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Opinion Paper

# Neglected diversity of crop pollinators: Lessons from the world's largest tropical country

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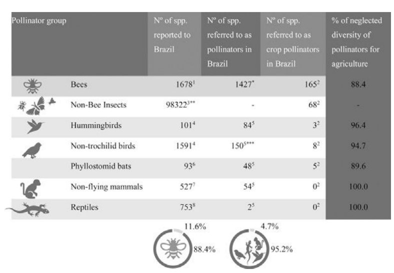
## HIGHLIGHTS

- Pollinators not yet reported as crop pollinators could likely contribute to agriculture.
- The neglected diversity of bees as potential crop pollinators in Brazil is 88.4%.
- The proportion of vertebrate pollinators not yet recorded as pollinating crops is 95.2%.
- Many plant–pollinator interactions are off the conservation agenda for agricultural stability.
- Efforts to protect agricultural pollinators should consider even species not yet recorded as crop pollinators.

## GRAPHICAL ABSTRACT



| Pollinator group | Nº of spp. reported to Brazil | Nº of spp. referred to as pollinators in Brazil | Nº of spp. referred to as crop pollinators in Brazil | % of neglected diversity of pollinators for agriculture |
|---|---|---|---|---|
| Bees | 1678[1] | 1427[*] | 165[2] | 88.4 |
| Non-Bee Insects | 98322[3**] | - | 68[2] | - |
| Hummingbirds | 101[4] | 84[5] | 3[2] | 96.4 |
| Non-trochilid birds | 1591[4] | 150[5***] | 8[2] | 94.7 |
| Phyllostomid bats | 93[6] | 48[5] | 5[2] | 89.6 |
| Non-flying mammals | 527[7] | 54[5] | 0[2] | 100.0 |
| Reptiles | 753[8] | 2[5] | 0[2] | 100.0 |



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## ABSTRACT

We draw attention to potential pollinator species that have not yet been reported as crop pollinators but could likely contribute to agricultural productivity. We refer to this as the neglected diversity of crop pollinators, which we argue should not be excluded from conservation strategies and land-use planning. We used Brazil as case study for at least five main reasons: (1) Brazil is one of the world's largest food producers and exporters; (2) Tropical agricultural production is highly dependent on pollinators; (3) Brazil is almost certainly the most biologically megadiverse country; (4) Brazil has high diversity of pollinators; (5) Brazil has played a leading international role in environmental sustainability. We estimated that the neglected diversity of bees as potential crop pollinators in Brazil is 88.4%. For vertebrates, the neglected diversity is 95.2%. This means that many yet to be observed plant–pollinator interactions are entirely off the radar in terms of the conservation agenda for agricultural stability.



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Animal pollinators are widely connected to human well-being through the maintenance of ecosystem health and functioning, wild plant reproduction, crop yields, and food security (IPBES, 2016). Growing attention towards natural pollinators and pollination is reflected in their importance in the provision of ecosystem services. This fosters the development of new strategies to maximize sustainable management and conservation of crop pollinators (Dicks et al., 2016), which may potentially be used to support biodiversity conservation policies (Porto et al., 2020). However, despite growing interest in pollination and pollinators (e.g. IPBES, 2016), there is still much 'pollination blindness' that poses risks to our food security (Oliveira et al., 2020). Here, we draw attention to potential pollinator species (and services) that have not yet been reported as crop pollinators but likely contribute to agricultural productivity. We refer to this as the neglected diversity of crop pollinators, which we argue should not be excluded from conservation strategies and land-use planning.

Some 90% of all flowering plant species, whether they are cultivated or wild, are pollinated by biotic vectors, such as bees, other insects (e.g., moths, butterflies, wasps, and beetles), bats, birds and other vertebrates (e.g., Ollerton et al., 2011). These animal pollinators affect the production of over 75% of all global food crops, ensuring or enhancing, to varying degrees, the fruit set, yield, fruit quantity and quality (Klein et al., 2007; IPBES, 2016). Consequently, pollinators also influence human dietary quality by supplying nutrients, especially lipids and vitamins, and contribute with medicines, biofuels, fibers, construction materials, musical instruments, sources of inspiration for art, music, literature, religion, and technology (IPBES, 2016). Annually, the global economic input of pollinators to agriculture, inflation-adjusted for 2020, conservatively ranges from US$195 billion to US$387 billion (Porto et al., 2020).

Brazil is an ideal case study to explore the neglected diversity of crop pollinators for at least five main reasons: (1) Brazil is one of the world's largest food producers and exporters and this agricultural output and cropland area will continue to grow in the 21st century (Schneider et al., 2021); (2) Tropical agricultural production is highly dependent on pollinators. In Brazil alone, at least 60% of all crop types depend, to some degree, on animal pollinators, and the annual contribution of pollinators is worth US$12 billion, meaning that 30% of the total annual agricultural revenue is derived from pollinator-dependent crops (up to US$45 billion/year for 2013) (Giannini et al., 2015a); (3) Given its continental extent and high geographic heterogeneity that reflects an elevated agricultural diversity, Brazil is almost certainly the most biologically megadiverse country, estimated to host approximately 42,000 plant species and 148,000 animal species (including 9000 vertebrates and at least 129,840 invertebrates) (BPBES, 2019); (4) There is a high diversity of pollinators in the country, with several groups having a restricted geographic distribution (i.e. endemic to some regions and/or biotas) (e.g. Imperatriz-Fonseca et al., 2012); and (5) In the last decades, Brazil has played a leading international role in environmental sustainability, thereby influencing policy-makers and land managers globally. We recognize that Brazil's continental size, its high diversity of species and ecosystems, and a large proportion of range-restricted species (as suggested by high levels of endemism) pose an enormous challenge to obtain a more refined and exact overview of the relationships between crops and pollinators. This is, however, an inevitable reality for most tropical regions.

A recent survey of cultivated and wild plant species related to food production in Brazil revealed at least 289 food species in human diets (BPBES/REBIPP, 2019). Data on the pollination biology are available for 191 species; at least 148 species (77.4%) have floral traits compatible with some biotic pollination system, which have been proportionally quantified as: bees (66.3%), beetles (9.2%), butterflies (5.2%), moths (5.2%), birds (4.4%), wasps (4.4%), flies (2.8%), bats (2%) and hemipterans (0.4%) (BPBES/REBIPP, 2019). A high frequency of animal-pollinated food species, mostly by bees and beetles, has also been recorded among edible fruit species in the Amazon forest (Paz et al., 2021). The Brazilian Thematic Report on Pollination, Pollinators and Food Production also compiled the level of dependence on biotic pollination for 91 of the 191 food species and recognizes that 74% of those (68 of the 91 spp.) depend to some degree on biotic pollination (BPBES/REBIPP, 2019). Despite such a clear dependence on biotic pollination, Brazil is widely known for its world-leading consumptive use of vast amounts and a wide spectrum of pesticides (e.g., Coelho et al., 2019), and the highest tropical deforestation rates since the 1980s (e.g., Escobar, 2020). These are widely recognized as the two leading drivers of global pollinator declines (Potts et al., 2010).

The Brazilian bee fauna is estimated to contain at least 1678 species (Moure et al., 2007), but only 165 species of which have been reported as crop pollinators (BPBES/REBIPP, 2019). Most bee species can operate as potential pollinators, excluding, for example, the kleptoparasites. Assuming that 15% of all bee species are kleptoparasites (see Batra, 1984 and Alves-dos-Santos, 2009 for reviews), the neglected diversity of bees as potential crop pollinators could be estimated at 88.4% (Fig. 1). Recent reviews show that field studies on crop pollination in Brazil remain disconcertingly scarce (Giannini et al., 2015a, b, 2020), leading to a lack of data on plant–pollinator interactions for major crops and other plant products with limited market access and/or used as local food sources. Furthermore, the geographic limitation of the vast majority of studies has clearly underestimated the huge diversity of native bee species as crop pollinators, especially in the forest and wooded savannah regions of northern and central Brazil (Giannini et al., 2015b; Paz et al., 2021).

Although most global syntheses on natural pollinators have focused on bees (e.g., Kleijn et al., 2015), other insects, such as flies, beetles, moths, and butterflies, are also important for the production cycle of some crops (e.g., Rader et al., 2016; Campbell et al., 2018). The insect diversity in Brazil is perhaps unsurpassed at an approximately 100,000 species (BPBES, 2019). Many of these species have the potential to serve as crop pollinators, especially hymenopterans (bees and non-bees), coleopterans, dipterans, and lepidopterans. Meanwhile, only 23 species of all Brazilian coleopterans (the world's most species-rich order of insects) have been referred to as crop pollinators (BPBES/REBIPP, 2019), suggesting staggering ignorance. As the number of non-bee insect species that potentially serve as crop pollinators in Brazil is unknown even within two orders of magnitude, we were unable to estimate the proportion of neglected diversity of non-bee insect pollinators for agriculture in the world's largest and most agricultural tropical country. Nevertheless, given the exceptional diversity of non-bee insects in Brazil ( 100,000 insect species from BPBES minus 1678 bee species from Moure et al., 2007, totaling 98,322 species; Fig. 1), we expect that the total number of non-bee insect species that are currently *known* to serve as crop pollinators is only a small tip of the iceberg.

Records of vertebrates observed as pollinators in Brazil to date include up to 338 species, including 84 hummingbirds, 150 non-trochilid birds (111 passeriforms and 39 non-passeriforms), 48 phyllostomid bats, 54 non-flying mammals, and two reptile species (Buzato et al., 2012) (Fig. 1). However, only three hummingbird species, eight non-trochilid birds (five passeriforms and three non-passeriforms), and five phyllostomid bats have been referred to as crop pollinators in the literature (BPBES/REBIPP, 2019) (Fig. 1). Accordingly, we again estimated the neglected diversity of vertebrate crop pollinators as the remaining proportion of pollinators that have not yet been recorded as actually pollinating crops. This neglected diversity is 96.4%, 94.7%, and 89.6% for hummingbirds,

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| Other birds | 1591[4] | 150[5***] | 8[2] | 94.7 |
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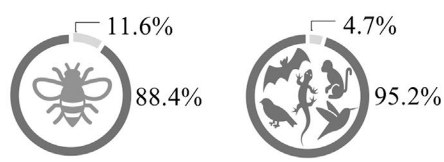


**Fig. 1.** Neglected diversity of pollinators for agriculture in Brazil in terms of bees, hummingbirds, non-trochilid birds, phyllostomid bats, non-flying mammals, and reptiles. Number of species reported in Brazil, number of species referred to as pollinators, number of species referred to as crop pollinators in Brazil, and percentage of neglected diversity of crop pollinators, or the proportion of pollinator species that have not yet been reported as crop pollinators. Doughnuts represent the percentage of neglected diversity of pollinators for agriculture (dark grey) and the percentage of bees and vertebrates known as crop pollinators (light grey). [1]Moure et al. (2007); [2]BPBES/REBIPP (2019); [3]BPBES (2019); [4]Piacentini et al. (2015); [5]Buzato et al. (2012); [6]SBEQ (2020); [7]Paglia et al. (2012); [8]Costa and Bérnils (2018); *Most bee species can act as potential pollinators (minus 15% of kleptoparasites *sensu* Batra, 1984; Alves-dos-Santos, 2009); **Number of insect species in the BPBES (2019) report minus the number of bee species reported in [1]Moure et al. (2007); ***111 passeriforms + 39 non-passeriforms, *sensu* Buzato et al. (2012); - no data available for numbers of species of non-bee insects referred to as pollinators in Brazil.

non-trochilid birds, and bats, respectively (Fig. 1). Notably, hummingbirds and phyllostomid bats are closely linked to pollination and given that there are at least 101 species of hummingbirds in Brazil (Piacentini et al., 2015) and 93 species of phyllostomid bats (SBEQ, 2020), this further increases any estimate of neglected diversity of pollinators for agriculture considering the total pool of species in these taxa (Fig. 1). For non-flying mammals and reptiles, none of the species recorded as pollinators has been identified as crop pollinators, so the neglected diversity of crop pollinators for these taxa is effectively 100% (Fig. 1). Even exotic species cultivated in Brazil that have specialized floral traits for vertebrate pollination could benefit from the neglected diversity of vertebrate pollinators. To give only one example, jambo (*Syzygium malaccense*, Myrtaceae) is an exotic tree species bearing widely consumed fruits throughout Brazil and is often a common landscaping element in urban green spaces (e.g. backyards, gardens, parks). Flowers of *S. malaccense* exhibit nocturnal anthesis, produce copious amounts of nectar and are frequently visited by effective pollinators such as nectar-feeding bats (AVL, personal observations). In addition to the neglected pollinator diversity, some other crops that had no records of pollinators in the Thematic Report on Pollination, Pollinators and Food Production in Brazil (BPBES/REBIPP, 2019) are in fact vertebrate pollinated, such as the dragon fruit/pitaya (*Hylocereus undatus*, Cactaceae), which is pollinated by bats (AVL, personal observation). There are many other yet to be observed plant–pollinator interactions which remain entirely off the radar in terms of the conservation agenda for agricultural sustainability.

There are at least two elements that hinder a comprehensive assessment on the neglected diversity of crop pollinators: the small number of agronomic and ecological studies on this topic (considering the Brazilian diversity) and the patterns of species geographic distributions. We highlight several taxa with high levels of endemism at a regional scale, for example, the exceptionally large number of Meliponini (stingless) bee species that are endemic to Brazil (e.g., Pedro, 2014). This pattern suggests that some groups are represented by high levels of alpha, beta, gamma, and zeta diversity, with the potential occurrence of ecological equivalents at regional to ecosystem scales, at least for agricultural plants. This perspective poses obvious implications for the sustainability of crop-pollinator interactions.

In fact, the IPBES Assessment Report on Pollinators, Pollination and Food Production explicitly recognizes that both wild and managed pollinators have significant roles in crop pollination, and an inclusive precautionary approach should aim to safeguard the persistence of *all pollinators* (IPBES, 2016). However, this report makes no attempt to extol the importance or estimate the amount of neglected pollinator diversity. Therefore, efforts to protect agricultural pollinators should consider even those species that have not yet been recorded as crop pollinators. Furthermore, in the local absence of key crop pollinators, the remaining native biodiversity could likely exert sufficient ecological redundancy to provide this service. Currently, few bee species are reared in Brazil, including both honeybees and some stingless bees, but practical knowledge on their management for crop pollination is poorly disseminated among farmers, hindering this approach (Giannini et al., 2020). Yet many farmers worldwide, and in the tropics in particular, still rely on wild insect pollinators to ensure significant levels of crop yields (Garibaldi et al., 2013).

In synthesis, ambitious new strategies will be essential to meet the many challenges of nature conservation in the near future. This goes beyond crop pollinators in assuming that key ecosystem services provided by native vegetation (e.g. tropical forest and savannahs) rely on the persistence of pollinators that sustain the reproductive biology of native plants. We also emphasize non-crop pollinators that remain anonymous, particularly in megadiverse countries, where even pollinators of major commercially-important crops remain neglected. In this context, regionally designed agendas are mandatory for a better understanding of plant–pollinator interactions considering local to regional arrangements and their levels of taxonomic and functional specificity. This should include intra- and inter-regional networks, ecological redundancy, and pollination services provided for both crop and non-crop plant species that are considered pivotal in the ecosystem such as tropical mega-tree species (Pinho et al., 2020). Such agenda meets safeguarding biodiversity, which is a requirement for achieving sustainable development, including the post-2020 global biodiversity framework as a key opportunity to radically shift business-as-usual food production (Wanger et al., 2020).

Strategic actions must address the threats to native biodiversity, and restore biodiversity or halt its net loss for the benefit of the planet and people (IUCN, 2020). Unfortunately, most public awareness policies are simply informational and lack adequate funding (Hipólito et al., 2021). Moreover, the perception of the importance of pollinators is almost exclusively restricted to bees (Hipólito et al., 2021). Although scientists are producing high-quality evidence-based studies to support governance and public initiatives, our incipient knowledge about non-bee pollinators and the lack of long-term monitoring of pollinators and pollination severely weakens research, planning and actions (e.g. Dicks et al., 2016; IPBES, 2016; BPBES/REBIPP, 2019; Porto et al., 2020; Hipólito et al., 2021). More holistic and cross-sectoral conservation policies and actions, combined with a forward-looking research agenda, must also shine the spotlight on species that are yet to be identified as crop pollinators, and the same applies to a myriad of tropical species whose biotic interactions provide other key ecosystem services.

## Conflict of interest

The authors declare that they have no conflict of interest.

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