Understanding urban plant phenology for sustainable cities and planet

To the Editor — Alongside the unparalleled changes in global climate, our home planet is experiencing an unprecedented period of urbanization, which is expected to continue across the next few decades. For plants, the impacts of urbanization, such as altered air quality, light regimes and water and nutrient availability, can induce large shifts in phenology (the timing of recurring life events[1]) with consequences for fitness, and for the ecological, climate, health and economic services that plants provide. Additionally, urbanization can elevate temperature and carbon dioxide (CO_2) concentration (Fig. 1a), which can mimic or magnify impacts of climate change. Understanding urban plant phenology is necessary to protect plants, cities and occupants under future change.

The broad impacts of urbanization on plant phenology can include advanced spring leaf-out and flowering, delayed autumn senescence and extended growing-season length[1,2] (Fig. 1b). These shifts can have benefits, such as increased cropping seasons for urban agriculture[3] or improved vegetation-based cooling in urban areas[4]. However, faster growth of urban trees due to extended growing-season length may lead to shortened lifetimes compared to trees in rural areas[5]. The advancement of spring leaf-out can also increase plant vulnerability to spring frost damage[6] and cause phenological mismatches, resulting in loss of pollination services and biological control of plant pests[7]. Moreover, phenology changes in cities have important cultural and economic implications by shifting significant events (for example, cherry blossom and maple foliage)[8] and can impact human health (for example, through changes in allergenic pollen release)[9]. Overall,

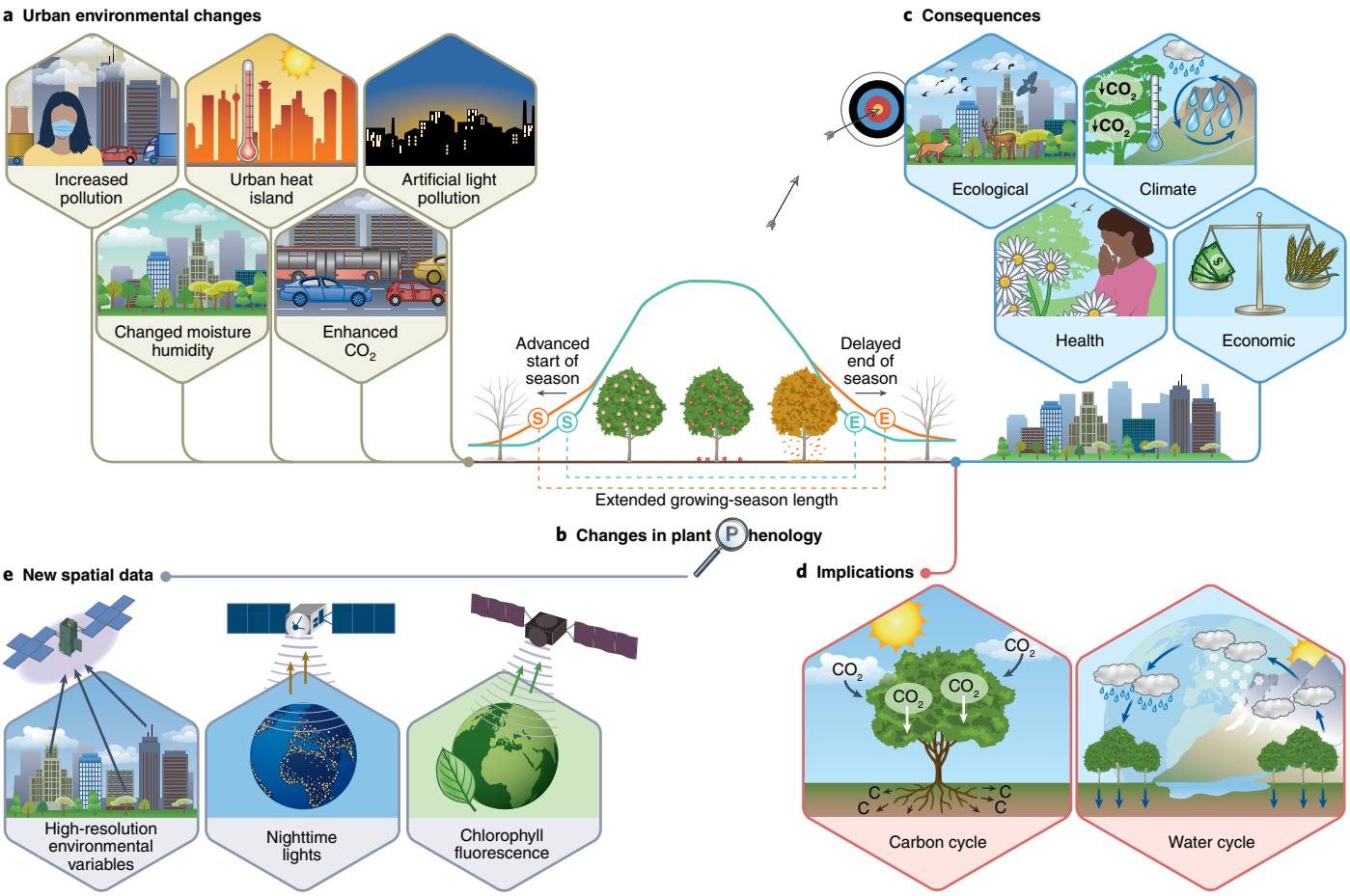

Fig. 1 | Understanding plant phenology in global cities: implications, challenges and opportunities. a,**b**, Changes in environmental factors (for example, temperature and light) in urban areas (**a**) lead to shifted spatiotemporal patterns of plant phenology (**b**). **c**,**d**, An improved understanding of urban phenology is important not only because of the consequences of phenological changes in urban areas (**c**), but also for its implications in the prediction of carbon and water cycles of the Earth system using cities as natural laboratories (**d**). **e**, New spatial data and technologies for monitoring urban phenology and environmental factors provide unique opportunities to address current challenges.

phenological changes in urban areas already have a variety of ecological, climate, health and economic consequences (Fig. 1c), with the probable existence of more impacts that are currently unclear. This urges the need for science and management communities to develop policies and plans to ensure sustainable urban ecosystems.

The higher temperature (and CO_2) in urban environments has led to their use as 'natural laboratories' to study phenological responses to changing climate, with the commonly used approach of space–time substitution[2,10], advancing the prediction of carbon and water cycles (Fig. 1d). For example, based on phenology sensitivities to CO_2 and temperature found in urban–rural gradients, prolonged photosynthetic seasons were projected under four Representative Concentration Pathway climate scenarios[10]. The benefits of these urban laboratories can extend to the inclusion of complex interactions that may not be considered, or easily incorporated, in natural environments. For example, findings related to the way that urban heat and nighttime lights jointly influence plant phenology may have implications for plants that redistribute to higher latitudes with altered daylength under climate warming[11].

Nonetheless, the complexity of urban environments may lead to difficulties when disentangling the linkages between phenology and individual environmental cues, which can limit the use of urban phenology as a precise predictor of climate futures. For example, gradients in urbanization have been found to be a poor analogue for temperature-driven changes in plant phenology, due to confounding effects from other factors[2]. Predicting phenological shifts within cities themselves may therefore also be complicated, as urban environments are highly heterogeneous, within individual cities and across geographic regions[12], and shifts can be affected by additional local biotic and abiotic context — such as irrigation practices, the presence of pests or disease, and light quality or quantity. Urban phenology responses to climate change have also been shown to be non-linear, with warming-driven advances of spring green-up declining with urban intensification[1]. These complexities must be incorporated into mechanistic understandings and future projections of phenological shifts, particularly as urban environments expand throughout the world.

Despite these significant challenges, opportunities are emerging with new spatial data and technologies to monitor spatiotemporal patterns of phenology and environmental factors within and across cities (Fig. 1e). Phenology indicators based on sun-induced chlorophyll fluorescence are better proxies of photosynthetic activities[10] as compared to the traditional greenness phenology data, while urban phenology indicators derived from high-spatial-resolution (for example, finer than 1 km grid spacing) satellite observations such as Landsat can better capture heterogeneous information in complex urban environments[13]. The recently developed Black Marble nighttime lights product[14] and gridded air temperature dataset[15] provide novel data to study the impact of artificial light and temperature on phenology. These novel technologies and datasets show promise to help disentangle the complex mechanisms of urban phenology changes.

The ongoing rapid urbanization and resulting environmental changes will keep altering plant phenology in global cities. The new data and technologies will greatly benefit the highly needed mechanistic studies of urban phenology beyond the traditional analyses that focused on urban–rural differences in phenology. An advanced understanding of mechanisms underlying changes in urban plant phenology is a must to develop nature-based solutions for urban issues, sustainable urban ecosystems and mitigation and adaptation strategies for the harmful consequences of phenological changes, as well as to improve the prediction of carbon and water cycles of the Earth system under a changing climate. ❐

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Competing interests

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