Using citizen science to build baseline data on tropical tree phenology

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Large-scale and long-term baselines on climate-sensitive phenology of widespread tree species are lacking in the Indian subcontinent. Citizen scientists can help bridge this information gap by contributing simple, technology-based data. Here we describe an India-wide initiative called SeasonWatch, with preliminary insights into contributor behaviour and species phenology. Between 2011 and 2019, cumulative contributor numbers have increased every year, although consistent contribution remains constant and low. We describe seasonal and spatial phenological patterns in most-observed species based on repeated monitoring and one-time 'bioblitz' events. We study in detail the flowering phenology of one particular species, Cassia fistula, which appears to show aberrant phenology, reflecting a potential shift away from culturally known flowering dates. We conclude that citizen science-contributed information can be a valuable reference database to compare future changes in tree phenology.

Keywords: Baseline data, citizen science, climate change, seasonality, tree phenology.

CYCLIC patterns of growth and reproduction – or phenology – of living organisms are seasonal and highly sensitive to the environment[1]. Discernible changes outside of the known variability in the phenology of organisms are often indicative of underlying changes in large-scale climate patterns. In temperate regions, higher temperatures are related to the onset of spring phenophases, such as flowering and leaf unfolding[2]. Increasingly, dates of bud-burst have been demonstrated to advance when compared with long-term averages due to advancement in the warm season, increase in winter and spring temperatures, and effects of urbanization such as pavements and light at night-time[2–5]. In the tropics, recent long-term phenological studies have shown that the onset, persistence and frequency of reproductive phenophases are affected by solar irradiance[6–8]. In other tropical systems, reproductive phenology has been reported to be affected by precipitation; fruiting intensity often increases with higher rainfall[9,10]. However, the impacts of changes in baseline environmental conditions on tropical tree phenology are poorly understood.

The bulk of our understanding of phenological patterns in plants and their response to climate change comes from Europe and North America[11]. Apart from contemporary studies, this understanding is supplemented by a number of historical datasets collected by hobbyists and naturalists, that serve as baselines for comparing current phenological patterns (e.g. Marsham phenological record[1]). Some of the largest historical datasets on phenology are from temperate regions, including the Kyoto cherry blossom dataset which is over 1300 years old[12]. Most contemporary phenology monitoring networks are also situated in temperate latitudes[13]. Information on tropical phenology is lacking both in contemporary as well as historical studies, and large-scale or generalizable responses to climate are not known[14].

Arriving at generalizable trends for phenological responses to climate requires data collected over large spatial scales and over multiple years, and integrating different datasets[15]. Intensive research efforts at such scales are often not possible due to resource and personnel limitations. Large-scale, long-term observations, however, can be facilitated by citizen scientists[16]. Citizen science involves members of the public in scientific studies to collectively generate information around issues of larger public concern. The term, initially coined by the Cornell Lab of Ornithology, USA, in 1995, has since been used to include a multitude of projects such as mapping and documenting biodiversity (iNaturalist, Project Noah, PlantWatch, eBird) population dynamics (StreamWatch), bird migration (North American Bird Phenology Program) and plant phenology (Nature's Calendar, SeasonWatch). Citizen science projects are designed such that interested people, with or without a formal training in science, volunteer their time and collect information required to build and co-create datasets of interest[17,18].

Worldwide, citizen science initiatives have contributed to the large-scale understanding of phenology, including quantification of climate change impacts on plant phenology. For instance, under different climate-change scenarios, the flowering and fruiting phenology of *Vaccinium membranaceum* is predicted to advance on average by 35 and 36 days respectively, in USA. These predictions are based on the current understanding of the environmental correlates of reproductive phenology of *V. membranaceum* from data contributed to the citizen science initiative USA National Phenology Network along with other long-term data sources[19].

Within India, multiple past or ongoing efforts have gathered long-term phenology data in different sites that

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are contextualized for the region and for the species occurring therein[20]. Among them, SeasonWatch, a citizen science initiative that started in 2010, is collating data on the phenology of common Indian trees at a country-wide level, with the ultimate aim of understanding geographical variation and the effects of climate change on the phenology of widespread species. Apart from the formal literature (floras, scientific articles, tree guides, etc.), there is also anecdotal and cultural information on the expected phenology of trees. For instance, the festival of Vishu (typically in the 15th week of the year, between 13 and 15 April) in Kerala is associated with flowering in *Cassia fistula*, with inflorescences forming an integral part of the festivities. In recent years, there have been anecdotal and media reports in Kerala, of the flowers of *C. fistula* being unavailable during the festival of Vishu, as well as aberrant flowering during other times of the year.

Here, we describe SeasonWatch as an attempt to develop a baseline dataset on tropical tree phenology using citizen science. We illustrate this by exploring phenological patterns of selected tree species across space and time. We also summarize contributor history and consistency, regional representation of trees and assess whether Season Watch data can be used to understand probable shifts in phenological patterns of trees in the future.

Specifically, we provide summaries of (i) contributor behaviour in the context of data upload patterns, (ii) tree behaviour and phenological patterns over time, (iii) flowering phenology of *C. fistula* over time and (iv) phenological patterns over space using data for *Mangifera indica*. We conclude with potential research questions of interest in the future.

Methods

Project summary

We summarize data contributed to SeasonWatch over a period of six years between 1 January 2014 and 31 December 2019. Data contribution requires registration with the SeasonWatch project. Registered contributors upload information on the phenology of 136 common, widespread (or locally abundant), native and non-native (planted along avenues and roadways, or invasive species of concern) woody plant species (list available at www.seasonwatch.in/species.php), using the project website (www.seasonwatch.in) or a freely downloadable Android app mobile phones.

Contributor summary

SeasonWatch has two main types of contributors: schools (teachers and students, typically of grades 6–9) and individuals (nature enthusiasts, students at universities). School teachers learn about participating in the project through state and district-level teacher-training workshops or through workshops at schools and implement the project in their school premises with groups of students. SeasonWatch typically partners with a regional organization in order to facilitate local outreach and training.

Contributors can choose to make an observation on a tree only once ('casual' henceforth), or register a tree with the project and make observations on its phenology every week ('regular' henceforth). A large proportion of the regular data is contributed by schools and these data are consistently received throughout the school year. Regular observations allow for understanding individual-level variation in seasonal phenology of trees, keeping location constant. Casual observations have been collected largely through four 'bioblitz' events held in December 2018, and March, June and September 2019 respectively. The aim of the four-day bioblitz events was to create a snapshot of phenology across India in different seasons. Casual observations allow for understanding latitudinal variation in species phenology.

Summary of observations

Each contributed data point contains the following information – tree location, date and time of observation, date of upload, species identity, and an estimate of leaf, flower and fruit quantity on the observed tree. 'Leaf', 'flower' and 'fruit' are further categorized into finer phenological stages (Table 1). The quantity of each phenophase is noted as one of the following – 'none', 'few' or 'many'. 'None' corresponds to the absence of the phenophase. If a phenophase is observed on one-third or less of the tree canopy, it is marked as 'few' by a contributor, indicating a lower volume of the tree having the reported phenophase. If a phenophase is observed on more than one-third of the tree canopy, it is marked as 'many' by a contributor, indicating a larger volume of the tree having the reported phenophase. 'Many' is considered as the phenophase peak at the level of each individual tree. On any given day, only one of these categories can be reported for a phenophase. Along with phenology observations, contributors can optionally note the presence of herbivores, pollinators and dispersers, and also make additional notes on natural history, interactions of interest, etc. All phenology data contributed to SeasonWatch are available to any contributor or non-contributor upon request.

Based on these contributed observations, we quantified the following:

Contributor behaviour and data upload patterns: We summarized contributor behaviour in the form of overall participation (in making regular and casual observations) from each Indian state and for each year. We quantified contributor consistency as a measure of continuity in regular observations on registered trees. A contributor is defined as 'consistent' if she makes phenology observations in 23 or more unique weeks in a year.

Tree behaviour and phenological patterns over time and space: We summarized average weekly phenological responses of tree species over a period of six years. We assessed regular phenology data for patterns of phenology using data contributed between 1 January 2014 and 31 December 2019. Since contributors are encouraged to record phenology once a week, we also considered the week as the smallest unit of time to report average patterns across species. Tree behaviour was quantified as the average proportion of trees displaying a particular phenophase in a week.

Flowering in Cassia fistula: We assessed long-term patterns of flowering in *C. fistula*, by combining regular and casual data for this species between 2014 and 2019. Tree behaviour was measured as the proportion of trees displaying the floral phenophase 'open flower', comparing seasonal patterns in any flowering (i.e. open flowers stages reported as 'few' or 'many') with those in full bloom (i.e. open flowers reported as 'many'). The denominator in these proportions is the total number of individuals for which phenology was reported in each week. We visually compared peaks in the proportion of trees showing any flowering with those that were reported as being in full bloom to understand whether overall flowering patterns in *C. fistula* were different from that which is anecdotally expected.

Patterns over space: Country-wide spatial phenological patterns in tree phenology were based only on casual observations during the four bioblitz events. We plotted the spatial locations of phenophases of interest in the most observed species on a map to understand latitudinal variation in species phenology.

Table 1. Tree phenophases recorded by citizen scientists in SeasonWatch. Phenophases are recognized based on descriptors

Phenological indicator	Phenophase	Descriptors
Leaf	Fresh	Leaf bud; recently emerged; small-sized; light green or pigmented
	Mature	Full-sized; dark green
	Dying	Necrotic; discoloured; extreme herbivory
Flower	Bud	Floral bud
	Male*	Androecium only, corolla unfurled
	Female*	Gynoecium only, corolla unfurled
	Open	Bisexual flowers, corolla unfurled
Fruits	Unripe	Small-sized; dark green
	Ripe	Full-sized; mature fruit coloration
	Open*	Fruit opened, seeds dispersed

*Phenophase present only in a few species. 'Dying' leaf and 'open' fruit phenophases were introduced in 2018 in order to capture deciduousness and seasonal splitting of pods/capsules respectively, of certain species.

Results

We summarized the overall and regional patterns of contributors and species phenology in SeasonWatch. Since 2011, 1050 individuals together with students from 889 schools from across India have contributed 351,481 phenology observations. Of these, 283,940 are repeat observations on registered trees, while 67,541 are one-time observations contributed during quarterly bioblitz events in 2018–19.

Contributor behaviour and data upload patterns: The total number of unique contributors with at least one valid phenology observation has been variable since 2011, with an increase in both individuals and schools since 2017 (Figure 1 *a*). The number of consistent contributors has remained constant and low since 2011, even though there is an increase in the total number of contributors (Figure 1 *b*). The South Indian state of Kerala has the largest number of contributors as well as the largest number of observations per contributor (Figure 1 *c*).

Tree behaviour and phenological patterns over time: The species with the most number of observations differed between the two types of observation. Sixty-two species were represented by 100 or more regular observations, while 73 were represented by 100 or more casual observations. Five species with the most number of regular observations were *Artocarpus heterophyllus* Lam. (jackfruit), *Mangifera indica* L. (mango), *Tamarindus indica* L. (tamarind), *Phyllanthus emblica* L. (Indian gooseberry) and *Cassia fistula* L. (Indian laburnum) (Figure 2 *a*). Five species with the most number of one-time observations were slightly different: *Tectona grandis* (teak), *Cocos nucifera* L. (coconut palm), *M. indica*, *A. heterophyllus* and *Azadirachta indica* A. Juss. (neem) (Figure 2 *b*).

Figure 3 *a–d* shows the seasonal patterns in the appearance of leaf, flower and fruit based on regular observations for four species with the most number of repeated observations. Peaks in flowering and fruiting are clearly discernible in *M. indica*, *A. heterophyllus* and *T. indica*, but not as apparent in *P. emblica.* Majority of regular observations were contributed from Kerala, and thus the peaks in phenology were most reflective of the seasonal response of trees at these latitudes (8.3218°–12.7890°N). Appendix 1 provides sample sizes for these patterns.

Flowering phenology of C. fistula: Between 2014 and 2019, we found that up to 40% of trees (on average) of this species were reported to have open flowers in nearly every week of the year. However, nearly 70% of the observed trees on an average, were reported to be in full bloom in the 13th week of the year, indicating a flowering peak.

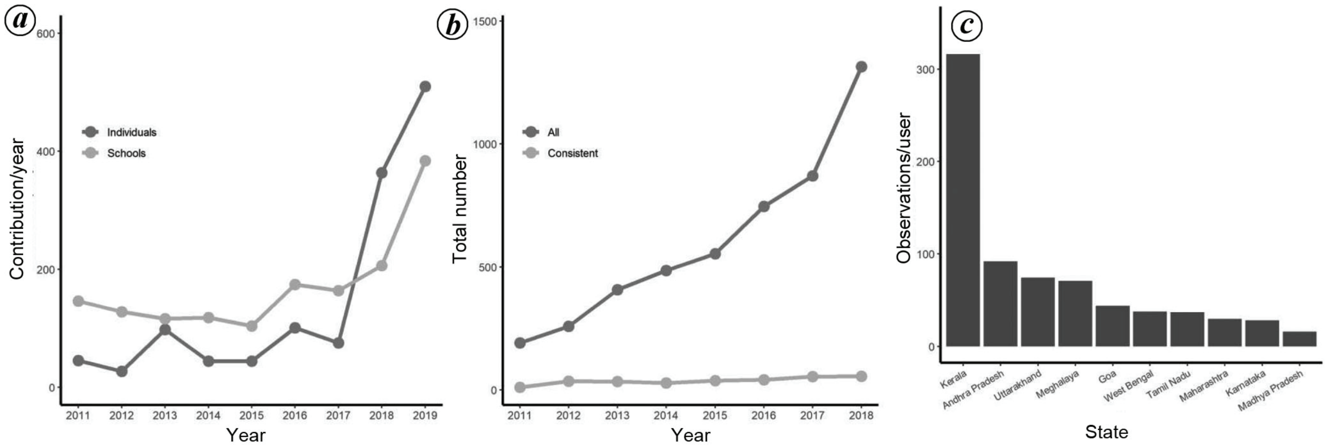


Figure 1. Contributor behaviour over time. ***a***, Number of schools and individuals with at least one valid phenology observation between 1 January 2014 and 31 December 2019. ***b***, Number of contributors added per year and number of consistent contributors with at least one observation made in at least 23 weeks of the year. ***c***, Per-contributor average number of observations from different states of India.

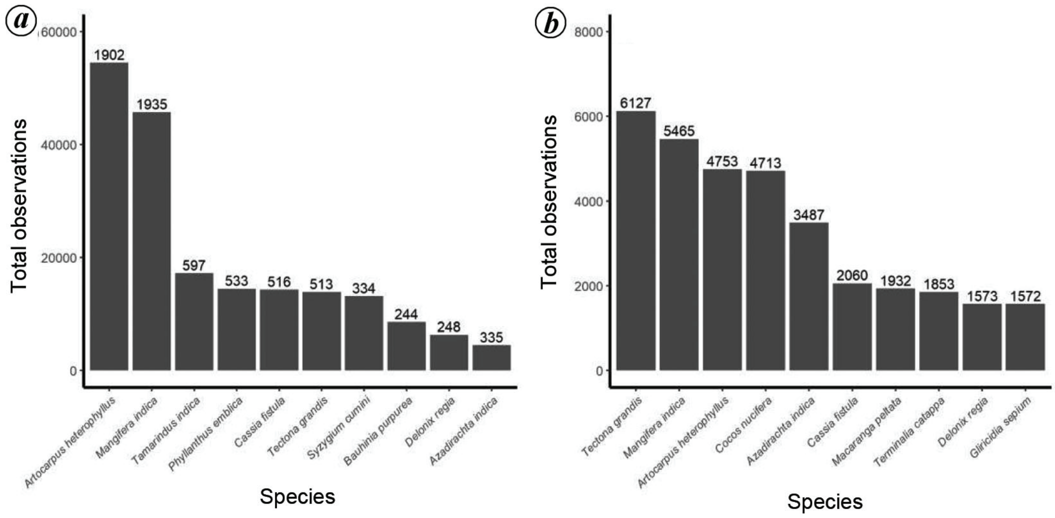


Figure 2. Total number of observations per species from 1 January 2014 to 31 December 2019. ***a***, 'Regular' observations are repeat observations on registered trees; numbers on top of the bars indicate registered individual trees for that species across India. ***b***, 'Casual' observations are made once on any individual tree; the number of observations is thus, the same as the number of individual trees observed, assuming that every casual observation is made on a different tree.

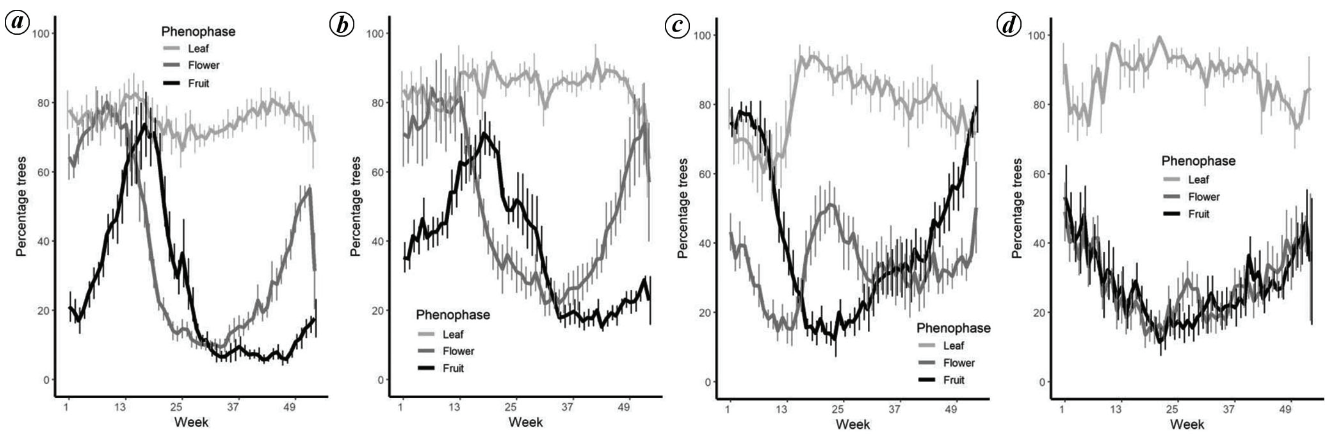


Figure 3. Phenology of four most observed species across India. (***a***) *Mangifera indica*, (***b***) *Artocarpus heterophyllus* and (***c***) *Tamarindus indicus* show clear seasonal peaks in flowering and fruiting. (***d***) *Phyllanthus emblica* shows moderate, persistent flowering and fruiting through the year. Bars indicate the standard error across five years. Appendix 1 gives the sample sizes for these patterns.

This declined to 50% of observed trees on an average by week 15 (Figure 4), and could indicate a shift in flowering from the expected time of week 15 in the year. Sample sizes for these observations, however, were low and highly variable (weekly ranging from 17 to 124 trees). More observations are required to determine whether there is a shift from the expected time of flowering in this species.

Phenological patterns over space: The number of contributors and observations during the four bioblitz events was variable, with maximum participation in December 2018, and maximum observations contributed in June 2019 by fewer contributors (Figure 5 *a* and *b*). The most reported species from different latitudes varied across the four bioblitz events and latitudinal patterns could be assessed for only the most widespread, commonly seen tree species.

M. indica and *T. grandis* were among the top 10 most reported species in all four events; here we present results only for *M. indica*. The fruiting phenology of *M. indica* was found to vary with latitude across four different months of assessment (Figure 6). In December 2018 and March 2019, a small proportion of the trees were in fruit, and these were primarily in southern India. In June 2019, trees were in fruit across all latitudes and by September 2019, fruiting in *M. indica* had receded, with less than 2% of trees in fruit, again restricted to the southernmost latitudes.

Discussion

Our first description of a long term, India-wide citizen-science dataset contributes towards a basic understanding of seasonal phenology of common, widespread trees. Across temperate latitudes, historical information on plant phenology has been used as a reference to compare contemporary phenological changes and also identify climatic correlates of these changes. In the tropics, and especially in India, a similar baseline for species phenology across latitudes and seasons is lacking[20]. The citizen-science study presented here provides information on four widespread, common tropical species, which can potentially serve as references for future changes in phenology. For instance, in *A. heterophyllus* and *M. indica*, flowering and fruiting peaks in Kerala are well-defined over time, and can be used to detect shifts in peaks observed in the future.

Current phenological patterns can be compared against anecdotal time-points (such as plant phenology traditionally associated with festivals) in order to assess possible shifts in the reproductive phenology of culturally important trees. For instance, SeasonWatch data can be used to provide quantitative support to anecdotal observations on changes in flowering dates of species such as *C. fistula.* In India, apart from Vishu, several seasonal festivals are associated with the appearance of flowers on culturally important tree species. The festival of Holi in North India is associated with flowering in *Butea monosperma* (Lam.) Taub. (flame-of-the-forest tree), the flowers of which are collected and used to make a dye used in the festivities[21]. Similarly, the Kannada/Telugu new year Ugadi and the Tamil harvest festival Pongal are associated with flowering in *Azadirachta indica* (neem tree).

Latitudinal patterns in the vegetative and reproductive phenology of widespread and abundant species can help discern the range of underlying environmental factors affecting the appearance of phenophases. In temperate regions, there is typically a negative relationship between autumn phenology and latitude, with the northern populations showing the appearance of phenophases such as leaf colour change and leaf fall before the southern populations. For example, in Japan, the timing of fall-leaf phenology was found to be negatively associated with latitude and temperature in the temperate species *Acer palmatum* and *Gingko biloba* over the duration of 53 years[22]. In tropical regions, on the other hand, where spring and autumn temperature changes are not as evident as in temperate latitudes, vegetative phenology such as leaf-out may be triggered, by photoperiod or preceding the onset of monsoons across different latitudes[23–25]. In SeasonWatch, however, we were unable to detect any changes in vegetative phenology with latitude due to the large time-gaps between consecutive bioblitz assessments. Reproductive phenology is also associated with latitude in temperate regions, with some herbaceous species such as *Lythrum salicaria* exhibiting growth and flowering phenology earlier in

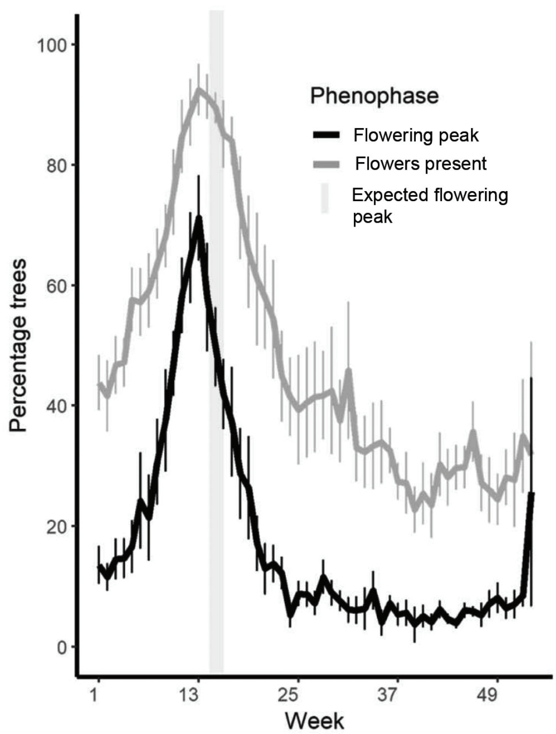


Figure 4. Proportion of trees with phenophase indicated as 'present' or 'many' (indicating a perception of phenophase peak by the contributor). Flowering in *Cassia fistula* compared against the expected peak flowering time indicated by the cultural festival of Vishu in Kerala.

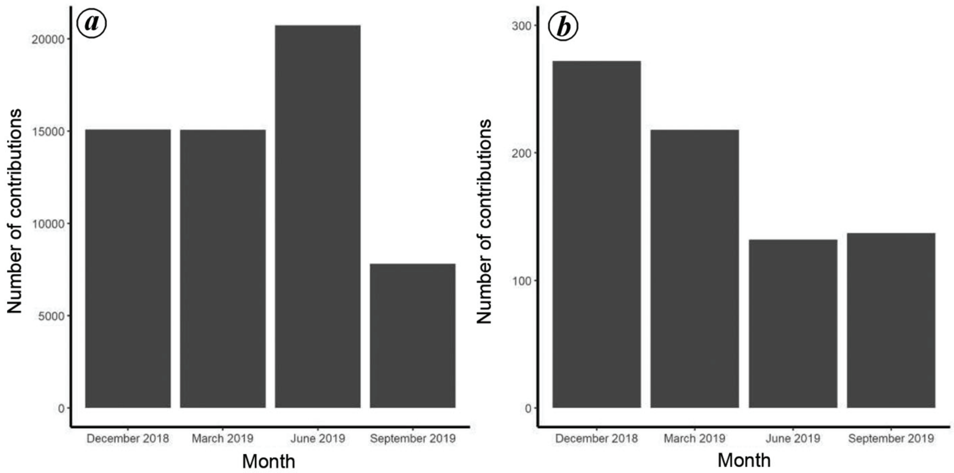


Figure 5. Number of observations (***a***) and number of participating contributors (***b***) in four bioblitz events held across India between December 2018 and September 2019.

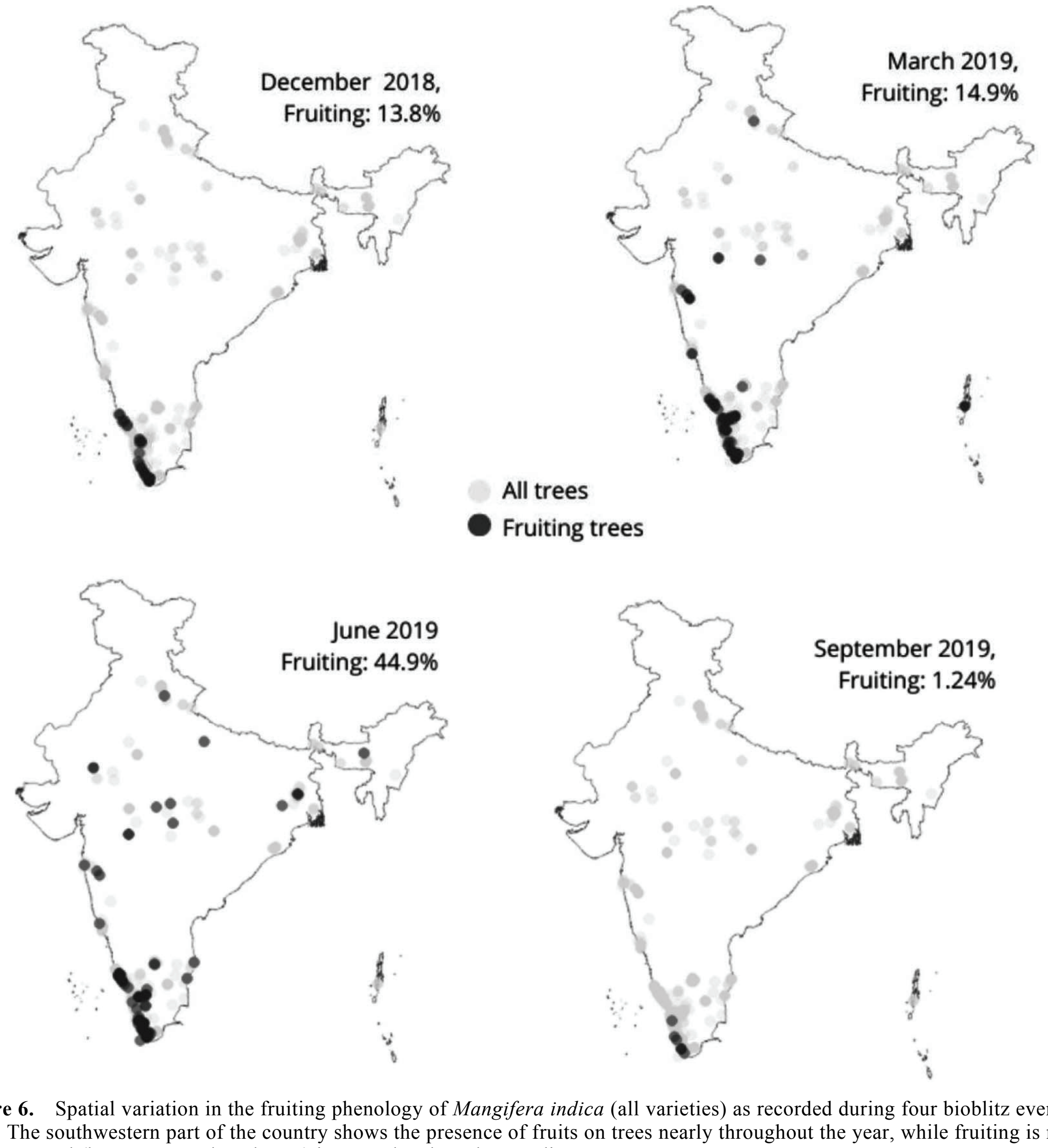
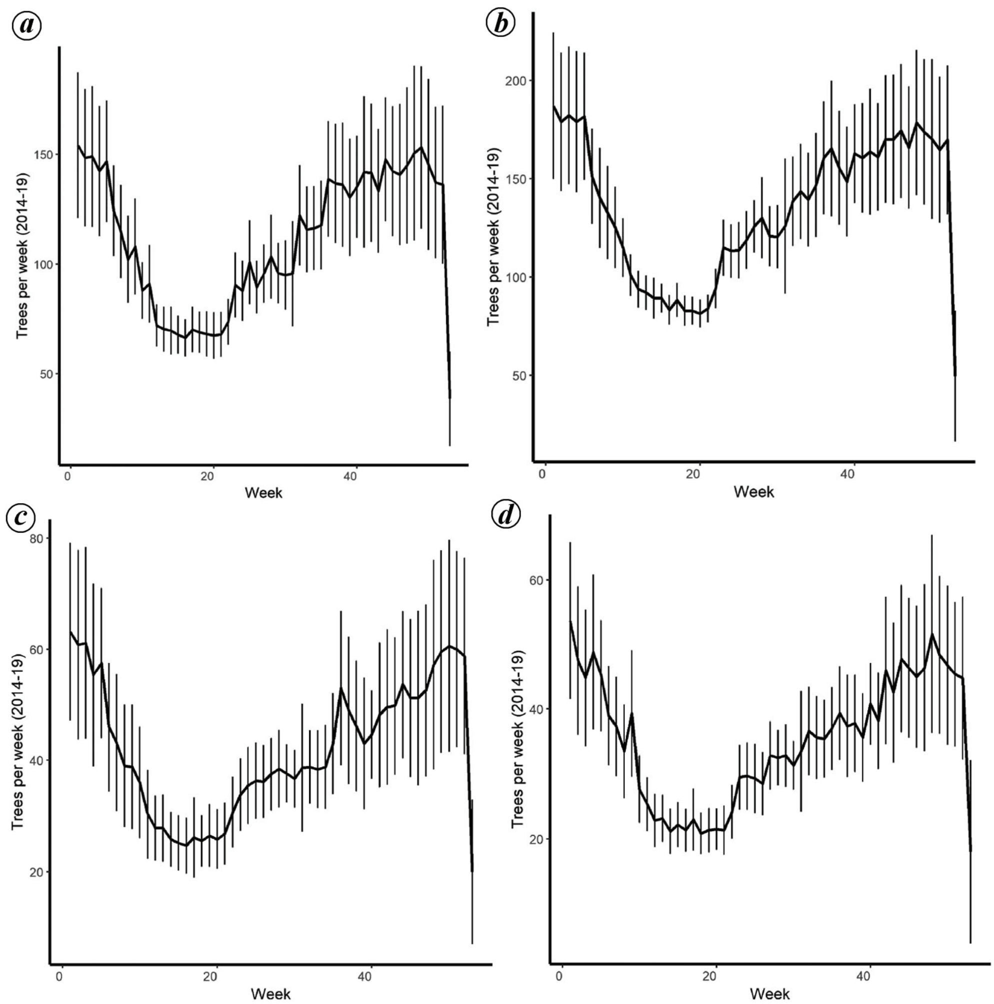


Figure 6. Spatial variation in the fruiting phenology of *Mangifera indica* (all varieties) as recorded during four bioblitz events in India. The southwestern part of the country shows the presence of fruits on trees nearly throughout the year, while fruiting is much more seasonal (between March and June) in central and northern India.



Appendix 1. Number of trees observed per species per week varies throughout the year. The patterns reported for species in Figure 3 are thus based on varying sample sizes per week. Lowest number of trees observed is usually between weeks 10 and 30 of the year – coinciding with summer holidays in schools in southern India. Sample sizes are as follows for these species; note that the *Y*-axis values vary: ***a***, *Mangifera indica*; ***b***, *Artocarpus heterophyllus*; ***c***, *Tamarindus indicus*; ***d***, *Phyllanthus emblica*.

northern latitudes[26]. In other species such as *Crataegus monogyna* the opposite pattern has been reported, with the southern populations showing fruiting phenology before the northern populations[27]. *M. indica* displays the latter pattern, with the southern populations showing reproductive phenophases before the northern populations, indicating a possible link with the Indian monsoon. In SeasonWatch, *M. indica* includes cultivated varieties as well, which may have variety-specific fruiting phenology.

The initial description of tropical tree phenology merits further studies in terms of underlying environmental correlates, such as temperature, precipitation and photoperiod. Given the large spatial skew in SeasonWatch data, correlational inferences at the country scale are likely to be affected by high variability. There is better scope, however, for exploring temporal patterns of environmental changes on tree phenology, at least from Kerala, with the addition of a few more years of data. A future research question could be addressing the changes in tree phenology in relation to changing climate. Overall changes in tropical tree phenology are expected to cascade through trophic levels. At present, the effects of phenological change in tropical tree species from the Indian subcontinent on the life cycle of animals are poorly known. A research question thus emerges: what are the downstream trophic impacts of tree phenology and what changes are likely to occur in these interactions due to climate change?

Conclusion

Citizen science has the potential to contribute immensely to mainstream scientific understanding of tropical tree phenology by building baselines. However, a citizen-science project such as SeasonWatch faces several challenges, including ensuring sufficient sample sizes per species per season from different locations, as well as data quality and accuracy. Managing these challenges is especially difficult in the Indian context given the high diversity of languages and unequal access to the internet, as well as mass and social media, and at times literacy. It is therefore not possible to sustain such programmes without initiating and maintaining long-term partnerships with regional groups and organizations. Despite increasing outreach in multiple languages to promote awareness about the project, providing technological support free of cost for contributors, and simple visual design of the user interface created by taking inputs from contributors during the testing stage, data quantity remains low and skewed to a single state in the country. Furthermore, mechanisms to ensure data quality need to be implemented at multiple stages of data contribution. With this article, we extend a call for action to sustain long-term interest and participation to develop a baseline for common tropical tree species that can be used to understand long-term consequences of climate change on tropical tree phenology.

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ACKNOWLEDGEMENTS. We thank the numerous citizen scientists from across India and especially Kerala, who have tirelessly contributed data to the SeasonWatch project and Wipro Foundation for funds. We also thank Muhammad Nizar (regional coordinator for Kerala) and regional partners Mathrubhumi for ensuring that citizen scientists engage with and contribute to the programme regularly. H. T. Veena and Farheen Anjum helped develop the SeasonWatch website and Android app that contributors use to upload data.

Received 19 November 2020; accepted 22 September 2021

doi: 10.18520/cs/v121/i11/1409-1416