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Editorial

Land-Use and Climate Impacts on Plant–Pollinator Interactions and Pollination Services

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Abstract: Most flowering plants rely on animals for pollination and most animal pollinators rely on flowering plants for food resources. However, there is an ongoing concern that anthropogenic-induced global change threatens the mutualistic association between plants and pollinators. Two of the most important factors of global change are land-use and climate change. Land-use and climate change may affect species distributions and species phenologies, leading to spatial and temporal mismatches between mutualistic partners. Land-use and climate change may also influence species abundances, nesting habitats, floral resources and the behaviors of pollinators. Thus, mutualistic plant–pollinator interactions should be more susceptible to global change than simple measures of biodiversity, such as species richness and species composition. The potential negative impacts of land-use and climate change on plant–pollinator interactions may have large consequences for the conservation of threatened plants and pollinators and economically by diminishing crop productivity. Here I highlight 'fruitful avenues' for research into better understanding the influence of land-use and climate change on plant–pollinator interactions.

Keywords: climate; conservation; economics of pollination; ecosystem services; global change; land-use; plant–pollinator interactions; pollination; pollinators

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The majority of the world's angiosperms rely on animals for pollination and likewise most pollinators rely on flowering plants for food resources [1,2]. Thus, plant–pollinator interactions are crucial for plants, pollinators, and the functioning of terrestrial ecosystems [3]. Pollination is also essential for the productivity of many of our crops [4,5], with an estimated annual economic value of 235–577 billion US dollars [6]. Plant–pollinator interactions are therefore important for both humans and nature.

However, plant–pollinator interactions are altered by anthropogenic-induced global change, notably land-use and climate change [4–9]. Land-use and climate change impact species distributions and species phenologies, which may lead to spatial and temporal mismatches between mutualistic partners. Land-use and climate change may also influence species abundances, nesting habitats, floral resources and behaviors of pollinators, with unknown effects on plant–pollinator interactions [8–11]. Thus, mutualistic plant–pollinator interactions should be more susceptible to global change and give an "early warning" signal before simple measures of biodiversity, such as species richness and species composition [9]. Despite recent advances, we are still far from understanding how land-use and climate change influence plant–pollinator interactions.

Here I present some 'fruitful avenues' for better understanding the influence of land-use and climate change on plant–pollinator interactions. To identify the exact mechanisms in which land-use and climate change impact plant–pollinator interactions, one may take an *experimental* approach [9], manipulating the land-use and/or climate to detect the mechanisms causing an impact on plant–pollinator interactions. Alternatively to an experimental approach, studies may take either a *temporal* or a *spatial* approach.

By using a *temporal* approach, one is able to examine how historical changes in land-use and climate have influenced a given plant–pollinator system. For instance, it is possible to examine changes in species phenology and temporal plant–pollinator co-occurrence patterns in relation to changes in climate [12] and/or in relation to land-use effects on spatial co-occurrence patterns of plants and pollinators, and thus plant–pollinator interactions [13]. Temporal studies are thus useful to link historical changes in land-use and climate to changes in plant–pollinator interactions [13]. Temporal studies should preferably be conducted over long time periods and be repeated across a variety of localities; however, such data rarely exist. An alternative 'fruitful avenue' is to take a *spatial* approach to understand land-use and climate change impacts on plant–pollinator interactions. When taking a spatial approach, it is important to sample throughout wide gradients of land-use and climate conditions. Land-use impacts can be examined in several ways. Notably, one may focus on the linear distance to a given habitat type or, alternatively, one can examine the proportion of a specific habitat type within a buffer surrounding each study site [4,5,14]. If taking the approach of estimating the linear distance to a patch of a given habitat type, one has to define the minimum patch size required to sustain pollinators and pollination services or, better, use several threshold values for the minimum patch size [4]. When taking the buffer approach, you can likewise use several diameters within which you estimate landscape level measures of each habitat type [14]. In both cases, it is important to pick spatial distances that make sense for the biological organism in question. When using a spatial approach to examine the impact of climate, one can use either large continental-scale gradients or smaller scale gradients [10,15]. Continental-scale gradients have the advantage that it is possible to examine the potential impact of historical changes in climate [10], whereas smaller spatial-scale gradients focus on contemporary variation in climate [15]. Mountains may be particularly useful laboratories to understand climate-driven changes to plant–pollinator interactions [15,16], as climate changes along elevation gradients and mountains encompass large variations in climatic conditions [17]. No matter whether taking an experimental, temporal, or spatial approach to understand land-use and climate change impacts on plant–pollinator interactions, it is important to have a standardized sampling protocol or take sampling efforts into account when comparing across space or time [18]. Finally, land-use and climate change may interact and jointly shape plant–pollinator interactions—more so than each driver alone [16]. Thus, it is important to focus on either a land-use or a climate gradient, keeping the other driver constant, or to have a setup that makes it possible to examine the interaction effects of land-use and climate change on plant–pollinator interactions.

Identifying the impacts of land-use and climate change on plant–pollinator interactions can have practical applications, such as for the conservation of endangered plants. Plants that are highly dependent on pollinators and have a specialized association with their pollinators are particularly at risk of suffering of lack of reproduction if their pollinators change in their temporal appearance, change their feeding behavior, become less abundant, or fully disappear from the localities of the plant [12,15]. Many crops around the world are also dependent on pollinators, and thus it is important to understand the effects of land-use and climate change on crop production and its economic value [4,5]. There may well be a trade-off between ensuring sufficient pollination of crops and saving endangered pollinators and plants. From a farming perspective, abundant common pollinators may sufficiently pollinate at least some crops, while land-use and climate change threatens endangered pollinators and plants in the surrounding landscape. This possible trade-off between farming and nature conservation is another fruitful avenue to understand to maximize the benefit for both humans and nature.

Conflicts of Interest: The author declares no conflict of interest.

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