*Proceedings of the Biennial Conference of the Society of South African Geographers 2018*

*University of the Free State, Bloemfontein*

*pp. 467-486*

AUTHOR'S COPY

# Advance in Jacaranda Blossom Phenology in the South African Highveld Interior: A Preliminary Analysis

Jennifer M. Fitchett* and Heritage A. Fani

School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, South Africa

* Corresponding author: Jennifer.Fitchett@wits.ac.za

## Abstract

Plant phenology represents one of the most sensitive biotic responses to climate variability and change. Shifts in the timing of annually recurrent biological events, including flowering, leafing and fruiting, are thus highly spatially and temporally specific. The paucity of data for the southern Hemisphere, and South Africa in particular, thus presents challenges to both regional and global monitoring of climate change impacts on natural ecosystems. To address the data paucity, we use a multi-method approach utilising accounts in the media of the flowering of Jacarandas in the two South African Highveld cities of Johannesburg and Pretoria. For the period 1924-1954, flowering dates are extracted from newspaper articles; for the period 2013-2016 dates are compiled from social media, including TripAdvisor, Twitter and Instagram. An advance in the flowering date of 2.4 days per decade is calculated for the period 1924-2016, from a mean flowering date of 315 Julian Days (mid-November) to 295 Julian Days (mid-October). This change in timing is consistent with globally observed phenological shifts.

**Keywords:** phenology, climate change, Jacaranda, Highveld, South Africa

## Introduction

Phenology refers to the timing of annually recurrent biological events (Badeck et al., 2004; Doi et al., 2017). For plants, these events are most noticeable in spring, including the appearance of flower and leaf buds, leaf growth, blossoming of flowers, and the development of fruits (Fitchett et al., 2015). Phenology does also include the timing of summer events such as fruit ripening, and autumn events including leaf colouration and leaf fall (Van Vliet et al., 2003; Doi et al., 2017). Under a warming climate, the timing of these events is shifting (Parmesan and Yohe, 2003). As late winter temperatures increase, the temperature thresholds that represent the trigger for spring events begin to take place, resulting in a progressively earlier occurrence of these events (Sparks et al., 2000; Nordli et al., 2008). These phenological shifts in turn represent one of the most sensitive biological indicators of climate change (Sparks and Carey, 1995; Badeck et al., 2004; Fitchett et al., 2015).

As both the contemporary climate and future climate projections are highly spatially heterogeneous, so too are phenological shifts (Parmesan and Yohe, 2003). This is in part due to the differences in the rate of temperature increase, but even when controlled for a single unit temperature increase, latitude, altitude and proximity to the ocean influence the rate of phenological shift (Primack et al., 2009a). The same species of granny smith apples (*Malus pumila*) have responded to climate change with advances at the rate of 2.4d/°C in Poland (Kalbarczyk, 2009) and 4.2d/°C in Cape Town (Grab and Craparo, 2011). In Iran, these differences are as stark as an advance in the flowering of Orange trees in the mountainous city of Shiraz and a delay in timing for the coastal city of Gorgan (Fitchett et al., 2014a). The shifts are also highly species specific, with some species reacting more rapidly to the same change in climatic conditions at a given location (Root et al., 2003; Wang et al., 2008). Due to the species and location specificity of phenological responses to climate change it is important to conduct phenological studies for as many plant taxa and as many global locations as possible (Parmesan and Yohe, 2003; Fitchett et al., 2015).

There is a paucity of studies on plant phenology across the African continent, and for South Africa in particular (Fitchett et al., 2015; Whitecross et al., 2017). This is largely due to an absence of phenological data, which has resulted from a relatively poor culture of long term diarising and record keeping, in contrast to the many generations of naturalists in Europe and North America (cf. Sparks and Carey, 1995; Ledneva et al., 2004; Miller-Rushing and Primack, 2008). This paucity of data, and in turn phenological studies, prohibits a comprehensive global understanding of phenological shifts, which in turn prevents the accurate modelling of future phenological shifts under continued climate change (Fitchett et al., 2015). To this end, this study utilises a mixed-method approach to track phenological shift in the timing of Jacaranda flowering in the Pretoria-Johannesburg region of South Africa from a combination of newspaper reports and social media accounts of Jacaranda bloom. This represents one of the first phenological records for South Africa, and the first phenological shifts documented for Jacarandas.

**Sources of Phenological Data**

The earliest sources of phenological data are from the recording of cultural celebrations associated with the onset of particular phenological events (Fitchett et al., 2015). Most widely published is the Japanese Kyoto Cherry Festival, a city festival of the onset of flowering of cherry trees, yielding a phenological record spanning 1300 AD to present (Aono and Kazui, 2008; Primack et al., 2009b). Comparatively shorter records, yet sometimes contributing often to datasets spanning 100s of years, are the diaries of naturalists and family estates (Sparks and Carey, 1995; Ledneva et al., 2004; Miller-Rushing and Primack, 2008; Amano et al., 2010). As the scientific investigation of phenology developed traction, a number of phenology gardens were established across Europe and the Middle East to facilitate the high resolution capturing and recording of phenological events (Chmielewski and Rötzer, 2002; Menzel et al., 2006; Fitchett et al., 2014a). More recently, as these phenological records have increasingly been studied and reported on, attempts have been made to find new sources of phenological data captured in letters, diaries, newspapers and logbooks (Keatley et al., 2013). These records represent part of a wide range of sources of ground-based phenological records, which include the deliberate recording of the timing of a phenological event for a given location, species and point in time. Ground-based sources represented the primary databases for the majority of early phenological studies, affording a high resolution, species-specific record for a given destination (Fitchett et al., 2015). Although concerns have been raised regarding the accuracy of records captured by non-specialists; inconsistencies introduced through the subjectivity of different members of groups of observers; and biases relating to perceptions of each phenological event, ground-based data remains widely used in phenological studies (Menzel, 2002; Ledneva et al., 2004; Fitchett et al., 2015).

Developments in remote sensing over the past four decades have provided a range of new approaches to phenological monitoring and modelling (Schwartz, 1999; Ahas et al., 2002; White et al., 2009). Remote sensing of the Normalised Difference Vegetation Index (NDVI), for example, allows for phenological shifts to be detected across a continental range, capturing and quantifying what is termed the ‘green wave’ (Schwartz, 1999; Pettorelli et al., 2005). Although these records cannot be used to identify the phenological shifts in individual species, they instead provide a valuable record across a wider spatial range than can be achieved through ground-based record capturing (Stöckli and Vidale, 2004; Zhao et al., 2015). Similarly, web-cameras and digital repeat photography have been used to capture phenological shifts across wide areas (Sonnetag et al., 2012). In this instance, species often can be identified, and depending on the temporal frequency of photographs, sub-daily comparisons can often be made (Richardson et al., 2009; Polgar and Primack, 2011). The key limitations for both satellite and digital-repeat photography as sources of phenological data are 1) the cost of capturing and storing data and 2) these technologies do not afford a long-term temporal record, as these are limited by the duration of existence of each platform (Richardson et al., 2007; Jacobs et al., 2009; White et al., 2009).

In recent years, a concerted effort has been made to capture and utilise the phenological observations of the local citizens who often have no formal phenological or even scientific education (Mackenzie et al., 2017; Leocadio et al., 2018). In the global North, this approach is driven through the development of cellular phone applications that facilitate citizen-science programmes, whereby photographs can be taken of plants, digitally identified in terms of species and phenophase, and automatically georeferenced (Graham et al., 2011; Criscuola et al., 2018). In the global South, this approach is grounded in efforts to record and understand indigenous knowledge systems that incorporate phenological knowledge (cf. Chambers et al., 2017; Fitchett and Ebhuoma, 2018).

**Study Site**

Native to western South America, *Jacaranda mimosifolia* was first introduced into South Africa in 1829 to suburban Pretoria (Henderson, 1990; Coetzee et al., 2015). Jacarandas thrive in sub-humid regions with a high moisture availability, growing easily along rivers and watercourses (Grobler et al., 2002; Coetzee et al., 2015). With a distinct purple flower it represents somewhat of a unique alien flagship species, on which the aesthetics of Pretoria and Johannesburg are grounded, with Pretoria referred to as the 'Jacaranda city' (Coetzee et al., 2015; van Eeden, 2015). With an estimated 33 630 Jacaranda trees within the City of Tswane, the species is estimated to represent ~17% of the total urban trees in the city (Stoffberg, 2006). Many of these trees were deliberately planted along the streets of the central business district and suburbs (Henderson, 1990). The species were soon after introduced into the adjacent city of Johannesburg (~50km south of Pretoria), with a significant number of Jacaranda trees planted during a 'tree planting bloom' in the late 19$^{th}$ century in an effort to both address the dust pollution associated with mining, and provide wood for mine supports (Schäffler and Swilling, 2013: 248). Alien invasives, including Jacaranda, black wattle and eucalyptus were favoured due to their rapid growth rates (Turton et al., 2006). Of these, Jacaranda remain among the key constituents of the Johannesburg urban forest, that covers 16.1% of the urban land area (Schäffler and Swilling, 2013).

Given the prevalence of Jacaranda trees in Johannesburg and Pretoria (Figure 1), the duration of the existence of the trees, and the importance of their flowers in the aesthetic identities of the two cities, this study focusses on the phenology in both Johannesburg and Pretoria, Gauteng Province. Gauteng Province is situated in the interior of South Africa on the Highveld plateau, with a mean elevation of 1500m.asl (Dyson et al., 2015). Due to the relatively high altitude, the province is characterised by a temperate climate with a distinct summer rainfall regime (Gijben, 2012). Mean annual temperatures range from 22°C for Johannesburg to 25°C for Pretoria (Dyson, 2009; Dyson et al., 2015). Mean annual rainfall varies from 600-700mm, characterised by heavy convective storms in the summer months. The winter months are characterised by dry conditions, with an average of 85 and 100 rain free days per winter season recorded for Johannesburg and Pretoria respectively (Kruger, 2004; Dyson, 2009; Dyson et al., 2015).

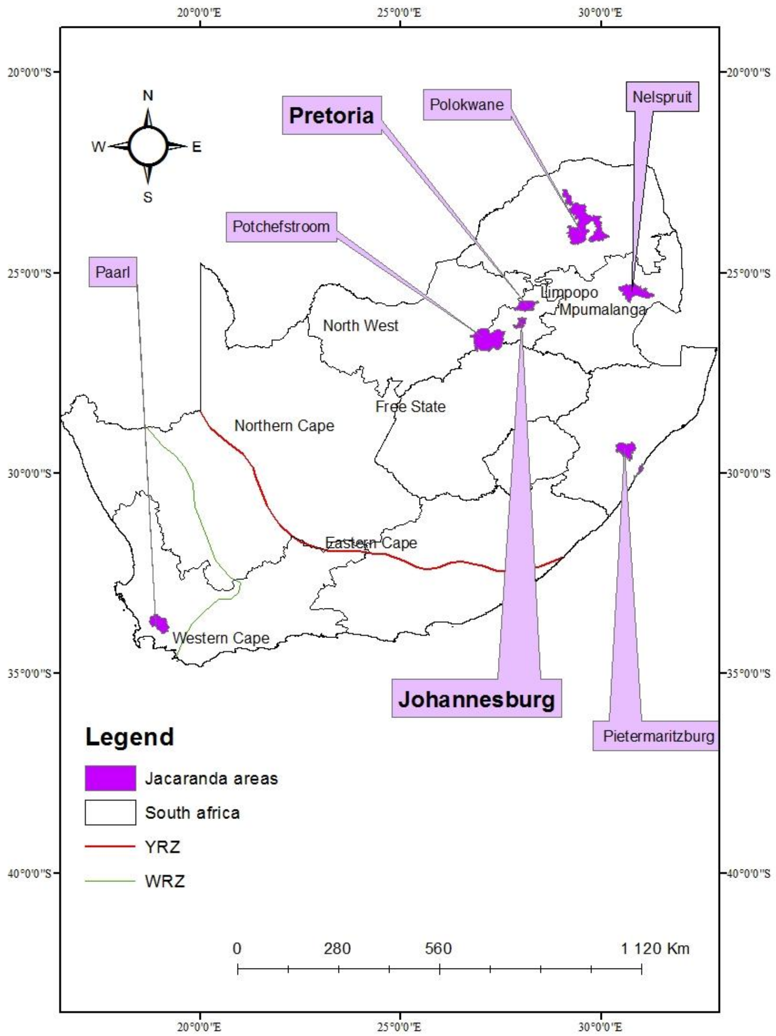


Figure 1: Map indicating the position of the study region and two focal cities.

**Methods**

This study utilises a mixed-method approach in collecting phenological data on the timing of Jacaranda flowering in the cities of Pretoria and Johannesburg, in the Gauteng Province of South Africa. For the period 1924-1954, Jacaranda flowering dates have been captured from newspaper articles, stored in the historical documents archive of the Cullen Library at the University of the Witwatersrand. All newspaper articles spanning the months of August – December were consulted for each year, identifying headlines or photographs that involved the bloom of the taxon of interest, Jacarandas, following the methodology adopted by Futter (2003). For any article with such a headline or photograph, the main body of text was consulted to determine whether this represented reporting on flowering in that year and for the specific time period of that article (Futter, 2003; Fitchett et al., 2018). Where that was the case, the date of flowering was recorded and converted to Julian Dates for the purpose of quantitative analysis (Luedelling and Gassner, 2012). Following 1954, Jacaranda bloom seldom featured in newspaper headlines, and thus this preliminary newspaper record terminates at this point. To create a comparative contemporary dataset, against which any phenological shifts between 1924-1954 could be compared, social media records from Instagram, Twitter and TripAdvisor were used to capture flowering dates of Jacarandas for the period 2013-2016, together with any accounts of Jacaranda blossoming in the news as documented across all online newspapers archived digitally through Google News. For these records, standard netnographic data collection approaches were adopted, with the aim to elicit scientific data from sub-daily, unstructured self-reported daily accounts of individual human observation (Miguéns et al., 2008). Only posts which represented a clearly stated account of an observation of Jacaranda bloom on that given day were captured. These eliminated explicit recounting of past events, as indicated through the 'flashback Friday' or 'throwback Thursday' hashtags and specific mentions of events having occurred in past months, particularly through time-of-travel records on TripAdvisor. They also included the more implicit indicators of past dissynchronous recording through the time of day, month of mention and the associated climatic conditions visible in the photograph or described in the account. Again, once a reliable account of flowering was obtained, this was captured against the date of occurrence. Due to the large number of phenological accounts from the social media record, the mean flowering date was accounted for each record, and then averaged between the records, to produce a single mean peak flowering date for each year, which was then converted to the Julian date. The phenological shift in Jacaranda flowering was computed through standard methods, using linear regression to determine the time trend in flowering dates. The change in flowering dates was calculated first for the period for which a uniform dataset was available (1924-1954), and then recalculated to include the contemporary data.

**Results**

The historical newspaper records yield phenological records for 11 years spanning the period 1924-1954. These records are relatively evenly distributed throughout this record, with a slight increase in incidence over the years 1940-1945. The records capture flowering dates ranging from 305-328 Julian days (~1-24 November). A statistical outlier is identified for 1944, with a Julian date of 279 (~6 October). As this date falls within the range of contemporary flowering dates for Jacaranda, it was provisionally retained in the dataset. Including this date, the historical newspaper record reveals a statistically insignificant advance in Jacaranda flowering dates at a rate of 4.98 days per decade over the period 1924-1954 ($r = -0.35$, $p = 0.2892$). Excluding the date, for documentation, the time trend remains statistically insignificant ($r = -0.54$, $p = 0.1088$), indicating a slower advance at 3.89 days per decade over this period.

The social media records indicate flowering dates notably earlier in the year than those captured in the historical newspaper record, ranging from a minimum Julian date of 288 (~15 October, recorded for Twitter and Instagram 2015 and Instagram 2014) to a maximum Julian date of 316 (~12 November, TripAdvisor 2014). A progressive improvement in the degree of agreement between the social media sources is evident (Figure 2), with a standard deviation in total recorded dates decreasing from 12.6 for 2014 to 4.35 and 4.34 for 2015 and 2016 respectively. The mean date compiled from the four social media databases fell within one standard deviation of the mean values for each independent dataset, yielding a high level of concurrence.

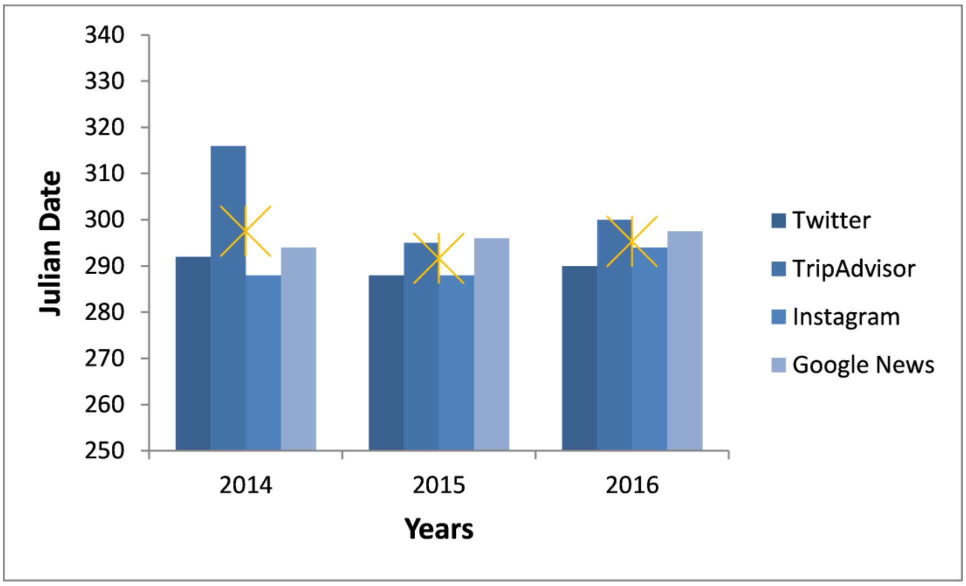


Figure 2: Mean flowering dates for each of the social media sources (blue) and the mean across all sources (yellow) for 2014-2016

The combined record integrating the historical newspapers and contemporary social media records reveals a statistically significant (r= -0.64, p = 0.0111) mean advance in Jacaranda blossom dates of 2.38 days per decade for the period 1924-2016. This represents a shift from a mean flowering date of 315 Julian Days (mid-November) to 295 Julian Days (mid-October). Excluding the outlier date from the historical newspaper record, a more rapid advance in Jacaranda flowering dates of 2.73 days per decade is calculated (r = -0.89. p < 0.0001). These rates of advance are noticeably slower than captured for the historical newspaper record alone (Figure 3); yet with statistically significant time trends, indicate a more reliable record of change.

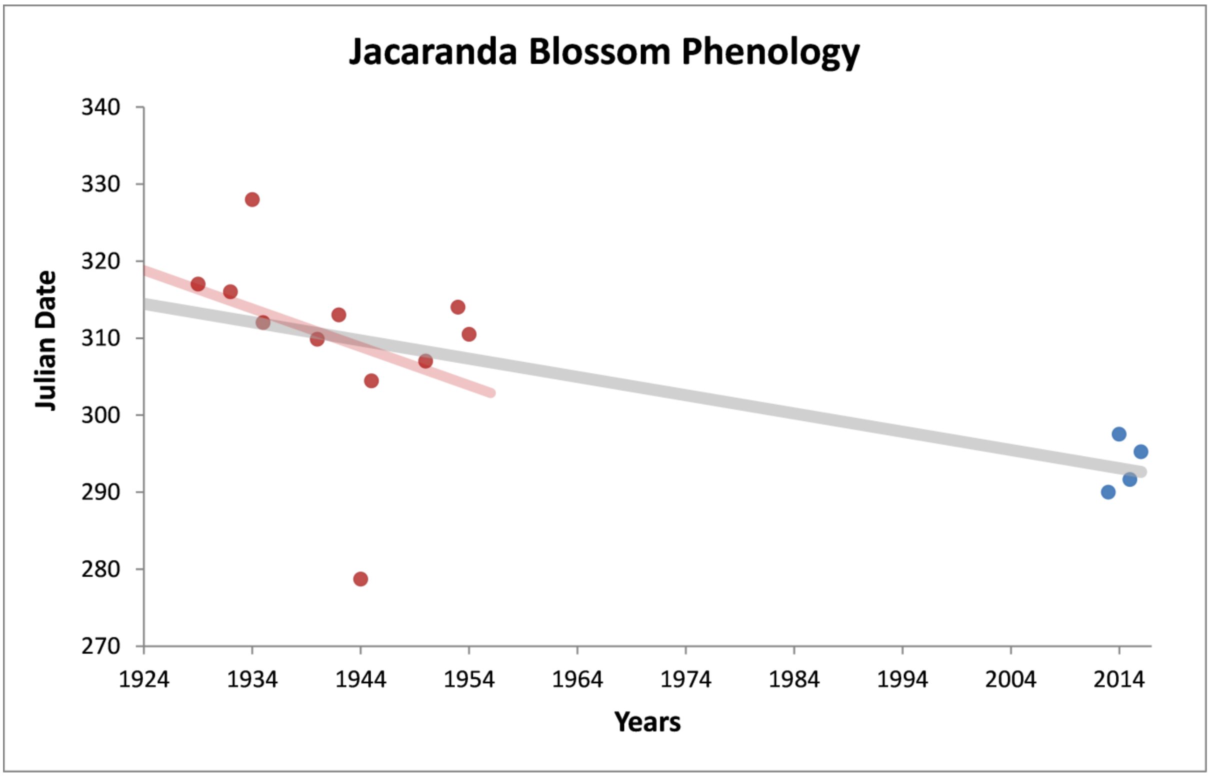


Figure 3: Jacaranda blossom phenological shift documented in newspaper records for the period 1924-194 (red) and composite record for the period 1924-2016 (grey) for Gauteng Province, South Africa.

**Discussion**

The 2.38 (2.78 excluding outliers) day per decade advance in the blossom phenology for Jacarandas in Gauteng Province, South Africa is consistent with global records in both magnitude and direction. A global meta-analysis of the phenological shifts of 1700 species yielded a mean advance in phenological events of 2.3 days per decade (Parmesan and Yohe, 2003). A subsequent reassessment involving a smaller pool of 2003 species in the northern Hemisphere, likewise to address issues of outliers and standardise the selection of sites and species in line with a similar meta-analysis conducted by Root et al. (2003), yielded a mean advance rate of 2.8 days per decade (Parmesan, 2007). More recent meta-analyses for the northern Hemisphere spanning 562 species and 18 locations interrogate the species and location specificity, yet similarly find that in 69.9% of cases phenological advances of <5 days per decade are recorded (König et al., 2018). The change in the rate of phenological shift throughout this record is likewise consistent with global records (Amano et al., 2010).

The paucity of phenological studies across the southern Hemisphere, and in South Africa in particular, precludes a comprehensive comparison of the rates of shifts (Fitchett et al., 2015). However, the existing records indicate that while globally consistent, this record is indicates a relatively rapid rate of phenological advance in the southern Hemisphere context. An analysis of apple and pear flowering dates in the southwestern Cape of South Africa yields a phenological advance of 1.6 days per decade (Grab and Craparo, 2011). For eucalyptus trees in Australia over the period 1920-1980, no net change in flowering commencement was detected (Keatley et al., 2002). A broader study of 65 species in Australia yielded phenological advances amongst only eight, but with a rapid mean rate of 1.7 days per year or 17 days per decade (Keatley and Hudson, 2012). The heightened rate of phenological advance observed for Jacarandas in Gauteng Province of South Africa relative to the apples and pear in the southwestern Cape may be as a result of the urban heat island effect; as these trees are situated within the centres of metropolitan areas (Rötzer et al., 2000). A deliberate comparison of Jacaranda tree phenology in rural and urban areas, or within large and small metropoles, would be valuable in testing this hypothesis.

This study highlights the potential for using creative approaches to obtain phenological records in data-scarce regions. The need for alterative phenological databases, and the utilisation of 'accidental' records, has been raised previously in the context of southern Hemisphere research (Chambers et al., 2013, 2016). This is particularly important given the apparent variation in the net rate of phenological change recorded for the northern and southern Hemisphere, and the global species and location specificity in phenological records (Primack et al., 2009a). This is particularly important in the South African context, given the significant spatial heterogeneity in climate and vegetation.

The phenological shift observed for Jacarandas in Gauteng raises concerns regarding the future of this relatively uniquely classified flagship invasive species. As phenology represents one of the most sensitive indicators of climate change impacts on the natural environment, it reveals the sensitivity of a plant to the climate changes it is experiencing (Badeck et al., 2004). The key threat in this regard is of a heightened exposure to late winter and early spring frost (Miller-Rushing and Primack, 2008). Increasingly studies have found that while flowering dates are advancing, final winter season frost dates are receding, placing a heightened risk of frost exposure to these early season flowers and to the plant as it moves out of its dormancy state (Fitchett et al., 2014b; Vitasse et al., 2018). Jacarandas, in particular, are recorded as being particularly susceptible to frost damage (Henderson, 1990), although arguably become less sensitive to longer-term climatic stressors such as drought with age (Suarez et al., 2004; Galik and Jackson, 2009). Jacarandas in South Africa have also been affected by root rot over recent decades, resulting in a heightened tree death rate; while this is caused by a species of *Ganoderma,* moisture availability increases the chances of incidence (Coetzee et al., 2015). The climate change threats to Jacarandas are of concern given that as a category three invasive species, Jacaranda trees cannot be replaced in South Africa (Stoffberg, 2006). These threats could thus result in the ultimate demise of this iconic feature of the urban landscape of the two cities.

**Conclusion**

This study represents only the second documented record of phenological shifts in the timing of tree blossoming in South Africa, and contributes to very small pool of literature on phenology in South Africa across faunal and floral species. The paucity of phenological records are largely due to an absence of records of phenological events, which plagues much of the southern Hemisphere. Due to the location and species specificity of phenological shifts under global climate change, a comprehensive understanding of the direction and magnitude of phenological shifts relies heavily on these spatial gaps in the phenological record being addressed. There is thus a need to explore unconventional sources and develop innovative methodological approaches to identify and examine phenological shifts for data-scarce regions.

The importance of this study is thus twofold. First it confirms the presence of phenological records of flagship species within historical newspaper records. Second, it highlights the capacity of social media records to capture and store data on phenological shifts through the encouragement of real-time seemingly mundane posting of ones day to day life, and the online integration of a range of sources. The successes in constructing a phenological record from this combination of sources should encourage scholars across the African continent to seek and interrogate these and other sources for hidden phenological data, and to quantify climate-change induced phenological shifts that these data may reveal.

This study presents very preliminary findings regarding phenological shifts in Jacaranda blossom dates in the cities of Johannesburg and Pretoria, Gauteng Province, South Africa. First, the record is at present temporally incomplete. A substantial temporal gap exists between 1955-2013. To quantify more accurately the magnitude and direction of the rate of change in flowering date, it is important to explore possible records to contribute data for this time period, which will involve a more comprehensive assessment of newspapers including small community publications, an analysis of local archive records, and consultation with community groups. Second, the record is not yet related to climatic change in the region. Phenological studies strive to relate directly the rate of phenological shift to the change in ambient temperature in the region, yielding an output value in days per degree Celsius warming. To do this, however, the first point needs to be achieved in addressing the temporal gaps. Finally, such a record should ideally be partitioned into the two cities, and if possible, reflect also on urban-rural differences induced by the urban heat island (Rötzer et al., 2000; Lu et al., 2006), to detect the location specific responses. Future research will endeavour to improve on this record to address these key research gaps.

**Reference list**


Ahas, R., Aasa, A., Menzel, A., Fedotova, V. and Scheifinger, H. (2002). Changes in European spring phenology. *International Journal of Climatology,* 22: 1727-1738.

Amano, T., Smithers, R., Sparks, T. and Sutherland, W. (2010). A 250-year index of first flowering dates and its response to temperature changes. *Proceedings of the Royal Society of Biological Sciences*, 277: 2451-2457.

Aono, Y. and Kazui, K. (2008). Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9$^{th}$ century. *International Journal of Climatology,* 28(7): 905-914.

Badeck, F., Bondeau, A., Böttcher, K., Doktor, D., Lucht, W., Schaber, J. and Sitch, S. (2004). Responses of Spring Phenology to Climate Change. *New Phytologist,* 162: 295-209.

Chambers, L.E., Atwegg, R., Barbraud, C., Barnard, P., Beaumont, L.J., Crawford, R.J.M., Durant, J.M., Hughes, L., Keatley, M.R., Low, M., Morellato, P.C., Poloczanska, E.S., Ruppolo, V., Vanstreels, R.E.T., Woehler, E.J. and Wolfaardt, A.C. (2013). Phenological changes in the southern Hemisphere. *Plos One,* DOI: 10.1371/journal.pone.0075514.

Chambers, L.E., Barnard, P., Poloczanska, E.S., Hobday, A., Keatley, M.R., Allsopp, N. and Underhill, L.G. (2016). Southern hemisphere biodiversity and global change: data gaps and strategies. *Austral Ecology,* 42(1): 20-30.

Chambers, L.E., Plotz, R.D., Dossis, T., Hiriasia, D.H., Malsale, P., Martin, D.J., Mitiepo, R., Tahera, K. and Tofaeono, T.I. (2017). A database for traditional knowledge on weather and climate in the Pacific. *Meteorological Applications,* 24(3): 491-502.

Chmielewski, F.M. and Rötzer, T. (2002). Annual and spatial variability of the beginning of the growing season in Europe in relation to air temperature changes. *Climate Research,* 19(3): 257-264.

Coetzee, M.P.A., Marincowitz, S., Muthelo, V.G. and Wingfield, J. (2015). *Ganoderma* species, including new taxa associated with root rot of the iconic *Jacaranda mimosifolia* in Pretoria, South Africa. *IMA Fungus,* 6(1): 249-256.

Criscuola, L., Carrara, P., Oggioni, A., Pugnetti, A. and Antoninetti, M. (2018). Can VGI and mobile apps support long-term ecological research? A test in rremote areas of the Alps. In Bordogna, G. and Carrara, P. (Eds.) *Mobile Information Systems Leveraging Volunteered Geographical Information for Earth Observation,* Springer: Cham, pp. 53-69.

Doi, H., Gordo, O., Mori, T. and Kubo, M.T. (2017). A macroecological perspective for phenological research under climate change. *Ecological Research,* 32(5): 633-641.

Dyson, L.L. (2009). Heavy daily-rainfall characteristics over the Gauteng Province. *Water SA,* 35(5): 627-638.

Dyson, L.L., van Heerden, J. and Sumner, P.D. (2015). A baseline climatology of sounding-derived parameters associated with heavy rainfall over Gauteng, South Africa. *International Journal of Climatology,* 35: 114-127.

Fitchett, J.M., Grab, S.W., Thompson, D.I. and Roshan, G. (2014a). Spatio-temporal variation in phenological response of citrus to climate change in Iran: 1960-2010. *Agricultural and Forest Meteorology,* 198: 285-293.

Fitchett, J.M., Grab, S.W., Thompson, D.I. and Roshan, G. (2014b). Increasing frost risk associated with advanced citrus flowering dates in Kerman and Shiraz, Iran: 1960-2010. *International Journal of Biometeorology,* 58(8): 1811-1815.

Fitchett, J.M., Grab, S.W. and Thompson, D.I. (2015). Plant Phenology and Climate Change: Progress in Methodological Approaches and Application. *Progress in Physical Geography,* 39(4): 460-482.

Fitchett, J.M. and Ebhuoma, E. (2018). Phenological cues intrinsic in indigenous knowledge systems for forecasting seasonal climate in the Delta State of Nigeria. *International Journal of Biometeorology,* 62(6): 1115-1119.

Fitchett, J.M., Grab, S.W. and Portwig, H. (2018). Advances in the timing of sardine migration in the South-West Indian Ocean: Ocean-Atmospheric Considerations under Global Change. *Submitted to International Journal of Biometeorology.*

Futter, M.N. (2003). Patterns and trends in southern Ontario lake ice phenology. *Environmental Monitoring and Assessment*, *88*(1-3): 431-444.

Galik, C.S. and Jackson, R.B. (2009). Risks to forest carbon offset projects in a changing climate. *Forest Ecology and Management*, 257(11): 2209-2216.

Gijben, M. (2012). The lightning climatology of South Africa. *South African Journal of Science,* 108(3/4): DOI: 10.4102/sajs.v

Grab, S. and Craparo, A. (2011). Advance of apple and pear tree full bloom dates in response to climate change in the southwestern Cape, South Africa: 1973-2009. *Agricultural and Forest Meteorology*, 151: 406-413.

Graham, E.A., Henderson, S. and Schloss, A. (2011). Using mobile phones to engage citizen scientists in research. *EOS,* 92(38): 313-315.

Grobler, C.H., Bredenkamp, G.J. and Brown, L.R. (2002). Natural woodland vegetation and plant species richness of urban open spaces in Gauteng, South Africa. *Koedoe,* 45(1): 19-34.

Henderson, L. (1990). Jacaranda. *Weeds,* 30: 9-10.

Jacobs, N., Burgin, W., Fridrich, N., Abrams, A., Miskell, K., Braswell, B., Richardson, A. and Pless, R. (2009). The global network of outdoor webcams: properties and applications. *ACM GIS: Seattle.*

Kalbarczyk, R. (2009). Air temperature changes and phenological phases of field cucumber (*Cucumis sativus L.*) in Poland, 1966-2005. *Horticultural Science,* 36(2): 75-83.

Keatley, M., Fletcher, T., Hudson, I. and Ades, P. (2002). Phenological studies in Australia: potential application in historical and future climate analysis. *International Journal of Climatology*, 22: 1769-1780.

Keatley, M. and Hudson, I. (2012). Detecting change in an Australian flowering record: comparisons of linear regression and cumulative sum analysis change point analysis. *Austral Ecology*, 37(7): 825-835.

Keatley, M.R., Chambers, L.E. and Phillips, R. (2013). Australia and New Zealand. In Schwartz, M.D. (Ed.) *Phenology: An Integrative Environmental Science.* Springer: Dordrecht, pp. 23-52.

König, P., Tautenhahn. S., Cornelissen, J.H.C., Kattge, J., Bönisch, G. and Römermann, C. (2018). Advances in flowering phenology across the Northern Hemisphere are explained in functional traits. *Global Ecology and Biogeography,* 27(3): 310-321.

Kruger, A.C. (2004). *Climate of South Africa. Climate Regions. WS45.* South African Weather Service: Pretoria.

Ledneva, A., Miller-Rushing, A., Primack, R. and Imbres, C. (2004).Climate change as reflected in a naturalist's diary, Middleborough, Massachusetts. *The Wilson Bulletin,* 116(3): 224-231.

Leocadio, J., Veiga, A., Barbosa, M., Albertini, B., Lohmann, L., and Saraiva, A. (2018). A multi-platform mobile application to collect citizen science data for Bignoniaceae phenological research. *Biodiversity Information Science and Standards,* 2. DOI: 10.3897/biss.2.25582.

Luedeling, E. and Gassner, A. (2012). Partial least squares regression for analysing walnut phenology in California. *Agricultural and Forest Meteorology,* 158: 43-52.

Mackenzie, C.M., Murray, G., Primack, R. and Weihrauch, D. (2017). Lessons from citizen science: assessing volunteer-collected plant phenology data with Mountain Watch. *Biological Conservation,* 208: 121-126.

Menzel, A. (2002). Phenology: its importance to the global change community, An Editorial Comment. *Climatic Change,* 54: 379-385.

Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, R., Alm-Kübler, K., Bissolli, P., Braslavská, O.G., Briede, A. and Chmielewski, F.M (2006). European phenological response to climate change matches the warming pattern. *Global Change Biology,* 12(10): 1969-1976.

Miguéns, J., Baggio, R. and Costa, C. (2008). Social media and tourism destinations: TripAdvisor Case Study. *Proceedings of the Advances in Tourism Research Conference 2008*, Aveiro, 26-28 May.

Miller-Rushing, A. and Primack, R. (2008), 'Global warming and flowering times in Thoreau's Concord: a community perspective', *Ecology* 89(2): 332-341.

Nordli, Ø., Wielgolaski, F., Bakken, A., Hjeltnes, S., Måge. F., Sivle, A. and Skre, O. (2008). Regional trends for bud burst and flowering of woody plants in Norway as related to climate change. *International Journal of Biometeorology,* 52: 625-639.

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

Parmesan, C. (2007). Influences of species, latitudes and methodologies on estimates of phenological response to climate warming. *Global Change Biology*, 13: 1860-1872.

Pettorelli, N., Vik, J., Mysterud, A., Gaillard, J., Tucker, C. and Stenseth, N. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology and Evolution,* 20(9): 503-510.

Polgar, C. and Primack, R. (2011). Leaf-out phenology of temperate woody plants: from trees to ecosystems', *New Phytologist,* 191: 926-941.

Primack, R., Ibáñez, I., Higuchi, H., Lee, S., Miller-Rushing, A., Wilson, A. and Silander, J. (2009a). Spatial and interspecific variability in phenological responses to warming temperatures. *Biological Conservation*, 142: 2569-2577.

Primack, R.B., Higuchi, H. and Miller-Rushing, A.J. (2009b). The impact of climate change on cherry trees and other species in Japan. *Biological Conservation,* 142(9): 1943-1949.

Richardson, A., Jenkins, J., Braswell, B., Hollinger, D., Ollinger, S. and Smith, M. (2007). Use of digital webcam images to track spring green-up in a deciduous broadleaf forest. *Oecologia,* 152(2): 323-334.

Richardson, A., Braswell, B., Hollinger, D., Jenkins, J. and Ollinger, S. (2009). Near-surface remote sensing of spatial and temporal variation in canopy phenology. *Ecological Applications,* 19(6): 1417-1428.

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

Rötzer, T., Wittenzeller, M., Haeckel, H. and Nekovar, J. (2000). Phenology in central Europe – differences and trends of spring phenophases in urban and rural areas. *International Journal of Biometeorology,* 44: 60-66.

Schäffler, A. and Swilling, M. (2013). Valuing green infrastructure in an urban environment under pressure—The Johannesburg case. *Ecological Economics*, 86*:* 246-257.

Schwartz, M. (1999). Advancing to full bloom: planning phenological research for the 21st century. *International Journal of Biometeorology,* 42: 113-118.

Sonnentag, O., Hufkens, K., Teshera-Sterne, C., Young, A., Friedl, M., Braswell, B., Milliman, T., O'Keefe, J. and Richardson, A. (2012). Digital repeat photography for phenological research in forest ecosystems. *Agricultural and Forest Meteorology,* 152: 159-177.

Sparks, T. and Carey, P. (1995). The responses of species to climate over two centuries: an analysis of the Marsham phenological record, 1736-1947. *Journal of Ecology*, 83: 321-329.

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

Stöckli, R. and Vidale, P. (2004). European plant phenology and climate as seen in a 20-year AVHRR land-surface parameter dataset. *International Journal of Remote Sensing,* 25(17): 3303-3330.

Stoffberg, G.H. (2006). Growth and carbon sequestration by street trees in the City of Tshwane, South Africa. *PhD Thesis submitted to the University of Pretoria,* Pretoria.

Suarez, M.L., Ghermandi, L. and Kitzberger, T. (2004). Factors predisposing episodic drought-induced tree mortality in Nothofagus–site, climatic sensitivity and growth trends. *Journal of Ecology*, 92(6): 954-966.

Turton, A., Schultz, C., Buckle, H., Kgomongoe, M., Malungani, T. and Drackner, M. (2006). Gold scorched earth and water: the hydropolitics of Johannesburg. *Water Resources Development,* 22(2): 213-235.

Van Eeden, J. (2015). A study in purple: the Jacaranda city in postcards. *Image and Text: A Journal for Design,* 25(1): 44-85.

van Vliet, A., de Groot, R., Bellens, Y., Braun, P., Bruegger, R., Bruns, E., Clevers, J., Estreguil, C., Flechsig, M., Jeanneret, F., Maggi, M., Martens, P., Menne, B., Menzel, A. and Sparks, T. (2003). The European phenological network. *International Journal of Biometeorology,* 47: 202-212.

Vitasse, Y., Schneider, L., Rixen, C., Christen, D. and Rebetez, M. (2018). Increase in the risk of exposure of forest and fruit trees to spring frosts at higher elevations in Switzerland over the last four decades. *Agricultural and Forest Meteorology,* 248: 60-69.

Wang, H., Gan, Y., Wang, R., Niu, J., Zhao, H., Yang, Q. and Li, G. (2008). Phenological trends in winter wheat and spring cotton in response to climate changes in northwest China. *Agricultural and Forest Meteorology,* 148: 1242-1251.

White, M., De Beurs, K., Didan, K., Inouye, D., Richardson, A., Jensen, O., O'Keefe, J., Zhang, G., Nemani, R., Van Leeuwen, W., Brown, J., De Wit, A., Schaepman, M., Lin, X., Dettinger, M., Bailey, A., Kimball, J., Schwartz, M., Baldocchi, D., Lee, J. and Lauenroth, W. (2009). Intercomparison, interpretation, and assessment of spring phenology in North America estimated from remote sensing for 1982-2006. *Global Change Biology,* 15: 2335-2359.

Whitecross, M.A., Witkowski, E.T.F. and Archibald, S. (2017). Savanna tree-grass interactions: A phenological investigation of green-up in relation to water availability over three seasons. *South African Journal of Botany,* 108: 29-40.

Zhao, X., Hu, H., Shen, H., Zhou, D., Zhou, L., Myneni, R.B. and Fang, J., 2015. Satellite-indicated long-term vegetation changes and their drivers on the Mongolian Plateau. *Landscape Ecology*, 30(9): 1599-1611.