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Perspective

Linking plant phenology to conservation biology

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ABSTRACT

Phenology has achieved a prominent position in current scenarios of global change research given its role in monitoring and predicting the timing of recurrent life cycle events. However, the implications of phenology to environmental conservation and management remain poorly explored. Here, we present the first explicit appraisal of how phenology — a multidisciplinary science encompassing biometeorology, ecology, and evolutionary biology — can make a key contribution to contemporary conservation biology. We focus on shifts in plant phenology induced by global change, their impacts on species diversity and plant–animal interactions in the tropics, and how conservation efforts could be enhanced in relation to plant resource organization. We identify the effects of phenological changes and mismatches in the maintenance and conservation of mutualistic interactions, and examine how phenological research can contribute to evaluate, manage and mitigate the consequences of land-use change and other natural and anthropogenic disturbances, such as fire, exotic and invasive species. We also identify cutting-edge tools that can improve the spatial and temporal coverage of phenological monitoring, from satellites to drones and digital cameras. We highlight the role of historical information in recovering long-term phenological time series, and track climate-related shifts in tropical systems. Finally, we propose a set of measures to boost the contribution of phenology to conservation science. We advocate the inclusion of phenology into predictive models integrating evolutionary history to identify species groups that are either resilient or sensitive to future climate-change scenarios, and understand how phenological mismatches can affect community dynamics, ecosystem services, and conservation over time.

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1. Introduction

Phenology is an integrative environmental science that has achieved a prominent position in current global-change research, due to its capacity to monitor, understand and predict the timing of recurrent biological events related to climate, such as bird migration, frog calling, and leafing, flowering and fruiting of plant populations (Rosenzweig et al., 2008). Phenological studies also provide key knowledge that can be incorporated into predictive models forecasting climate change scenarios (IPCC, 2014; Rosemartin et al., 2014).

Climate is the main factor controlling and regulating phenological events in plants, and global warming has affected species distributions and the timing of leaf change and reproduction (Chuine and Beaubien, 2001; Menzel et al., 2006), with likely effects on biogeochemical processes and physical properties of the atmosphere (van der Sleen et al., 2015). Across the tropics, subtle changes in temperature have been regarded as a less important phenological trigger, whereas seasonal variation in rainfall has been usually considered as an environmental cue for phenology (Borchert, 1998; Morellato et al., 2000, 2013). However, plant phenology responses to invariant cues, such as photoperiod, may be important in defining the timing, periodicity and particularly the synchrony of plant reproduction, especially in tropical environments where climatic seasonality is low (Borchert et al., 2005; Rivera and Borchert, 2001). Long-term phenological time series from the Northern Hemisphere have shown a strong link between the earlier onset of leafing and flowering and elevated temperatures due to climate change (Menzel et al., 2006; Schwartz et al., 2006). However, information on the effects of climate change in tropical regions is still sparse, particularly in the Southern Hemisphere, and long-term data sets are rare (Chambers et al., 2013; Morellato et al., 2013).

The management and conservation of natural systems can be critically enhanced with a greater understanding of the triggers regulating and controlling plant cycles and differences across species, populations and communities (Miller-Rushing and Weltzin, 2009; Polgar and Primack, 2011). In this regard, recent improvements in vegetation monitoring techniques such as repeated digital photographs, and the growing field of satellite-derived phenology (Alberton et al., 2014; Morisette et al., 2009; Richardson et al., 2013) have paved the way to inferences about temporal shifts at multiple scales that can be applied worldwide.

Despite the well-known connection between phenology and climate change (IPCC, 2014), its relevance and implications for resource conservation and management remain poorly understood. These implications include the synchronicity between flowering and pollinator activity or fruiting and seed disperser activity, the connectivity and gene flow through pollen and seed movements across fragmented landscapes, and the forecasting of climate-change effects on species distributions and ecosystem processes. In fact, plant phenology links different hierarchical levels and functional groups within a community, including decomposers, detritivores, herbivores, predators, pollinators, and seed dispersers. Consequently, efforts to conserve these temporal links will safeguard the functionalities and long-term maintenance of ecosystem services. In this context, we explore how phenology — as a multidisciplinary science encompassing biometeorology, ecology, and evolutionary biology (Wolkovich et al., 2014) — can be harnessed as a key research endeavour in applied ecology and conservation biology, with special emphasis on the tropics.

Our framework is centred on the potential shifts in plant phenology driven by global environmental change and their impact on the high diversity of species and plant–animal interactions found in the tropics (Fig. 1). One key issue would be to incorporate phenology into community-level coexistence theory tied to the species niche concept. As such, broadening the ecological niche to a more explicit temporal space would allow investigators to test hypotheses and make predictions regarding plant responses to environmental and competitive changes at different scales (e.g. Schellhorn et al., 2015; Wolkovich and Cleland, 2011; Wolkovich et al., 2014). We highlight issues where phenology can provide a major contribution to conservation science. We begin addressing how phenology can help conservation efforts in relation to plant–animal interactions from the perspective of resource availability in plant populations and communities, and bottom-up trophic organization. We point out the relevance of ecological networks to understand the effects of temporal changes and mismatches between resources and consumers on the maintenance of mutualistic interactions (Fig. 1). We examine how phenological mismatches affect communities, ecosystem services, and ecosystem recovery dynamics over time. Furthermore, we discuss how knowledge of plant phenology can help evaluate and mitigate the effects of land-use change on ecological interactions, including habitat fragmentation, edge effects, and fire. We also consider the thorny problem of exotic and invasive species and the key role of phenology in managing biological invasions and restoring natural ecosystem integrity. We indicate the use of phenology as a functional trait that, combined with traditional leaf morphology and other traits, would be a more accurate indicator of plant functions related to responses to climate and other environmental cues, such as wildfires (Carvalho and Batalha, 2013) or biological invasions (Wolkovich and Cleland, 2011).

To our knowledge, this is the first appraisal specifically addressing the implications of phenological knowledge to conservation biology. We propose, therefore, a set of avenues that would allow a stronger and more effective contribution of organismal phenology to conservation science. We point out the value of novel monitoring strategies improving spatial and temporal coverage of phenological monitoring, from satellites to drones and digital cameras. We highlight the key role of retrieving historical information from herbaria and observational studies to fill the gaps of long-term time series (e.g. Hart et al., 2014; Primack et al., 2004; Primack, 2014) and shed light on the potential effects of climate change and the consequences of directional phenological shifts in tropical systems. In this sense, the concept of "phenospecies" (i.e. sympatric species that share the same phenological triggers and strategies (Proença et al., 2012), may help reconstruct longer