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Climate change threatens pollination services in tomato crops in Brazil

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ABSTRACT

Understanding how climate change may affect species distribution helps predict how ecosystem services, such as pollination, could be impaired in the future. We examine the potential consequences of climate change on the geographical distribution of five native bee species and estimate the possible effects of bee distribution shifts on tomato crops in Brazil. Ensemble forecasting was implemented through five algorithms in two carbon emission scenarios to predict range shifts for five tomato-visiting bee species for the year 2100. We then calculated the total tomato crop area in the cells with at least 50% bee suitability, for each bee species, in each scenario. Results showed that all species will undergo a reduction in suitable areas in both scenarios. *Bombus morio* had the greatest area reduction in 2100 under the optimistic and pessimistic scenarios: near 38% and 71%, respectively. *Centris tarsata* had the smaller area reduction under the same scenarios: 8.5% and 19.5% respectively. The high agreement between tomato crops and bee distribution observed in the present will also be reduced in both scenarios for all species, especially in the pessimistic scenario. *B. morio* had the highest reduction in range due to habitat suitability and will be restricted to some parts of southeastern and southern Brazil. Over 60% of the tomato crop area presently within the distribution of *B. morio* will become climatically unsuitable in the pessimistic emission scenario. This study indicates that the predicted climate change may negatively impact several species associated with tomato crops in Brazil by the year 2100. This is troubling, as it could result in tomato production losses, which would bring economic and environmental losses to the tomato-producing regions with implications for pollinator conservation.

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1. Introduction

Climate change is among the greatest biodiversity threats of the 21st century (Araújo et al., 2004; Brook et al., 2008; Leadley et al., 2010; Kerr et al., 2015). The impacts of global change may vary among species and change their phenology (Root et al., 2003; Ahmed et al., 2016) and geographical distribution (Araújo et al., 2004) as well as possibly cause the extinction of several species (Pounds et al., 2006). The reduction in the availability of suitable habitat is one of the main effects of climate change (Giannini et al., 2013) and may lead to reductions or shifts in range (Kuhlmann et al., 2012; Kerr et al., 2015). The extent of these effects is alarming, with estimates that 57% of all plants and 34% of all animals will have about 50% of their geographical distributions displaced by the year 2100 (Warren et al., 2013). Furthermore, climate change effects may decrease the efficiency of protected areas, as such areas may become climatically inadequate in the future (Ferro et al., 2014; Martins et al., 2015).

Climate change may cause temporal and spatial mismatches between plants and their pollinators due to changes in their phenology and geographic ranges, in addition to the direct effects on the species (Memmott et al., 2007; Hegland et al., 2009; Polce et al., 2014; Kerr et al., 2015). Pollinators are extremely important for the maintenance of global biodiversity, because they provide a vital ecosystem service for natural systems and agriculture (Daily, 1997). A total of 78% of the known plant species in temperate zones and 94% of tropical plant communities are pollinated by animals (Ollerton et al., 2011). Insects, especially bees, are involved in pollination of 75% of all cultivated species, which are highly important in the global human food supply (Klein et al., 2007).

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Additionally, pollinators increase the quality and amount of fruits and seeds of different cultivars in the world (Klein et al., 2007). One third of agricultural production depends on animal pollination services (Kremen et al., 2007; Klatt et al., 2014).

The animal-pollination of cultivated and wild plants is one of the ecosystem services currently at risk due to rapid and increasing anthropogenic changes (Steffan-Dewenter et al., 2005; Biesmeijer et al., 2006; Aizen and Harder, 2009; Potts et al., 2010; Goulson et al., 2015). The main threat to native pollinators in developed countries is intensive agriculture, whereas in developing countries, deforestation and destruction of natural areas are cited as the main threats (Aizen et al., 2008). The use of pesticides, introduction of exotic species, environmental pollution, and diseases and parasites in managed pollinators are other equally important factors (Kevan and Imperatriz-Fonseca, 2006). However, the decline in pollination services in agriculture due to global changes has not been properly evaluated (Gallai et al., 2009).

Bees are the main pollinators of angiosperms and are responsible for about 35% of global food production. They increase the production of coffee, canola, soybean, orange, apple, passion-fruit, tomato, and others (Klein et al., 2003; Kremen et al., 2007; Klatt et al., 2014). A considerable increase in the production of fruits and seeds after pollination by native or introduced bees has been observed in these crops (Veddeler et al., 2008). Recent studies have found a 55.2% increase in the productivity of pollinated canola plants (Durán et al., 2010; Rosa et al., 2011). Studies showed an increase of up to 200% in coffee fruit yield after bee pollination (De Marco and Coelho, 2004; Ricketts et al., 2008) and 65% in the production of tomato fruits when bees visit tomato flowers (Melo-Silva et al., 2013).

Brazil is ninth in world production of tomato and is the largest producer in Latin America. Brazilian annual production is estimated as 4.4 million tons (FAO, 2013). The Brazilian Institute of Geography and Statistics (IBGE) estimated that tomato production in Brazil made a profit of R$ 6.6 billion (US$ 2 billion) in 2011. Most of this production is concentrated in the states of Goiás, São Paulo, Minas Gerais, Paraná, and Bahia (Brito and Melo, 2010). Flowers of cultivated tomato varieties can be self-pollinated because their stigmas are shorter than the stamens and are located within the anther pollen tube. The pollen is released from flower anthers through a pore opening located in the distal part of the anthers. This kind of anther opening makes it essential for the pollinator to vibrate the anthers for pollen grain release. Therefore, only bees able to perform buzz pollination (vibration process) are regular pollinators of tomato flowers (Fontes and Silva, 2002). This behavior increases the pollen load on the stigma, thus, increasing the fruit and seed production (Greenleaf and Kremen, 2006; Melo-Silva et al., 2013). A recent study showed that global warming may change the geographical distribution of *Xylocopa frontalis,* an uncommon tomato visitor (Giannini et al., 2013). However, no study has predicted changes in the geographical distribution of the main tomato pollinators due to global warming. A computer platform for ensemble forecasting of species distributions, such as BIOMOD, which enables the treatment of a range of methodological uncertainties in models and the examination of species-environment relationships, is an appropriate approach to deal with this challenge. This platform models species distributions using several techniques, tests models with a wide range of approaches, and projects species distributions in different environmental conditions (e.g. climate or land use change scenarios) (Thuiller et al., 2009).

This study aimed to examine the potential consequences of climate change on the geographical distribution of five native bee species that are known to be among the most frequent visitors to tomato crops in Brazil. Some studies, both in temperate and tropical regions, indicate that climate change adversely affects bee populations (Giannini et al., 2012; Polce et al., 2014) and that even small temperature changes can alter their foraging behavior (Heard and Hendrikz, 1993; Stone 1994). Therefore, we tested the hypothesis that, in two climate change scenarios projected for the year 2100, the distribution of most abundant floral-visitor bees in tomato crop will not match current planting areas and reduce this ecosystem service in cultivation.

2. Methods

2.1. Biotic data

We analyzed four Apidae and one Halictidae bee species, namely *Exomalopsis analis* Spinola, 1853; *Bombus morio* (Swederus, 1787); *Eulaema nigrita* Lepeletier, 1841; *Centris tarsata* Smith, 1874; and *Augochloropsis callichroa* (Cockerell, 1900). These five species were among the most abundant bees from the 46 bee species that were observed visiting tomato flowers in conventional tomato plantations in the state of Goiás, Brazil (Silva-Neto et al., 2017). Some of these bees are also among the most common tomato-flower visitors in plantations located in other Brazilian States, such as Sergipe (Santos and Nascimento, 2011), Minas Gerais (Santos et al., 2014), Rio de Janeiro, and Sao Paulo (Gaglianone and Campos, 2015). These five species represent well the diversity of bees that visit tomato flowers, including small (*A. callichroa*, *Ex. analis*) and large bees (*B. morio*, *Eu. nigrita*) as well as bees with different levels of sociality (*Exomalopsis analis* is para-social, *Bombus morio* is social, and the other three are solitary bees).

Occurrence points of each species were compiled using different data sources, especially Internet data providers (Global Information Biodiversity Facility, Species-Link), literature (Silva-Neto et al., 2017), and field data from bee collections in Goiás state ("Online Resource 1"). The details of the data sources can be found in the Online Resource 1.

2.2. Climate data

Climate data were used to determine a model of the current range of five native bee species using the Ecoclimate database (ecoclimate.org; Lima-Ribeiro et al., 2015a,b). The five bioclimatic variables used were selected among the variables with the highest loadings in the first five Varimax rotated eigenvectors of the correlation matrix between all variables (Terribile et al., 2012). This procedure avoids collinearity problems when building species distribution models (SDMs).

For future climate predictions, we used the same five layers projected to the year 2100, for the mean of the simulations for 2080–2100. The projections were also provided by Ecoclimate. Two carbon emission scenarios were applied. In the one more optimistic scenario (RCP 2.6), the radiative forcing is projected as around $3\,W\,m^{-2}$ (watts per square meter) and the CO_2 equivalent concentration will peak at about 490 ppm (parts per million) before 2100 and then decline. In the other more pessimistic scenario (RCP 8.5) the radiative forcing is projected as greater than $8.5\,W\,m^{-2}$ and the CO_2 equivalent concentration greater than 1370 ppm carbon emission rate for 2100 (see details in Taylor et al., 2009, 2012). The expected increase of average temperature varies from 0.3–1.7 °C in the RCP 2.6 scenario, which is considered as optimistic, and the mean increase from 2.6–4.8 °C is expected in the RCP 8.5 scenario, which is considered pessimistic (IPCC, 2014). Regional projections for Brazil indicate an increase in temperature of 3–5 °C in the optimistic scenario and 4 to 8 °C in the worst case scenario for the Amazon. Midwestern and southeastern Brazil could experience increases of 2–3 °C and 4–6 °C in the optimistic and pessimistic scenarios, respectively (Marengo et al., 2007).

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