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Phenological synchrony between a plant and a specialised herbivore

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Abstract

Global anthropogenic climate change is altering the phenology of many species, with implications for interacting species. If species use different cues or respond at different rates, this could result in asynchrony between hosts and herbivores. The larval stage of the endemic critically endangered Sinai Baton Blue butterfly (*Pseudophilotes sinaicus*) feeds exclusively on the buds and flowers of an endangered near-endemic plant, the Sinai Thyme (*Thymus decussatus*), with a narrow window in time when both larvae and flowers are present. We test for synchrony in time and space between the flowering phenology of the host plant and the associated timings and abundances of the Sinai Baton Blue. Together with significant spatial variation amongst patches, there were large inter-annual variations in flowering period, up to two weeks between years, indicating phenotypic plasticity in response to abiotic conditions. The butterfly flight period was approximately synchronised to the flowering of its host plant, but there was no evidence of any detailed spatial or temporal correlations in phenology. The dramatic annual population changes, possibly cycles, in the butterfly, may partly be driven by differences in the responses between plant and herbivore to climate that cause varying degrees of synchrony between years.

Zusammenfassung

Der globale anthropogene Klimawandel verändert die Phänologie vieler Arten, was Auswirkungen auf interagierende Arten hat. Wenn Arten unterschiedliche Signale nutzen oder mit unterschiedlicher Geschwindigkeit reagieren, kann dies zu Asynchronität zwischen Wirten und Herbivoren führen. Die Larven des endemischen, vom Aussterben bedrohten Sinai-Bläulings (*Pseudophilotes sinaicus*) fressen ausschließlich an den Knospen und Blüten einer gefährdeten, fast endemischen Pflanzenart, des Sinai-Thymians (*Thymus decussatus*), wobei es ein enges Zeitfenster gibt, während dessen sowohl Larven als auch Blüten vorhanden sind. Wir prüften die Synchronität in Raum und Zeit zwischen der Blühphänologie der Wirtspflanze und dem zugehörigen zeitlichen Auftreten und der Abundanz des Sinai-Bläulings. Zusammen mit signifikanter räumlicher Variation unter den patches gab es große Schwankungen zwischen den Jahren bei der Blühperiode (bis zu zwei Wochen), was auf phänotypische Plastizität in der Reaktion auf abiotische Bedingungen hinweist. Die Flugperiode des Bläulings war ungefähr mit der Blüte der Wirtspflanze synchronisiert, aber es gab keinen Beleg für eine detaillierte räumliche oder zeitliche Korrelation bei der Phänologie. Die dramatischen jährlichen Populationsschwankungen, möglicherweise Populationszyklen, des Bläulings könnten zum

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Teil durch Unterschiede zwischen Pflanze und Herbivor hinsichtlich ihrer Reaktion auf das Klima bestimmt werden, wodurch sich unterschiedliche Grade der Synchronität in einzelnen Jahren ergeben.

Keywords: Phenology; Phenotypic plasticity; Mismatch; Population cycle; Host plant; Butterfly; Egypt

Introduction

Climate change, particularly global warming, poses a serious threat to many species, with habitats expected to become drier accompanied with a rise in average temperatures (Giannakopoulos et al. 2009). Species dependent on environmental cues face problems if climatic patterns change, especially for herbivorous insects where ecological success is correlated to synchrony with host plants (Powell & Logan 2005). Some interacting species will use the same cues and show similar magnitudes of response, but not all species will respond in the same way (Phillimore et al. 2012). Such differences in species response to cues could result in increasing levels of asynchrony between interacting species, with the potential for a complete mismatch leading to extinction (Visser & Holleman 2001). Short-lived species are particularly vulnerable because consecutive years of sub-optimal resources (both in terms of quantity and quality) could lead to rapid declines in numbers and the possibility of local extinction. Synchrony can have vital consequences for the whole set of interacting species, affecting their population dynamics through bottom-up forces (Miller-Rushing et al. 2010).

Spring temperatures play a dominant role in determining plant phenology, with advancing phenologies associated with rising spring temperatures (Cook et al. 2012). The phenology of many plants in the Northern hemisphere is affected by spring temperatures (Doi and Katano 2008; Ovaskainen et al. 2013), but by no means all, since flowering can be influenced by other abiotic cues, particularly photoperiod, but also soil moisture and winter temperatures (Anderson et al. 2012; Cook et al. 2012). A study of 500 plant species in Concord (Massachusetts, USA) since 1852 showed that flowering has advanced 3.3 days earlier in the year per 1 °C rise in mean monthly temperatures for January, April and May (the last two being the two months preceding flowering) (Miller-Rushing & Primack 2008). The pattern of extinctions observed in Concord indicates that susceptibility is linked to climate response: species whose phenology did not follow the rising temperatures were much more likely to become locally extinct (Willis et al. 2008). Spatial variation in the phenology of host plants leads to pressure for their associated herbivores to be phenologically synchronised appropriately, otherwise there might be detrimental consequences for their population dynamics and abundance (Phillimore et al. 2012). For butterflies that can move, however, spatial variation in host–plant phenology could act as an insurance mechanism against temporal variation in their phenology (Weiss et al. 1988).

Insect herbivores also respond to rising average temperatures, usually by a shift in the flight season: adult emergence in many insect species varies with temperature and other environmental cues (Van Asch & Visser 2007; Robinet & Roques 2010). In general, insect phenologies seem to be changing at a steeper rate than plant phenology. This could lead to the adult insects appearing earlier when there are fewer resources, reducing survival and reproduction (Gordo & Sanz 2005; Mattila et al. 2006). Climate change seems also to be altering population cycles, disrupting mutually beneficial ecological interactions, particularly in insects whose life cycles are climate-dependent (Ims et al. 2008; Memmott et al. 2007).

There is a lack of long-term observational data that establish the extent of asynchrony and mismatches across multiple systems (Miller-Rushing et al. 2010). Where there have been long-term studies, such as the phenological timings of the plants in Concord, there are no recordings of their interactions with insects (e.g. pollinators), so it is impossible to investigate changing levels of synchrony (Miller-Rushing & Primack 2008; Singer & Parmesan 2010). In most cases we do not know what the ‘normal’ levels of asynchrony are, making it impossible to say whether detrimental effects of asynchrony are being exaggerated (Singer & Parmesan 2010).

Here we study the critically endangered Sinai Baton Blue butterfly and its exclusive larval host plant, the Sinai Thyme, an endangered plant growing in the arid mountains of the St Katherine Protectorate in South Sinai in Egypt, the most arid country in the world (FAO 2012, www.fao.org/ last accessed 10/03/2013). We study spatio-temporal variation in the timings of butterfly flight period and host plant phenology among ten patches.

Materials and methods

The study system

The Sinai Baton Blue butterfly (*Pseudophilotes sinaicus* Nakamura, 1975: Lycaenidae) is critically endangered, one of two endemic butterfly species in the St Katherine Protectorate, South Sinai, Egypt and a flagship species for the area (Thompson & Gilbert 2013). The larvae feed exclusively upon the buds and flowers of the host plant, Sinai Thyme (*Thymus decussatus* Bentham, 1834: Lamiaceae), restricting the butterfly’s distribution to a network of patches on the mountaintops above 1800 m (James 2006c; Thompson & Gilbert 2014). The host plant only grows in well-defined soils