prairie crocus) and *Populus tremuloides* (aspen poplar). Some of these species have North American or even circumboreal distributions. For setting up observer networks in other regions, related species such as *Populus tremula* in Europe might be taken into consideration.

With respect to observation protocols, our data suggest that it is useful to distinguish between first, mid, and full bloom phases, which represent sequential stages in individuals (trees and shrubs) or patches of smaller plants. All three stages provide data that can be used with appropriate adjustments to estimate any particular bloom stage, particularly if data is scarce for particular years, species, or regions. Data describing the micro-environment of observed plants, such as shading, proximity to buildings, or slope and aspect did not have a significant effect on bloom dates in our study. We think that further research restricted to particular species and locations might yield different insights, but our conclusion is that at least provincial or national scale analyses are not compromised if volunteers do not report such data.

We think that it is essential for observers to be properly trained in recognition of species and phases, and that many years of experience observing plants contributes to better data. We also found that long-term observers contributed disproportionally to the total amount of data reported. Nevertheless, our analysis suggests that even data from one-time reporters are unbiased and precise and that efforts to include, for example, school children, are a worthwhile endeavor. This result is supported by other publications on citizen science networks, although a 'learning effect' where new participants in volunteer-based monitoring programs are the source for most of the variation has been found by others.

To encourage and keep volunteers in this citizen science program, we need coordination that identifies and meets the needs and interests of observers, and provides appropriate training, frequent feedback, and rewards. As this support of volunteers requires considerable financial and other resources, government support is essential and has been the backbone of many long-term phenology networks in the United States and Europe. As Bonney et al. (2009) notes: "An effective citizen science program requires staff dedicated to direct and manage project development; participant support; and data collection, analysis, and curation. Such a program can be costly; the Cornell Laboratory of Ornithology's current citizen science budget exceeds $1 million each year … Considering the quantity of high-quality data that citizen science projects are able to collect once the infrastructure for a project is created, the citizen science model is cost-effective over the long term."

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References

Beaubien EG (1991) Phenology of vascular plant flowering in Edmonton and across Alberta. MSc thesis. University of Alberta, Edmonton, Alberta

Beaubien EG, Freeland HJ (2000) Spring phenology trends in Alberta, Canada: links to ocean temperature. Int J Biometeorol 44:53–59

Beaubien EG, Hall-Beyer M (2003) Plant phenology in western Canada: trends and links to the view from space. Environ Monit Assess 88:419–429

Beaubien EG, Hamann A (2011) Spring flowering response to climate change between 1936 and 2006 in Alberta, Canada. Bioscience 61 (in press). doi:10.1525/bio.2011.61.7.6

Beaubien EG, Johnson DL (1994) Flowering plant phenology and weather in Alberta, Canada. Int J Biometeorol 38:23–27

Bird CD (1983) Alberta flowering dates. Alberta Nat 13(Suppl 1):1–4

Bonney R, Cooper C, Dickinson J, Kelling S, Phillips T, Shirk JL (2009) Citizen science: a developing tool for expanding science knowledge and scientific literacy. Bioscience 59:977–984

Delaney DG, Sperling CD, Adams CS, Leung B (2008) Marine invasive species: validation of citizen science and implications for national monitoring networks. Biol Invasions 10:117–128

Dickinson JL, Zuckerberg B, Bonter DN (2010) Citizen science as an ecological research tool: challenges and benefits. Annu Rev Ecol Evol Syst 41:49–172

Droege S (2007) Just because you paid them doesn't mean their data are better. Pages 13–26 in McEver C, Bonney R, Dickinson J, Kelling S, Rosenberg K, Shirk J, (eds) Citizen Science Toolkit Conference Proceedings. Cornell Lab of Ornithology, Ithaca, New York, June 20–23, 2007

Fitter AH, Fitter RSR (2002) Rapid changes in flowering time of British plants. Science 296:1689–1691

Jackson MT (1966) Effects of microclimate on spring flowering phenology. Ecology 47:407–415

Koch E (2010) Global framework for data collection-Data bases, data availability, future networks, online databases. In: Hudson IL, Keatley MR (eds) Phenological research, methods for environmental and climate change analysis. Springer, Dordrecht, pp 23–61

Kross A, Fernandes R, Seaquist J, Beaubien E (2011) The effect of the temporal resolution of NDVI data on season onset dates and trends across Canadian broadleaf forests. Remote Sens Environ 115:1564–1575

Leopold A, Jones SA (1947) A phenological record for Sauk and Dane counties, Wisconsin, 1935–1945. Ecol Monogr 17:81–122

Louv R (2008) Last child in the woods: saving our children from nature-deficit disorder. Algonquin, Chapel Hill, NC

Moss EH (1983) In: Packer JG (ed) Flora of Alberta, 2nd edn. University of Toronto Press, Toronto, ON

Natural Regions Committee (2006) Natural regions and Subregions of Alberta. Compiled by DJ Downing and WW Pettapiece. Edmonton. Pub. No. T/852. Alberta Environment, Government of Alberta, Edmonton, AB

R Development Core Team (2008) R: A language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org

Ryan R, Kaplan R, Grese R (2001) Predicting volunteer commitment in environmental stewardship programmes. J Environ Plan Manag 44:629–648

SAS Institute (2008) SAS/STAT 9.2 User's guide. SAS Institute, Cary, NC

Schmeller DS, Henry PY, Julliard R, Gruber B, Clobert J et al (2009) Advantages of volunteer-based biodiversity monitoring in Europe. Conserv Biol 23:307–316

Schwartz MD, Beaubien EG (2003) Chapter 2.4. North America. In: Schwarz MD (ed) Phenology: an integrative environmental science. Kluwer, Dordrecht, pp 57–73

Vasseur L, Guscott RL, Mudie PJ (2001) Monitoring of spring flower phenology in Nova Scotia: comparison over the last century. Northeast Nat 8:393–402