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Valuing nature's contribution to people: The pollination services provided by two protected areas in Brazil

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ABSTRACT

The assessment of nature's contribution to people (NCP) is an important strategy for decision-making given the increasing need to reconcile biodiversity and human society with conservation. A monetary and a non-monetary approaches were combined to evaluate the pollination services provided by two Brazilian protected areas (PAs) in northern (Serra da Bocaina, Pará) and southeastern region (Mata do Jambreiro, Minas Gerais) within the Amazon forest and Atlantic forest biomes, respectively. The monetary valuation methodology was based on the role of pollination for crop production in the municipalities surrounding the PAs, and the non-monetary involved estimating the areas with wider range of resources for sustaining pollinators. In Serra da Bocaina, the total annual monetary value of the pollination services performed by bee species was estimated at approximately 564,000 dollars and in Mata do Jambreiro, 246,000 dollars, both for 2016. The non-monetary valuation highlighted the PAs and their surrounding areas with denser plant coverage. The methods used in this study allowed us to evaluate and integrate different types of information: bee diversity data, the spatial data of the PAs and their surroundings, and the economic value of the agricultural production of the neighbouring municipalities. The results can be applied in management and sustainability studies aiming to increase awareness about the importance of PAs and their value and importance for agricultural production. This study demonstrates where efforts can be concentrated for future proposals for valuating pollination services and conservation strategies, especially in areas where data are scarce.

1. Introduction

Ecosystem services were originally defined as the benefits that mankind derives, either directly or indirectly, from ecosystem functions (Constanza et al., 1997, 2014; Daily, 1997), and they were first discussed in detail in the pioneering work

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of the Millennium Ecosystem Assessment (2005). The concept of nature's contribution to people (NCP) (Díaz et al., 2018) has emerged as a key element of the conceptual framework of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2015). NCPs are composed of a set of all of nature's contributions to human wellbeing, and they are based on the ecosystem services concept (IPBES, 2017; Díaz et al., 2018). Thus, initiatives that protect biodiversity can guarantee human well-being and natural resource sustainability (Bennett et al., 2015; Watson et al., 2018).

NCPs can be assessed by quantifying the benefits provided by ecosystems (Roubik, 2002; Ricketts et al., 2004, Millennium Ecosystem Assessment, 2005; Gallai and Vaissière, 2009) as an incentive for the preservation of such services (Abson and Termansen, 2010) and ecosystems (Daily et al., 2000). NCP value assessments assist in the decision-making process and are particularly useful in stressing the importance of the sustainable use of resources provided by biodiversity because they clarify the costs and benefits of different land uses (Pascual et al., 2017). However, despite the importance of such valuation of services, the number of studies applying this approach into the decision-making processes is still low (Breeze et al., 2016), and even fewer have considered the valuation of service at a local scale or in areas where data are scarce or of low quality (Pandeya et al., 2016). Therefore, combining monetary and non-monetary valuation methodologies can be an interesting strategy for covering multiple factors present in complex real world situations, including services that can be evaluated in terms of monetary values for society and others that cannot be so easily translated into such values (Small et al., 2017).

Pollination is the most studied NCP worldwide (Breeze et al., 2016) because most flowering plants (approximately 78%) depend on pollinators for their reproduction and survival (Ollerton et al., 2011). In crop environments, the presence of pollinators increases production (Klein et al., 2007), which directly affects the food security of human populations (Potts et al., 2016; Garibaldi et al., 2016). Due to their importance in agricultural production, pollination services have been valued using a variety of methods (Gallai and Vaissière, 2009; Breeze et al., 2016), both in global (Klein et al., 2007, 2018; Lautenbach et al., 2012) and regional contexts (Losey and Vaughan, 2006; Breeze et al., 2011; Calderone, 2012; Giannini et al., 2015a). Pollination services depend on the landscape and other local factors, such as crop management or property size. The proximity and diversity of preserved natural areas relative to the agricultural fields have also been considered as important factors to ensure the presence of pollinators and, consequently, crop production (Carvalheiro et al., 2010; Wratten et al., 2012; Kennedy et al., 2013; Garibaldi et al., 2017; Hipólito et al., 2018).

Regulations for protected areas (PAs) in Brazil were enacted in 2000 with the objective of promoting and encouraging the recognition of areas as special spaces for the maintenance of the natural environment, biodiversity conservation, preservation of genetic heritage and protection of natural ecosystems (SNUC, 2000). The benefits offered by such PAs extend to their surroundings and exceed those resulting from biodiversity conservation, such as the conservation of wildlife and water resources and protection of historic and cultural sites, and air and water quality, all of which are essential to sustain life quality for the local human population (SNUC, 2000). The benefits obtained from more ecologically friendly landscapes extend beyond financial factors, including multiple economic and socio-environmental dimensions (Hipólito et al., 2016; Small et al., 2017). Thus, the assessment of pollination services in agricultural areas next to PAs is an additional tool for supporting the management and conservation decisions in these areas.

The objective of this study is to assess the value of the pollination services provided by two Brazilian Protected Areas (PAs). We addressed the monetary and non-monetary values based respectively in crop pollination and on spatial analyses of the vicinities of both PAs. PAs are located in the northern and southeastern regions of Brazil: the Serra da Bocaina, in the Campos Ferruginosos National Park (Amazon Forest biome, state of Pará, northern Brazil) and the Mata do Jambreiro Natural Heritage Private Reserve (Atlantic Forest biome, state of Minas Gerais, southeastern Brazil). The study presents methods at the local scale and is an additional tool for supporting decisions involving the management and conservation of PAs, thus increasing their conservation value by considering the NCPs they provide, as well as their surrounding landscapes.

2. Materials and methods

2.1. Study areas

The study areas correspond to two Protected Areas in Brazil. The first one is the Serra da Bocaina a plateau within the Campos Ferruginosos National Park (CFNP) (ICMBIO, 2017) in the municipality of Canaã dos Carajás (Pará, Brazil) (Fig. 1A). The CFNP is a protected area recently created (ICMBIO, 2017) containing two plateaus: Serra da Bocaina and Serra do Tarzan, in the vicinities of the Serra do Rabo which is located to the west of Serra da Bocaina. Serra da Bocaina is located in the Amazon Forest biome, and consists of tropical forest and rocky outcrops covered by savannah vegetation. The area of Serra da Bocaina has approximately 183,000 ha, an average altitude of 600 m and a tropical climate. Agricultural activity is intense in the surroundings, resulting in greater soil desiccation, prevalence of pioneer plant species and early successional stages, and fires during the dry season (Souza-Filho et al., 2016).

The Natural Heritage Private Reserve Mata do Jambreiro is located in the municipality of Nova Lima (Minas Gerais, Brazil) (Fig. 1B), and consists of a tropical forest (Atlantic Forest) in transition to high-altitude savannah vegetation, with a mountainous relief typical of the Serra da Calçada mountain range. The average altitude is 900 m. It has approximately 56,000 ha and a humid subtropical climate. This PA was created in 1998 and is one of the most important green areas of the Belo Horizonte (state capital, with high population density) metropolitan area because it is located only 14 km from the city centre. Thus, the surroundings of this area are characterized by strong urban pressure.

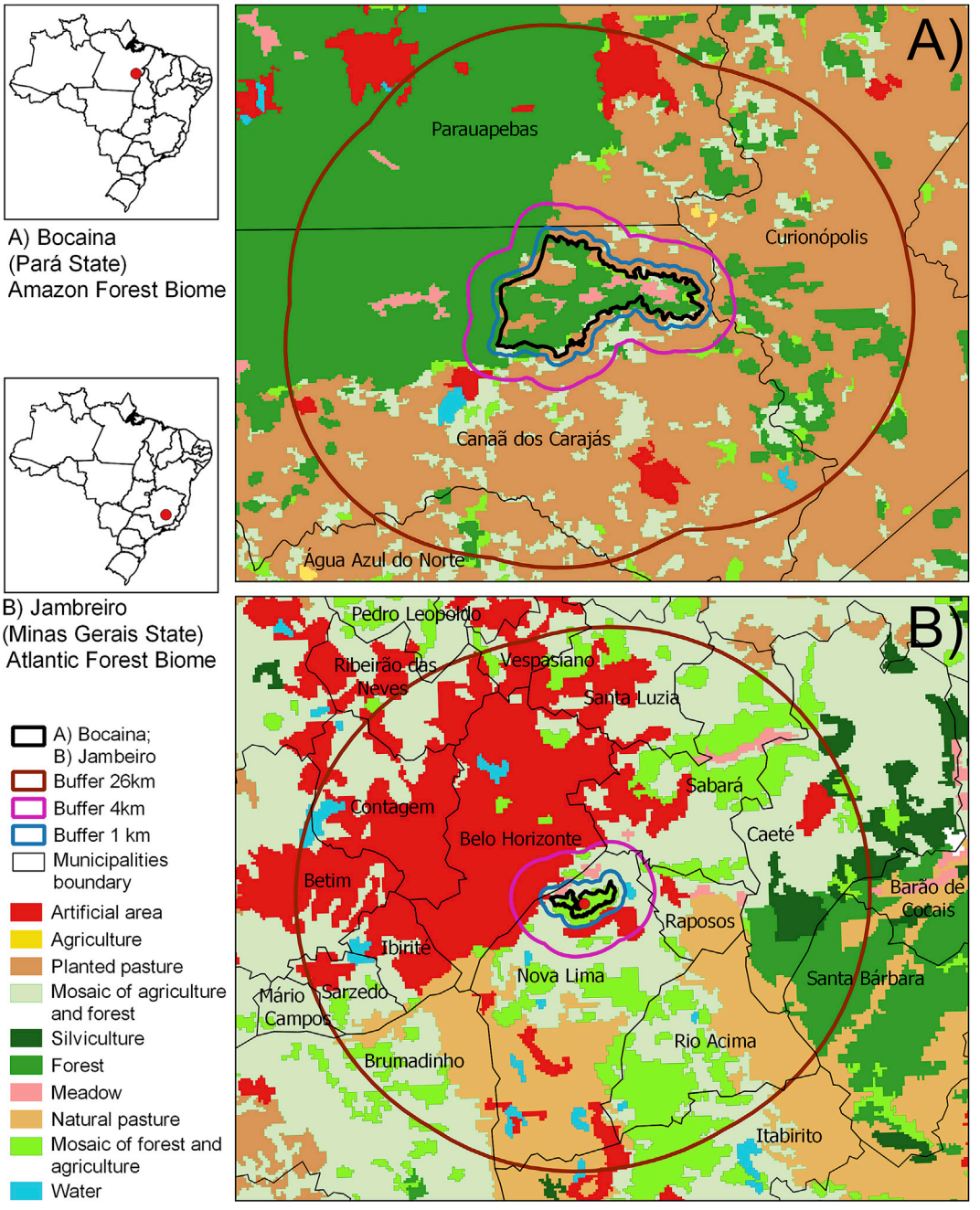

Fig. 1. Location of the two Brazilian Protected Areas. A) Serra da Bocaina (Canaã dos Carajás) and B) Mata do Jambreiro (Nova Lima) and their surrounding areas.

Although both areas are associated with tropic forest, there are differences between the history of land use in their surroundings as above mentioned, which makes the study particularly interesting as it intends to discuss the pollination services delivered by the PAs.

2.2. Monetary valuation

Valuation of the pollination services provided by the bees around each of the PAs was based on the area of maximum foraging distance (MFD) (Greenleaf et al., 2007) of the bees listed for each PA (data can be find in the Supplementary Information A). The MFD was estimated from beeś intertegular distance (ITD), a measurement often used to estimate bee body size (Greenleaf et al., 2007), obtained with a stereomicroscope from three specimens of each species. The conversion of ITD to

MFD was carried out using the BeeIT (Cariveau et al., 2016) package for R (The R Project for Statistical Computing). The ITD and MFD values were used to define three classes of bee body size: "small", defined as an ITD between 0.6 and 2 mm (MFD between 0.1 and 1 km); "medium", ITD between 2.1 and 4 mm (MFD between 1.1 and 4 km); and "large", ITD between 4.1 and 8.7 mm (MFD between 4.1 and 26 km). These classes were used to determine three buffers around each of the 2 PA at 1 km (relative to the MFD of the small bees), 4 km (MFD of the medium-sized bees) and 26 km (MFD of the large bees) from the perimeter of each area (Fig. 1A and B).

The total agricultural area per hectare of each municipality was obtained from the 2014 land use and land cover map published by the Brazilian Institute of Geography and Statistics (IBGE, 2016) that is based on the Moderate Resolution Imaging Spectroradiometer (MODIS - modis.gsfc.nasa.gov/data/). The original resolution of MODIS (250 m) was maintained. The percentages of the agricultural areas of each municipality covered by each of the three buffers were used to estimate the percentage of production that could benefit from pollination based on the three classes of bee body size defined above.

The total production value of each crop in each of the analysed municipalities was compiled from the IBGE for the year 2016 (Supplementary Information B). The degree of dependence of each crop on animal pollination was based on previous work conducted for Brazil (Giannini et al., 2015a) and specifically for açaí berry (Campbell et al., 2018). Four classes of crop dependence to animal pollination were defined following Klein et al. (2007): essential, high, modest, and little. These classes were used to estimate the value of the pollination services for each crop following the procedure suggested by Gallai and Vaissière (2009), which associate the dependence classes to dependence rates (DRs) as follows: essential, DR = 0.95 (indicates that the production value mediated by pollination is between 100% and 90%); high, DR = 0.65 (40–90%); modest, DR = 0.25 (10–40%); and little, DR = 0.05 (1–10%). This rate was multiplied by the economic value of the annual crop production for each crop in each municipality to estimate the economic value of the pollination service (Gallai and Vaissière, 2009). The final value of pollination service was calculated considering the percentage of agricultural area of the surrounding municipalities within each of the three buffers to establish the contribution of small, medium and large bees for this service considering their different MFDs.

2.3. Non-monetary valuation

The non-monetary valuation of the pollination services of the study areas was carried out with the InVEST software program (Integrated Valuation of Environmental Services and Tradeoffs - available on naturalcapitalproject.stanford.edu/invest/) version 3.7.0 (Hamel et al., 2015) using the "Pollination" module, which incorporates geographically oriented measurements in the analyses based on the landscape (Daily et al., 2009). This method is useful for identifying and measuring attributes associated with locally provided services, which are more efficient for conservation and management since they are specific to the scale of the analysis (Raymond et al., 2009). Because ecosystem services are geographically variable (Brooks et al., 2014), such an approach is most useful at multiple scales (Soberon and Sarukhan, 2009). The use of InVEST software is also justified by the fact that it is developed by frontier institutions dedicated to environmental analyses and because it is inserted into the Natural Capital project context (Daily et al., 2011).

Data required by InVEST pollinator module are (i) land use and land cover maps (IBGE, 2016), including the availability of nesting and floral resource for each use class (Supplementary Information C); (ii) list of bee species reported for both area (Serra da Bocaina and Mata do Jambreiro) (Supplementary Information A), which was based on data from an internal database and from public biodiversity data providers, such as speciesLink (a Brazilian repository of biodiversity data) and the Global Biodiversity Information Facility (GBIF); data from two Brazilian entomological collections that hold bees from both areas and are not available online were also included: the collection at Museu Paraense Emílio Goeldi (MPEG) and the collection at Federal University of Minas Gerais (UFMG); (iii) nesting sites, foraging activity seasonality, and relative abundance of each bee species were based on literature review and field observations (Supplementary Information A); and (iv) MFD (in metres) estimated from the ITD (Greenleaf et al., 2007) according to Cariveau et al. (2016) as described above.

Among the main results obtained using InVEST, four models are produced representing the potential availability of nesting sites (soil and cavities) and flowers available as food resources (during spring and during summer) in each landscape cell. A consensus map was than constructed for each PA and their surrounding areas, in which the four models were summed. The final model was associated with the municipalities and the buffers as described above for each PA to identify areas that could potentially provide higher availability of resources to the bees.

3. Results

For the Serra da Bocaina, a total of 73 bee species were obtained: 27 in the small body size class (MFD up to 1 km), 27 in the medium body size class (MFD up to 4 km) and 19 in the large body size class (MFD up to 26 km) (Supplementary Information A). For the Mata do Jambreiro, a total of 60 species of bees were obtained, with 21 small, 17 medium and 22 large bees (Supplementary Information A).

Considering the requirements for monetary valuation, the Serra da Bocaina and surrounding area (based on the three proposed buffers) contains four municipalities that produce 17 agricultural crops, which are distributed as follows based on their dependence on pollination services: two crops (passion fruit, watermelon) are essentially dependent on animal pollination; two crops (açaí and tomato) are highly dependent on animal pollination; three crops (coffee, coconut and soybean) are modestly dependent; two (beans, papaya) are little dependent on animal pollination; and eight crops do not

depend on animal pollinators (Table 1; Supplementary Information B). Considering the presence of agricultural areas within the three analysed buffers, the value of pollination service provided by small, medium and large bees is equivalent to approximately 2,800 dollars (buffer 1 km), 18,500 dollars (buffer 4 km) and 564,500 dollars (buffer 26 km), respectively (Table 2). The only municipality that received potential benefits from all three bee size classes is Canaã dos Carajás; however, the municipality with the highest total value of pollination services is Parauapebas (Table 2).

For Mata do Jambreiro, the surrounding area included 19 municipalities, 15 of these had agricultural production associated and 16 crops were produced in the analysed year (2016) (Table 1; Supplementary Information B). Regarding their degree of dependence on pollination services, three of these crops (avocado, guava, tomato) are highly dependent; two (orange, coffee) are modestly dependent; three (beans, lemon, tangerine) are little dependent; and eight are not dependent. Considering the presence of areas with agricultural production within the three buffers analysed, the pollination services value of small, medium and large bees was zero (buffer 1 km); 158.6 dollars (buffer 4 km), and 246,000 dollars, respectively (Table 2). None of the municipalities evaluated benefitted from pollination services by all three bee size classes, and only one (Sabará) received potential benefits from bees in the 4 km buffer. The municipality with the highest total value of pollination services was Sarzedo (Table 2).

Regarding the non-monetary valuation (Fig. 2), a greater potential availability of nesting and food resources is associated with areas with higher vegetation coverage, indicating a greater availability of pollination services. For the Serra da Bocaina (Fig. 2A), a large adjacent area with significant vegetation cover is observed from west to north, and it corresponds to another PA, the Carajás National Forest. The municipalities that potentially have more resources for bee species and potentially greater availability of pollination services are Canaã dos Carajás, considering all the three buffers, and Parauapebas, which has a larger area within the 26 km buffer available for large-size bees (Table 3). For Mata do Jambreiro (Fig. 2B), most areas with a greater concentration of resources for bees are located outside the metropolitan area of Belo Horizonte; the municipality of Nova Lima presents the largest area available for the three bee size classes, especially for larger-size bees (Table 3). The municipalities of Caeté, Rio Acima and Santa Luiza are also noteworthy as areas with resource availability for larger bees.

4. Discussion

Two valuation methodologies were used here to assess the delivery of pollination services by two PAs in Brazil: an economic methodology based on monetary market values and a non-monetary ecological valuation based on spatial data. The values of pollination services obtained for the studied year were higher for Serra da Bocaina than for Mata do Jambreiro and higher for longer bee's foraging distances, which correspond to the services performed by larger body size bees. Municipalities with denser vegetation cover around the PAs were those that presented greater potential amount of resources for the bees and therefore can potentially deliver more pollination services.

The difference found between the pollination service values provided by the two PAs is related to certain characteristics of each region. First, different crops are found in the areas surrounding each of the PAs, and these crops present varying levels of dependence on animal pollination, which translates into different service values. For example, surrounding Mata do Jambreiro, none of the listed crops has an essential dependence on pollinators. In addition, crops present different production volumes, which directly affects the final estimated value of pollination services. The PAs also show important differences in the geographical characteristics of their surroundings, which affect agricultural development and directly influence the service values. The Serra da Bocaina is surrounded by a more higher number of agricultural fields, especially in its eastern portion, whereas Mata do Jambreiro has a different occupation history of its environment. In addition to the rugged relief that hinders agricultural practices on this last PA, considerable urbanization pressure is present in the surrounding areas. This

Table 1
Agricultural crops that depends on pollinators and are produced in each municipality of the analysed areas (IBGE, 2016). Their degree of dependence on animal pollination are based on Giannini et al. (2015) and Campbell et al. (2018).

Crop	Dependence	Municipalities
Açai	high	Água Azul do Norte, Curionópolis, Parauapebas
Avocado	high	Brumadinho, Pedro Leopoldo, Sarzedo
Bean	little	Água Azul do norte, Canaã dos Carajás, Parauapebas, Barão de Cocais, Betim, Brumadinho, Caeté, Ibirité, Itabirito, Ribeirão das Neves, Sabará, Santa Bárbara, Santa Luzia, Sarzedo, Vespasiano
Cocoa	essential	Parauapebas
coconut	modest	Curionópolis, Parauapebas
Coffee	modest	Parauapebas, Caeté, Santa Bárbara
Guava	high	Betim, Rio Acima
Lemon	little	Brumadinho, Caeté, Betim
Orange	modest	Brumadinho, Itabirito
Papaya	little	Parauapebas
Passionfruit	essential	Canaã dos Carajás, Curionópolis, Parauapebas
Soy	modest	Parauapebas
Tangerine	little	Betim, Caeté, Brumadinho, Itabirito
Tomato	high	Parauapebas, Betim, Sarzedo, Brumadinho, Pedro Leopoldo, Caeté, Ibirité, Sabará
Watermelon	essential	Água Azul do norte, Canaã dos Carajás, Parauapebas

Table 2
Economic value of annual pollination services (PS) in each municipality analysed relative to bee body size based on the intertegular distance (ITD) and maximum foraging distance (MFD).

	PS (USD)		
	MFD 0.1–1 km ITD 0.6–2 mm	MFD 1.1–4 km ITD 2.1–4 mm	MFD 4.1–26 km ITD 4.1–8.7 mm
Bocaina			
Água Azul do Norte	–	–	2616.08
Canaã dos Carajás	2886.17	12,301.10	60,886.17
Curionópolis	–	761.92	40,436.45
Parauapebas	–	5477.80	460,526.36
TOTAL	**2886.17**	**18,540.82**	**564,465.06**
Jambreiro			
Barão de Cocais	–	–	10.21
Belo Horizonte	–	–	–
Betim	–	–	2264.02
Brumadinho	–	–	70,661.41
Caeté	–	–	28,880.02
Contagem	–	–	–
Ibirité	–	–	15,026.32
Itabirito	–	–	8559.16
Mário Campos	–	–	–
Nova Lima	–	–	–
Pedro Leopoldo	–	–	381.55
Raposos	–	–	–
Ribeirão das Neves	–	–	194.02
Rio Acima	–	–	3078.95
Sabará	–	158.58	13,538.27
Santa Bárbara	–	–	27.96
Santa Luzia	–	–	3673.84
Sarzedo	–	–	99,691.15
Vespasiano	–	–	51.78
TOTAL	**-**	**158.58**	**246,038.67**

region also has a history of occupation associated with mining and is adjacent to two other PAs, namely Serra do Curral Park and Mangabeiras Park. Thus, agricultural production is lower in Mata do Jambreiro than that recorded for the surroundings of Serra da Bocaina, also directly influencing the pollination services value. It is also important to note that certain regional crops that may be crucial to the local economy are not surveyed by the IBGE, thus leading to an undervaluation of the total contribution of pollinators in the agricultural production of those municipalities. This lack of information is more noteworthy for municipalities in northern Brazil. It must also be noted that the monetary value of pollination calculated in this study is based only on agricultural crop production; however, the value could be even higher if other by-products relevant to agricultural areas are considered, such as increased biological control services, reduced soil erosion, increased nutrient cycling, and increased property value (Wratten et al., 2012). Moreover, determining the dependence of crops for animal pollination is not an easy task, since it demands time-consuming experimental fieldwork (e.g. Klatt et al., 2014; Campbell et al., 2018) and values can vary between crops and varieties (Klein et al., 2007; Breeze et al., 2016). This is an open field of study and more details are urgently needed to address valuation of crop-pollination services (Breeze et al., 2016), mainly on geographically-large tropical areas with high biodiversity and scarce data such as Brazil.

The importance of large-bodied bees that are capable of flying greater distances, reaching a higher number of areas and contributing more to pollination was also evidenced by our results. Of the 34 identified species capable of foraging at distances greater than 4 km, 26 (76.5%) belonged to four genera (*Bombus, Centris, Eulaema* and *Xylocopa*), and three of these genera represent predominantly solitary bees, excepting *Bombus* that presents social behaviour. Previous work has shown that 1/5 of the Brazilian agricultural crops are predominantly pollinated by three genera of bees: bumblebees (*Bombus* spp.), oil-collecting bees (*Centris* spp.) and carpenter bees (*Xylocopa* spp.) (based on data from 75 crops; Giannini et al., 2015b), and most of the species in these genera are considered large bodied. Other studies also showed the importance of solitary bees for agriculture in temperate countries, such as *Osmia* (*O. lignaria* and *O. cornuta*), *Peponapis pruinosa* and *Melissodes bimaculata* (Klein et al., 2018), which have not been recorded in Brazil. In addition, species of *Bombus* are used in the large-scale pollination of greenhouse crops in Europe, Africa, Asia and the Americas, including tomato, peppers, apples, pears, kiwi and cherry (Velthuis and Van Doorn, 2006).

A Brazilian survey on bees that pollinate agricultural crops (Giannini et al., 2015b) showed that the pollinators of only one of the thirteen crops listed in the present study (i.e., lemon tree) have not yet been studied (see also Wolowski et al., 2019). Among the other 12 crops, only one (i.e., açai palm) does not have large-sized bees among their pollinators (Campbell et al., 2018). All the other species depend especially on *Bombus, Xylocopa, Centris* (genera with mostly large bees) as well as *Apis mellifera*, which is considered a medium-sized bee and has a flight range sufficient to reach areas within the 4.1–26 km buffer. Açai crops are produced only in northern Brazil, and it is mainly pollinated by small bees; thus, the closer the PA is to an açai crop, the greater the contribution of these bees to fruit setting. It is important to emphasize the scarcity of data on the

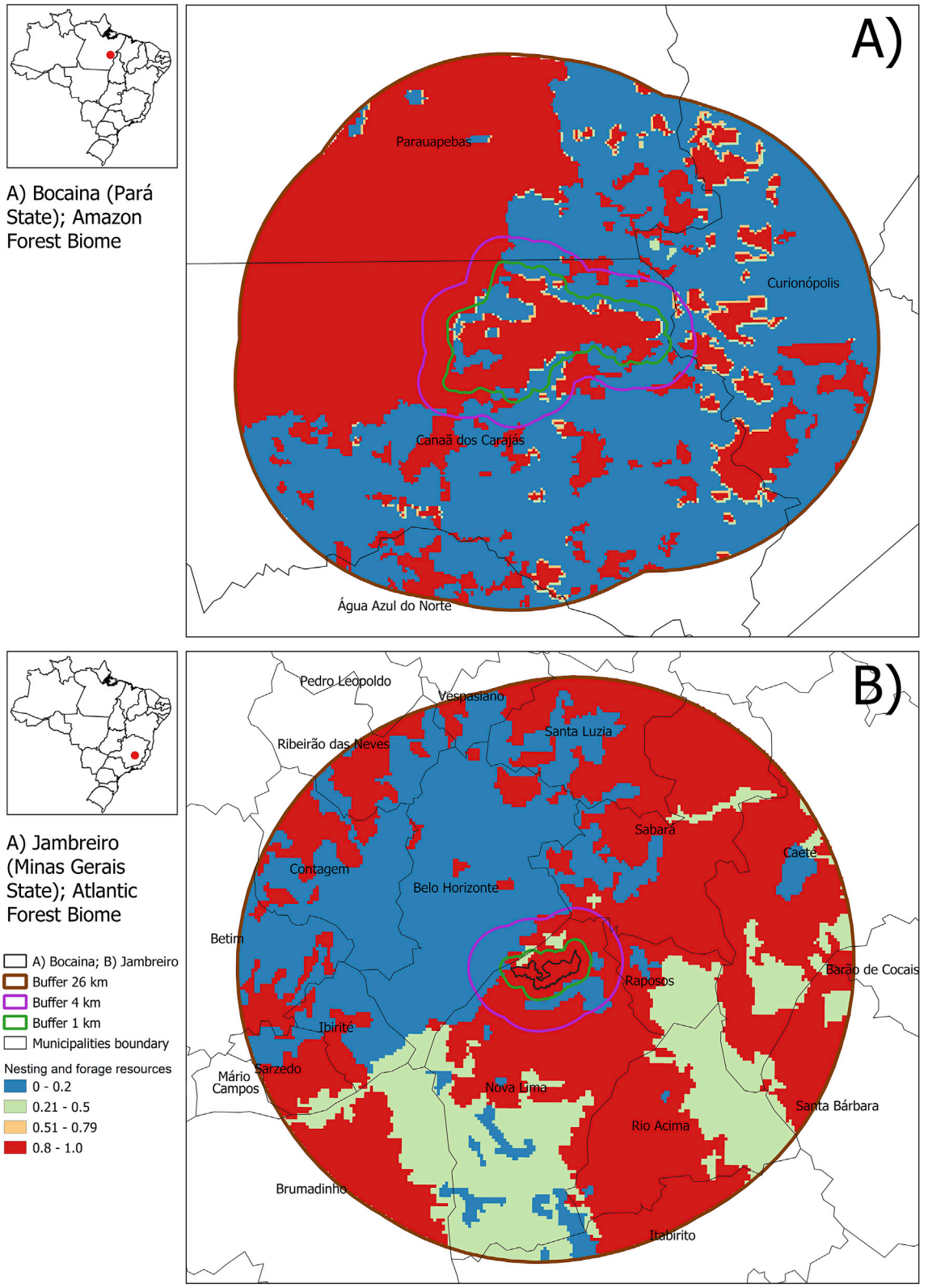

Fig. 2. Main sites offering nesting resources (cavity and soil) and floral resources (spring and summer) for A) Serra da Bocaina and B) Mata do Jambreiro and their surrounding areas.

Table 3
Area (km^2) of each municipality with a higher potential to provide nesting and food resources (80–100%; Fig. 2) relative to bee body size (based on the intertegular distance, ITD) and maximum foraging distance (MFD).

	Area (Km2)		
	MFD 0.1–1 km ITD 0.6–2 mm	MFD 1.1–4 km ITD 2.1–4 mm	MFD 4.1–26 km ITD 4.1–8.7 mm
Bocaina			
Canaã dos Carajás	168.4	271.4	912.8
Curianópolis	–	3.3	184.5
Parauapebas	–	9.7	699.7
Água Azul do Norte	–	–	44.8
Jambreiro			
Barão de Cocais	–	–	4.7
Belo Horizonte	0.7	7.5	27.5
Betim	–	–	28.2
Brumadinho	–	–	90.6
Caeté	–	–	169.4
Contagem	–	–	45.9
Ibirité	–	–	20.6
Itabirito	–	–	50.2
Mário Campos	–	–	0.8
Nova Lima	27.2	71.9	216.7
Pedro Leopoldo	–	–	1.6
Raposos	–	4.2	34.4
Ribeirão das Neves	–	–	40.1
Rio Acima	–	–	133.3
Sabará	–	2.6	235
Santa Bárbara	–	–	64.4
Santa Luzia	–	–	105.1
Sarzedo	–	–	36.9
Vespasiano	–	–	14.2

interactions between bees and agricultural plants in northern Brazil. Few studies have been conducted in this region and a great shortage of data on pollinators of Brazilian crops in the region as well as pollinators of local crops remains. A recent review that analysed 289 references of Brazilian crop pollination showed that only 13% of the studies were conducted on Northern region (Wolowski et al., 2019). Thus, further studies on local agricultural pollinators could provide additional details for the valuation presented here.

Regarding the non-monetary valuation, the InVEST results demonstrated the importance of the two PAs and their surrounding areas as they can provide resources for pollinators. The importance of surrounding areas associated with denser vegetation cover and native vegetation must be highlighted. It should be noted here that native vegetation was considered only by the non-monetary valuation method since the monetary valuation considers only the perspective of agricultural lands. Thus, although pollination services are provided by PAs, the monetary valuation considered the crops value and is thus dependent on the type of land use around the PAs. On the other hand, the non-monetary valuation method reinforces the importance of the PAs themselves and other (semi) natural areas where the pollinators can find nesting and food resources, thus demonstrating the direct importance of such areas for the provision of services. Therefore, InVEST software was useful for an ecological valuation based on spatial analyses that consider the landscapes diversity and availability of nesting and food resources, and its use can be adapted to any location for which data are available. Results obtained here illustrates the importance and necessity of using complementary approaches that include monetary and non-monetary valuation. On Brazil, protected areas accounts for 2251 unities covering a total area of 1.54 million km2 (Pacheco et al., 2018), whose conservation has been increasingly threatened (Fearnside, 2016; Begotti and Peres, 2019). Our results reinforce previous statements that intact forests delivery important NCPs with high value for societies (Watson et al., 2018; Franklin Jr. and Pindyck, 2018) and should be preserved as a public good for future generations (Nobre et al., 2016).

Given the diversity of vegetation types found in the two PAs, it is expected that in addition to pollination services, other important NCPs typical of forest cover sites, but not included in the present study, could be found, such as biomass production, provision of wildlife habitats, seed dispersal, nutrient cycling and resistance to extreme biotic conditions (Brockerhoff et al., 2017; Mori et al., 2017). Each PA studied here also has its own specific characteristics. Serra da Bocaina presents the potential for ecotourism because it has areas of great scenic value and a unique landscape structure due to the mountainous relief and rocky vegetation at high altitude surrounded by the Amazon Forest. Mata do Jambreiro presents the potential for ecological activities due to its proximity to urban areas of the metropolitan region of the state capital of Minas Gerais. In fact, the area is already open to visitation by environmental education programmes and partnerships with local schools.

Future studies should assess ecosystem services in a broader decision-making context, including aspects of ecological, social, cultural and environmental valuation, to ensure the sustainability of ecosystem service provisioning (Pandeya et al., 2016). Such studies can be used as a support for public plans and policies aimed at raising awareness of the connection

between the conservation of natural ecosystems and social well-being, and the relevance of such conservation to other sectors in addition to agriculture and food security, such as health, energy, water security, infrastructure, urban development, finance and national security (Guerry et al., 2015).

5. Conclusions

The isolated use of different methods such as those applied in this study (monetary and non-monetary) for the valuation of NCPs may not reflect the total value of PAs with respect to the provision of ecosystem services. However, the combination of the two methods can foster a more comprehensive perspective that considers the complexity of the subject. However, the greater the complexity of valuation is, the greater the need for high-quality data. Further research is needed to increase the quality of data used as input for InVEST and to provide additional interaction data for crops and pollinating bees, mainly in the northern region of Brazil, and higher quality spatial data on crop lands in Brazil. The approach applied herein can be used in other contexts and in other areas. Such an application is useful for characterizing the importance and value of ecosystem services provided by PAs to surrounding areas as well as to local human communities. This approach can help in valuation and decision-making processes involving the conservation and management of biodiversity conservation areas.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2019.e00782.

References

Abson, D.J., Termansen, M., 2010. Valuing ecosystem services in terms of ecological risks and returns. Conserv. Biol. 25, 250–258.
Begotti, R.A., Peres, C.A., 2019. Brazil's indigenous lands under threat. Science 363, 592.
Bennett, E.M., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B.N., Geijzendorffer, I.R., Krug, C.B., Lavorel, S., Lazos, E., Lebel, L., Martin-lopéz, B., Meyfroidt, P., Mooney, H.A., Nel, J.L., Pascual, U., Payet, K., H. A., Harguindeguy, N.P., Peterson, G.D., Prieur-Richard, A., Reyers, B., Roebeling, P., Seppelt, R., Solan, M., Tschakert, P., Tscharntke, T., Turner II, B.L., Verburg, P.H., Viglizzo, E.F., White, P.C.L., Woodward, G., 2015. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr. Opin. Environ. Sustain. 14, 76–85.
Breeze, T.D., Bailey, A.P., Balcombe, K.G., Potts, S.G., 2011. Pollination services in the UK: how important are honeybees? Agric. Ecosyst. Environ. 142, 137–143.
Breeze, T.D., Gallai, N., Garibaldi, L.A., Li, X.S., 2016. Economic measures of pollination services: shortcomings and future directions. Trends Ecol. Evol. 31, 927–939.
Brockerhoff, E.G., Barbaro, L., Castagneyrol, B., Forrester, D.I., Gardiner, B., González-Olabarria, J.R., Lyver, P.O., Meurisse, N., Oxbrough, A., Taki, H., Thompson, I.D., van der Plas, F., Jactel, H., 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers. Conserv. 26, 3005–3035.
Brooks, T.M., Lamoreux, J.F., Soberón, J., 2014. IPBES ≠ IPCC. Trends Ecol. Evol. 29, 543–545.
Calderone, N.W., 2012. Insect pollinated crops, insect pollinators and US agriculture: trend analysis of aggregate data for the period 1992–2009. PLoS One 7, e37235.
Campbell, A.J., Carvalheiro, L.G., Maués, M.M., Jaffé, R., Giannini, T.C., Freitas, M.A.B., Coelho, B.W.T., Menezes, C., 2018. Anthropogenic disturbance of tropical forests threatens pollination services to açaí palm in the Amazon river delta. J. Appl. Ecol. 55, 1725–1736.
Cariveau, D.P., Nayak, G.K., Bartomeus, I., Zientek, J., Ascher, J.S., Gibbs, J., Winfree, R., 2016. The allometry of bee proboscis length and its uses in ecology. PLoS One 11, e0151482.
Carvalheiro, L.G., Seymour, C.L., Veldtman, R., Nicolson, S.W., 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. J. Appl. Ecol. 47, 810–820.
Constanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Glob. Environ. Chang. 26, 152–158.
Daily, G.C., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.
Daily, G.C., Sliderqvist, T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P.R., Folke, C., Jansson, A., Jansson, B., Kautsky, N., Levin, S., Lubchenco, J., Maler, K., Simpson, D., Starrett, D., Tilman, D., Walker, B., 2000. The value of nature and the nature of value. Science 289, 395–396.
Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7, 21–28.
Daily, G.C., Kareiva, P.M., Tallis, H., Ricketts, T.H., 2011. Natural Capital: Theory & Practice of Mapping Ecosystem Services. Oxford University Press.
Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J.R., Arico, S., Báldi, A., Bartuska, A., Baste, I.A., Bilgin, A., Brondizio, E., Chan, K.M., Figueroa, V.E., Duraiappah, A., Fischer, M., Hill, R., Koetz, T., Leadley, P., Lyver, P., Mace, G.M., Martin-Lopez, B., Okumura, M., Pacheco, D., Pascual, U., Pérez, E.S., Reyers, B., Roth, E., Saito, O., Scholes, R.J., Sharma, N., Tallis, H., Thaman, R., Watson, R., Yahara, T., Hamid, Z.A., Akosim, C., Al-Hafedh, Y., Allahverdiyev, R., Amankwah, E., Asah, S.T., Asfaw, Z., Bartus, G., Brooks, L.A., Caillaux, J., Dalle, G., Darnaedi, D., Driver, A., Erpul, G., Escobar-Eyzaguirre, P., Failler, P., Fouda, A.M.M., Fu, B., Gundimeda, H., Hashimoto, S., Homer, F., Lavorel, S., Lichtenstein, G., Mala, W.A., Mandivenyi, W., Matczak, P., Mbizvo, C., Mehrdadi, M., Metzger, J.P., Mikissa, J.B., Moller, H., Mooney, H.A., Mumby, P., Nagendra, H., Nesshover, C., Oteng-

Yeboah, A.A., Pataki, G., Roué, M., Rubis, J., Schultz, M., Smith, P., Sumaila, R., Takeuchi, K., Thomas, S., Verma, M., Yeo-Chang, Y., Zlatanova, D., 2015. The IPBES Conceptual Framework — connecting nature and people. Curr. Opin. Environ. Sustain. 14, 1–16.
Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359, 270–272.
Fearnside, P.M., 2016. Brazilian politics threaten environmental policies. Science 353, 746–748.
Franklin Jr., S.L., Pindyck, R.S., 2018. Tropical forests, tipping points, and the social cost of deforestation. Ecol. Econ. 153, 161–171.
Gallai, N., Vaissière, B.E., 2009. Guidelines for the economic valuation of pollination services at a national scale. Food and Agriculture Organization of the United Nations.
Garibaldi, L.A., Carvalheiro, L.G., Vaissière, B.E., Gemmill-Herren, B., Hipólito, J., Freitas, B.M., Ngo, H.T., Azzu, N., Sáez, A., Åström, J., An, J., Blochtein, B., Buchori, D., Chamorro García, F.J., Silva, F.O., Devkota, K., Ribeiro, M.F., Freitas, L., Gaglianone, M.C., Goss, M., Irshad, M., Kasina, M., Pacheco Filho, A.J., Kiill, L.H., Kwapong, P., Parra, G.N., Pires, C., Pires, V., Rawal, R.S., Rizali, A., Saraiva, A.M., Veldtman, R., Viana, B.F., Witter, S., Zhang, H., 2016. Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science 351, 388–391.
Garibaldi, L.A., Gemmill-Herren, B., D'Annolfo, R., Graeub, B.E., Cunningham, S.A., Breeze, T.D., 2017. Farming approaches for greater biodiversity, livelihoods, and food security. Trends Ecol. Evol. 32, 68–80.
Giannini, T.C., Cordeiro, G.D., Freitas, B.M., Saraiva, A.M., Imperatriz-Fonseca, V.L., 2015a. The dependence of crops for pollinators and the economic value of pollination in Brazil. J. Econ. Entomol. 108, 849–857.
Giannini, T.C., Boff, S., Cordeiro, G.D., Cartolano Jr., E.A., Veiga, A.K., Imperatriz-Fonseca, V.L., Saraiva, A.M., 2015b. Crop pollinators in Brazil: a review of reported interactions. Apidologie 46, 209–223.
Greenleaf, S.S., Williams, N.M., Winfree, R., Kremen, C., 2007. Bee foraging ranges and their relationship to body size. Oecologia 153, 589–596.
Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Ruckelshaus, M., Bateman, I.J., Duraiappah, A., Elmqvist, T., Feldman, M.W., Folke, C., Hoekstra, J., Kareiva, P.M., Keeler, B.L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., Ricketts, T.H., Rockström, J., Tallis, H., Vira, B., 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Proc. Natl. Acad. Sci. 112, 7348–7355.
Hamel, P., Chaplin-Kramer, R., Sim, S., Mueller, C., 2015. A new approach to modeling the sediment retention service (InVEST 3.0): case study of the Cape Fear catchment, North Carolina, USA. Sci. Total Environ. 524–525, 166–177.
Hipólito, J., Viana, B.F., Garibaldi, L.A., 2016. The value of pollinator-friendly practices: synergies between natural and anthropogenic assets. Basic Appl. Ecol. 17, 659–667.
Hipólito, J., Boscolo, D., Viana, B.F., 2018. Landscape and crop management strategies to conserve pollination services and increase yields in tropical coffee farms. Agric. Ecosyst. Environ. 256, 218–225.
IBGE. Instituto Brasileiro de Geografia e Estatística, 2016. Cobertura e Uso da Terra. Accessed on Aug 2019. www.ibge.gov.br/geociencias/informacoes-ambientais/cobertura-e-uso-da-terra/15831-cobertura-e-uso-da-terra-do-brasil.html?=&t=cobertura-e-uso-da-terra.
ICMBIO. Instituto Chico Mendes de Conservação da Biodiversidade, 2017. Decreto sem nº, de 5 de junho de 2017. Accessed on 20th Aug 2019. http://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros/amazonia/unidades-de-conservacao-amazonia/8971-parna-dos-campos-ferruginosos.
IPBES. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2017. Plenary 5 Decision IPBES-5/1: Implementation of the First Work Programme of the Platform.
Kennedy, C.M., Lonsdorf, E., Neel, M.C., Williams, N.M., Ricketts, T.H., Winfree, R., Bommarco, R., Brittain, C., Burley, A.L., Cariveau, D., Carvalheiro, L.G., Chacoff, N.P., Cunningham, S.A., Danforth, B.N., Dudenhöffer, J.H., Elle, E., Gaines, H.R., Garibaldi, L.A., Gratton, C., Holzschuh, A., Isaacs, R., Javorek, S.K., Jha, S., Klein, A.M., Krewenka, K., Mandelik, Y., Mayfield, M.M., Morandin, L., Neame, L.A., Otieno, M., Park, M., Potts, S.G., Rundlöf, M., Saez, A., Steffan-Dewenter, I., Taki, H., Viana, B.F., Westphal, C., Wilson, J.K., Greenleaf, S.S., Kremen, C., 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems, 2013 May Ecol. Lett. 16 (5), 584–599. https://doi.org/10.1111/ele.12082. Epub 2013 Mar 11.
Klatt, B.K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E., Tscharntke, T., 2014. Bee pollination improves crop quality, shelf life and commercial value. Proceedings of the Royal Society B 281, 20132440.
Klein, A.-M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.a., Kremen, C., Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. Biol. Sci. 274, 303–313.
Klein, A.M., Boreux, V., Fornoff, F., Mupepele, A.V., Pufal, G., 2018. Relevance of wild and managed bees for human well-being. Current Opinion in Insect Science 26, 82–88.
Lautenbach, S., Seppelt, R., Liebscher, J., Dormann, C.F., 2012. Spatial and temporal trends of global pollination benefit. PLoS One 7, e35954.
Losey, J., Vaughan, M., 2006. The economic value of ecological services provided by insects. Bioscience 56, 311–323.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
Mori, A.S., Lertzman, K.P., Gustafsson, L., 2017. Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. J. Appl. Ecol. 54, 12–27.
Nobre, C.A., Sampaio, G., Borma, L.S., Castilla-Rubio, J.C., Silva, J.S., Cardoso, M., 2016. Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. Proc. Natl. Acad. Sci. 113, 10759–10768.
Ollerton, J., Winfree, R., Tarrant, S., 2011. How many flowering plants are pollinated by animals? Oikos 120, 321–326.
Pacheco, A.A., Neves, A.C.O., Fernandes, G.W., 2018. Uneven conservation efforts compromise Brazil to meet the target 11 of convention on biological diversity. Perspectives in Ecology and Conservation 16, 43–48.
Pandeya, B., Buytaert, W., Zulkafli, Z., Karpouzoglou, T., Mao, F., Hannah, D.M., 2016. A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions. Ecosyst. Serv. 22, 250–259.
Pascual, U., Balvanera, P., Diaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Dessane, E.B., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S.M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y.S., Amankwah, E., Asah, S.T., Berry, P., Bilgin, A., Breslow, S.J., Bullock, C., Caceres, D., Daly-Hassen, H., Figueroa, E., Golden, C.D., Gomez-Baggethun, E., Gonzalez-Jimenez, D., Houdet, J.I., Keune, H., Kumar, R., Ma, K., May, P.H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B.B., Belt, M., Verma, M., Wickson, F., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability 26, 7–16.
Potts, S.G., Imperatriz-Fonseca, V.L., Ngo, H.T., 2016. The assessment report on pollinators, pollination and food production. IPBES.
Raymond, C.M., Bryan, B.A., MacDonald, D.H., Cast, A., Strathearn, S., Grandgirard, A., Kalivas, T., 2009. Mapping community values for natural capital and ecosystem services. Ecol. Econ. 68, 1301–1315.
Ricketts, T.H., Daily, G.C., Ehrlich, P.R., Michener, C.D., 2004. Economic value of tropical forest to coffee production. Proc. Natl. Acad. Sci. U.S.A. 101, 12579–12582.
Roubik, D.W., 2002. The value of bees to the coffee harvest. Nature 417, 708.
Small, N., Munday, M., Durance, I., 2017. The challenge of valuing ecosystem services that have no material benefits. Glob. Environ. Chang. 44, 57–67.
SNUC - Sistema Nacional de Unidades de Conservacaõ, 2000. Brazilian Law N. 9.985 from July 18th 2000.
Soberon, J.M., Sarukhan, J.K., 2009. A new mechanism for science-policy transfer and biodiversity governance? Environ. Conserv. 36, 265–267.
Souza-Filho, P.W.M., Souza, E.B., Silva-Júnior, R.O., Nascimento, W.R., Mendonça, B.R.V., Guimarães, J.T.F., Dall'Agnol, R., O Siqueira, J., 2016. Four decades of land-cover, land-use and hydroclimatology changes in the Itacaiúnas River watershed, southeastern Amazon. J. Environ. Manag. 167, 175–184.
Velthuis, H.H.W., Van Doorn, A., 2006. A century of advances in Bumblebee domestication and the economic and environmental aspects of its commercialization for pollination. Apidologie 37, 421–451.

Watson, J.E.M., Evans, T., Venter, O., Williams, B., Tulloch, A., Stewart, C., Thompson, I., Ray, J.C., Murray, K., Salazar, A., McAlpine, C., Potapov, P., Walston, J., Robinson, J.G., Painter, M., Wilkie, D., Filardi, C., Laurance, W.F., Houghton, R.A., Maxwell, S., Grantham, H., Samper, C., Wang, S., Laestadius, L., Runting, R. K., Silva-Chávez, G.A., Ervin, J., Lindenmayer, D., 2018. The exceptional value of intact forest ecosystems. Nature Ecology and Evolution 2, 599–610.
Wolowski, M., Agostini, K., Rech, A.R., Varassin, I.G., Maués, M., Freitas, L., Carneiro, L.T., Bueno, R.O., Consolaro, H., Carvalheiro, L., Saraiva, A.M., Silva, C.I., 2019. Relatório temático sobre polinização, polinizadores e produção de alimentos no Brasil. Cubo, São Carlos.
Wratten, S.D., Gillespie, M., Decourtye, A., Mader, E., Desneux, N., 2012. Pollinator habitat enhancement: benefits to other ecosystem services. Agric. Ecosyst. Environ. 159, 112–122.