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Article *in* Agriculture Ecosystems & Environment · May 2013

DOI: 10.1016/j.agee.2013.03.003

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Agriculture, Ecosystems and Environment 171 (2013) 39–46

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Identifying the areas to preserve passion fruit pollination service in Brazilian Tropical Savannas under climate change

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ARTICLE INFO

Article history:
Received 22 October 2012
Received in revised form 28 February 2013
Accepted 8 March 2013
Available online 17 April 2013

Keywords:
Agriculture
Apidae
Conservation
Forage plants
Pollinators
Xylocopa

ABSTRACT

The aim of this study was to identify future distribution areas and propose actions to preserve passion fruit pollination service under a scenario of future climate change. We used four species of *Xylocopa* bees that are important for passion fruit pollination in Brazilian Tropical Savannas. We also used the known forage plant species (33 species) that are associated with this same area, since passion fruit flowers provide only nectar for bees and only during their blossoming period. We used species distribution modeling to predict the potential areas of occurrence for each bee and plant based on the current day distribution and a future climate scenario (moderate projections of climate change to 2050). We used a geographic information system to classify the models and to analyze the future areas for both groups of species. The current day distribution map showed that *Xylocopa* and plant species occurred primarily in the southern and central-eastern areas of the Brazilian Tropical Savannas. In the north, *Xylocopa* species only occurred in a small area between the states of Maranhão and Piauí while forage plant species were only observed in the northern part of the Tocantins State. However, both future scenarios (bees and plants) showed a shift in distribution, with occurrence predominantly detected in the northern areas of Brazilian Tropical Savannas. Possible conservation areas and the use of appropriate agricultural practices were suggested to ensure the maintenance of the bee/plant focal species.

1. Introduction

Ecosystem services are the benefits delivered directly or indirectly to humans by natural ecosystems (Daily, 1997; MEA, 2005). Ecosystem services have been considered to be an important link between key scientific organizations, environmental policy bodies and research funding organizations (Larigauderie and Mooney, 2010), aiming to build the capacity to use science in policy making and decisions (Perrings et al., 2011).

Pollination is considered a key element of ecosystem services (Costanza et al., 1997; Daily, 1997). Ollerton et al. (2011) estimated that the proportion of animal-pollinated species is near 78% in temperate zone communities and 94% in tropical communities and that the global number of animal-pollinated angiosperms is near 300 000, 87.5% of the estimated species-level diversity of flowering plants. Pollination is also considered fundamental in ensuring the production of food because one-third of agricultural production depends on animal pollination (Kremen et al., 2007). Although the crops that have the greatest production volume (e.g. rice and wheat) are wind-pollinated, a large proportion of crops with high nutritional value (e.g. fruits and vegetables) are dependent of pollinators (Potts et al., 2010).

The decline of pollinators has been noted since the mid-1990s (Buchmann and Nabhan, 1996; Kearns et al., 1998). Recently, multiple drivers (including the loss and fragmentation of habitats, aggressive agricultural practices, pathogens, invasive species and climate change) were identified as the primary cause of this decline

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0167-8809/$ – see front matter
http://dx.doi.org/10.1016/j.agee.2013.03.003

(Potts et al., 2010; Schweiger et al., 2010). Climate change was proposed as the probable cause of pollinator decline in studies based on data from historical surveys of pollinators (Biesmeijer et al., 2006; Dupont et al., 2011).

Species distribution modeling (SDM) has been used to investigate the impact of climate change on the geographic distribution of species (Franklin, 2009). This tool has different names, such as ecological niche modeling or habitat suitability modeling. It uses the known occurrences of species and different environmental variables to define a set of suitable conditions under which the species can maintain viable populations (Peterson et al., 2011).

The data needed for SDM includes biological and environmental information. The best conditions of both datasets to perform SDM include the following features (Franklin, 2009): (1) Biological data (reported occurrence points): designed surveys often produce data that is more appropriate to SDM than random ones; larger samples improve models and can help to correct noisy and biased data; whenever possible, a balance of presence and absence data must be achieved; the extent of study area has to be a good representative of the real extent of distributional area; biological surveys can be repeated regularly and provide useful information about species distribution on different time periods; existing data provided by biological collection must be examined for spatial and taxonomic bias; since the distribution of most species are still poorly known, one of the main challenges is the lack of sufficient number of observations to perform SDM. (2) Environmental data (environmental layers): SDM can use broad scale climatic variables where extremes of temperature and precipitation are often more related to limited species growth and survival than annual averages; finer scales factors derived from topographic data can also be included; SDM for animal species can include predictors related to food or water availability, if applicable; vegetation type or landscape structure can also be used as predictors. SDM has been used successfully to guide searches for and discovery of unknown populations and occurrence areas of species; conservation application, aiming to provide effective guidance for conservation actions; projections of climate change impact; estimate susceptible areas to species invasion; determine the geography of disease transmission and; link ecological niches with evolutionary processes (Peterson et al., 2011).

With the goal of determining conservation areas, SDM has been used to investigate localities in which species will find suitable habitats in the future. For example, SDM was used to assess the adequacy of conservation areas to protect endemic birds (Marini et al., 2009) and odonates (Nóbrega and De Marco, 2011) in the light of future scenarios of climate change. SDM has also been used to define suitable habitats and identify potential areas for conservation of a threatened species (*Heloderma horridum*) (Domíguez-Vega et al., 2012) and to guide a restoration program for American chestnut (*Castanea dentata*) (Fei et al., 2012).

Certain crops are particularly dependent on bee pollinators. This is the case for passion fruit crops (Souza et al., 2004). The pollinator species richness (Yamamoto et al., 2012), abundance (Camillo, 2003) and frequency of visitation (Benevides et al., 2009) have been proved to increase the fruit set in passion fruit orchards. Brazil is the largest producer of passion fruit in the world, and its trade is important to the Brazilian economy, with most of the production based on *Passiflora edulis* Sims (Meletti and Brückner, 2001). The Brazilian production of passion fruit reached almost one million tons in 2010 (IBGE, 2011). Passion fruit flowers can be manually pollinated, but natural pollination is cost free and increases the quality and quantity of fruits (Roubik, 1995), providing higher income and giving value to this commodity. Furthermore, the crop is produced primarily by small farms and family farming (Meletti, 2011). These characteristics provide a good opportunity for the implementation of pollinator-friendly management in the light of agricultural practices and the impact of climate change.

Passion fruits are pollinated by large bees, usually species of *Xylocopa*, *Bombus*, *Centris*, *Epicharis* and *Eulaema* (Camillo, 2003; Hoffmann et al., 2000; Malerbo-Souza et al., 2002; Sazima and Sazima, 1989). *Xylocopa* Latreille, 1802 (Apidae) species are considered the most effective pollinators due to their size and foraging behavior involving the flowers (Sazima and Sazima, 1989). *Xylocopa* bees are also known as "carpenter bees" due to their nesting habit of excavating tunnels in wood (Hurd, 1958). However, passion fruit flowers provide only nectar (Camillo, 2003) and do so only during their blossoming period. Thus, bee species require extra sources of nectar in seasons other than the season in which the passion fruit are flowering and need extra pollen sources to feed their offspring. As a result, the pollinators depend on resources from other plant species. Therefore, the delivery of passion fruit pollination services depends on both the pollinator bees and the plants on which they forage.

The principal objective of this study was to identify future distributional areas for the *Xylocopa* bees as passion fruit pollinators and their forage plants in the Tropical Savanna areas of midwestern Brazil under a realistic climate change scenario.

2. Materials and methods

The study was performed in the area of Brazilian Tropical Savanna (BTS) (Fig. 1). We used the biome classification in Olson et al. (2001) to specify the study area. To characterize and discuss the status of current vegetation coverage of BTS, we used the database of Bontemps et al. (2010), which shows the global land cover for 2009. To depict the current conservation areas, we used a dataset available on the IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) website. To determine the municipalities within BTS where passion fruit was cultivated during the last twenty years, we used an agricultural dataset available on the IBGE (Brazilian Institute of Geography and Statistics) website.

We chose the midwestern areas of Brazil because the interactions between passion fruit pollinator bee (Yamamoto et al., 2012) and forage plant species were determined in a previous field study that was conducted over a year in four localities inside BTS (Silva et al., 2010). Based on this previous study, we chose four *Xylocopa* species (*X. frontalis* Olivier, *X. suspecta* Moure & Camargo, *X. hirsutissima* Maidl and *X. grisescens* Lepeletier) and 33 plant species that were important sources of nectar and pollen for these bees (Silva, 2009) (see Table 1 for the list of plant species). These four species were considered as effective pollinators and presented a relative frequency of visitation of 12.8% (*X. frontalis*), 11.5% (*X. suspecta*), 1.3% (*X. grisescens*) and 0.2% (*X. hirsutissima*) (Yamamoto et al., 2012). Other effective pollinators in the same area were: *Acanthopus excellens* Schrottky (0.5%), *Bombus pauloensis* Friese (2.7%), *Centris denudans* Lepeletier (0.3%), *Centris scopipes* Friese (4.8%), *Centris sponsa* Smith (0.03%), *Centris longimana* Fabricius (1.2%), *Epicharis flava* Friese (0.5%) and *Eulaema nigrita* Lepeletier (0.3%).

To perform SDM, we compiled a dataset based on the literature and Internet data sources for the occurrence (see Appendices A1 and A2 for bees and plants data sources, respectively, and Appendix B for details about plant species). We also used 19 layers of bioclimatic variables that consider the temperature and precipitation averages of the last 50 years, with a resolution of 30″ (Hijmans et al., 2005). We used the same layers for the year 2050 in a future projection to address a scenario of climate change. This future scenario was created by the CCCMA (Canadian Centre for Climate Modelling and Analysis) (Ramirez and Jarvis, 2008) and includes a moderate climate change scenario (A1B – IPCC, 2001). The moderate scenario (A1B) seems to be more adequate to be used in this case study when one considers the storyline of Intergovernmental Panel of Climate Change (IPCC) and the Brazilian politic-economic

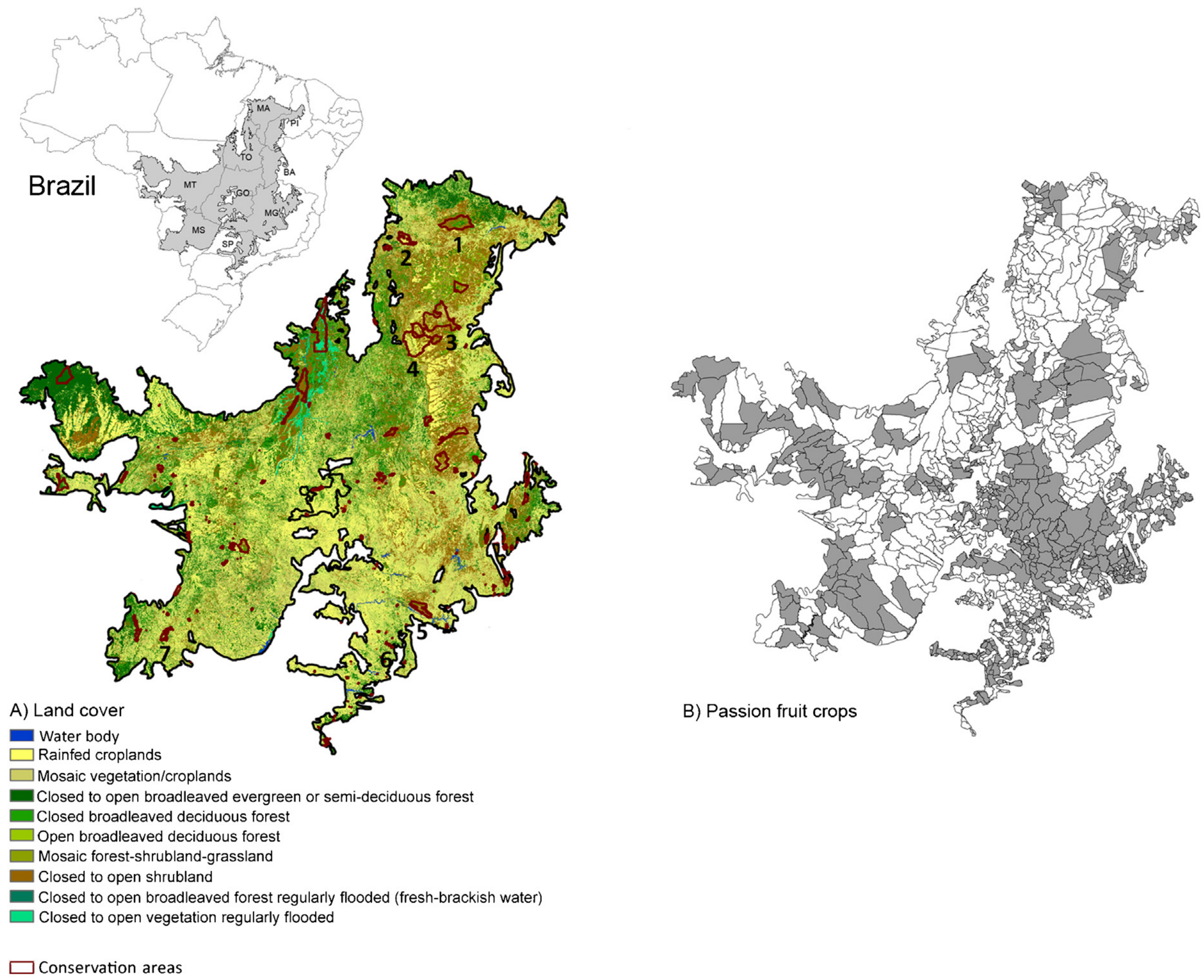

Fig. 1. Tropical Savannas in the midwestern areas of Brazil (according to Olson et al., 2001) showing (A) the land cover in 2009 (Bontemps et al., 2010) and conservation areas: 1. Mirador, 2. Mesas, 3. Nascentes do Parnaíba, 4. Serra do Tocantins, 5. Canastra, 6. Jataí, and 7. Maracaju (IBAMA – Brazilian Institute of Environment and Renewable Natural Resources); (B) the municipalities that produced passion fruit during 2000–2010 (according to IBGE – Brazilian Institute of Geography and Statistics). MA – Maranhão State, PI – Piauí, MG – Minas Gerais, BA – Bahia, TO – Tocantins, GO – Goiás, MT – Mato Grosso, MS – Mato Grosso do Sul, SP – São Paulo.

reality: "A1B describes rapid economic development and growth, with balanced technological development across all sources, i.e. neither fossil intensive nor all non-fossil sources" (Cameron et al., 2012).

We used the Maxent algorithm, which estimates a target probability distribution by finding the probability associated with the maximum entropy (or the closest to a uniform distribution) (Phillips et al., 2006). The Maxent approach is useful primarily because it can be applied to analyze small and presence-only datasets (Wisz et al., 2008). The area under the curve (AUC) of the receiver-operating graph (ROC) was used to estimate the success and failure of the prediction during the modeling process with a set of test data (30% of the data) (Fielding and Bell, 1997). The AUC values vary from 0 to 1. A value of 1 indicates the highest accuracy.

The output of Maxent represents the occurrence probability for each grid cell used in the model. We classified these probabilities into three categories: high probability, corresponding to the cells that show a predicted probability of presence of more than 75%; medium probability, corresponding to a range of probabilities of 50–75%; and minimum probability, representing probabilities less than 50%. We classified all of the models of all of the species using these three classes.

We first compared the total frequency of pixels with the maximum occurrence probability (>75%) obtained for the current and 2050 scenarios per species. Based on this information, we evaluated the change in the amount of suitable area for each species based on the future scenario of climate change. Because our objective was to determine future suitable areas to protect species, we used the highest probability of occurrence to avoid spending resources to preserve species in unsuitable areas (Araújo and Peterson, 2012).

We then overlapped the areas of maximum probability for all of the bee species to build the final models; we performed the same overlapping with the models of all of the plant species. The purpose of this procedure was to build a representation of the total area that shows the highest suitability both for all passion fruit pollinator bees and for their forage plants. We considered the same procedure to forecast the future potential occurrence according to the postulated scenario of climate change.

Finally, we overlapped the current and future models of bees and plants to identify the areas in which both groups of species are potentially present now and the areas in which they will occur under the future scenario. This procedure aimed to identify potential areas for preserving these species. All of the procedures involving the maps obtained through modeling were performed with ArcGIS 10 (Esri Inc.).

3. Results

A total of 678 occurrence points were found for *Xylocopa* bees and 7 450 for plant species (see Appendices A1 and A2 for bees

Table 1
Shift in the percentage of the highest occurrence probability areas (total number of pixels) of each forage plant and *Xylocopa* bee species, given a moderate (A1B) scenario of future climate change for the year 2050 (negative value indicates potential loss of suitable area and positive, gain).

Species	Percentage
Ouratea spectabilis	−95.2
Myrcia canescens	−93.0
Vernonia fruticulosa	−92.4
Qualea multiflora	−89.6
Styrax ferrugineus	−88.7
Solanum lycocarpum	−75.9
Fridericia florida	−74.5
Microlicia isophylla	−71.7
Vochysia tucanorum	−71.2
Dalbergia misclobium	−67.3
Caesalpinia peltophoroides	−64.4
Senna rugosa	−59.6
Eriotheca gracilipes	−58.9
Kielmeyera coriacea	−57.7
Palicourea rigida	−57.6
Bauhinia brevipes	−56.9
Copaifera langsdorffii	−51.6
Campomanesia adamantium	−49.6
Chamaecrista viscosa	−45.3
Cuspidaria pulchra	−44.3
Senna occidentalis	−34.3
Senna velutina	−28.3
Eugenia calycina	−27.1
Heteropterys escalloniifolia	−4.8
Kielmeyera rubriflora	6.7
Senna obtusifolia	12.1
Davilla elliptica	18.4
Byrsonima intermedia	18.4
Bidens gardneri	22.1
Byrsonima basiloba	24.1
Byrsonima pachyphylla	37.4
Crotalaria micans	47.3
Solanum paniculatum	56.8
X. hirsutissima	−93.7
X. suspecta	−19.8
X. grisescens	−9.3
X. frontalis	−0.4

and plants data sources, respectively). Brazilian herbaria have important collections all over the country and most of them were available on the Internet; thus the plant data were considered of good quality. On the other hand, there were less data available for bees, especially in the Midwestern area of Brazil; nevertheless, maps obtained and used for *Xylocopa* species distribution covered most of their known range.

The models obtained for all of the species exhibited AUC values greater than 0.9 (details of the AUC value for each species model can be found in the Appendix C), indicating that the models can be considered accurate.

The future scenario suggested that the habitat areas for most of the species will decrease severely (Table 1). The shift in the total frequency of pixels per species demonstrated the greatest decrease in the distribution areas of plants under the future scenario. For example, 18 plant species showed a decrease of more than 50% in the areas with the highest potential of occurrence. Three of these plant species are endemic to Brazil (*Dalbergia misclobium* Benth., *Microlicia isophylla* DC. and *Ouratea spectabilis* (Mart. ex Engl.) Engl.), and 8 of them are sources of pollen for *Xylocopa* species. Three species (*O. spectabilis*, *Myrcia canescens* O. Berg and *Vernonia fruticulosa* Mart. ex DC.) showed a reduction of more than 90% in their distribution areas. *Solanum lycocarpum* A. St.-Hil. and *Senna rugosa* (G. Don) H.S. Irwin & Barneby, two particularly important sources of pollen (Silva et al., 2012), showed decreases of more than 70% and 50%, respectively. However, nine species showed an increase in their occurrence areas according to the future scenario; three of these species belong to *Byrsonima* (Malpighiaceae) that includes species that are distributed over broad areas and that are pollen sources for *Xylocopa*.

Of the *Xylocopa* species examined, *X. frontalis* was the only bee species that showed almost no variation in its potential occurrence under the future scenario. The areas of potential occurrence of *X. hirsutissima* decreased by approximately 90%, although two other bees (*X. suspecta* and *X. grisescens*) showed decreases of less than 20% (19 and 9%, respectively) (Table 1).

The present day model for *Xylocopa* showed that the bees occurred primarily in the southern part of the BTS (Fig. 2A1). In the north, a small area in Maranhão and Piauí States also showed a high potential of occurrence. However, the future scenario for the distribution of the bees involved a potential shift (Fig. 2B1). The northern BTS areas will also be suitable for these bees under future scenarios of climate change, increasing almost 10 times (see Appendix D for details). The northern and southern areas will be united by a central area of potential occurrence. This area passes primarily through the states of Goiás and Tocantins. A comparison of both models (present day and future, Fig. 2A1 and B1, respectively) suggested that an increase in the total area of distribution of *Xylocopa* will occur in the future because the distributions of two species (*X. frontalis* and *X. suspecta*) will shift toward the northern areas of the BTS (see the details of each *Xylocopa* species model in the Appendix E). Therefore, despite the potential loss of area per bee species, the total area of the future distribution of all of the bees will increase.

The present day model for plant species showed a broader distribution than that for the bees (Fig. 2A1). The areas with the highest probability of occurrence extended toward the north, showing a continuous diagonal pattern of distributional areas through the center of Mato Grosso do Sul, Goiás and Bahia States. However, this diagonal pattern will be affected substantially under the future scenario (Fig. 2B1), and the potential distribution will extend from the south toward the north through areas of the central BTS, primarily through Goiás and Tocantins States. The predictions for the plant species differed from those for the bee species. The plant species will experience a decrease in the total area showing the highest probability of occurrence, and this decrease will be more severe in the southern areas for approximately 4 times (see Appendix C).

The present day areas with the highest probability of bee and plant occurrences showed a pattern in which areas that include both the bees and the plants ("common areas") are most evident in the central-south region, covering most of the southern areas of the BTS (Fig. 3A). In contrast, the future common areas with the highest probability occur primarily in the northern and central areas of the BTS (Fig. 3B), with only a few fragments of habitats in the south, common to both groups of species. However, there is a continuous vertical line of highest probability that extends from south to north, beginning in São Paulo State and extending toward Maranhão and Piauí. It is possible that this linear feature could represent an important area for the protection of these species.

4. Discussion

In this study, we found that both plant and pollinator species associated with passion fruit will experience decreases in their distribution ranges with climate change over the next 40 years, particularly in the southern part of the study area. This finding is consistent with the results of a previous study that investigated the general impact of climate change on plant species in the same biome (BTS). Based on two different scenarios and 162 species of trees, Siqueira and Peterson (2003) showed losses of more than 50% of the potential distribution areas. We are aware of only three previous studies that analyzed future scenarios of climate change for bee

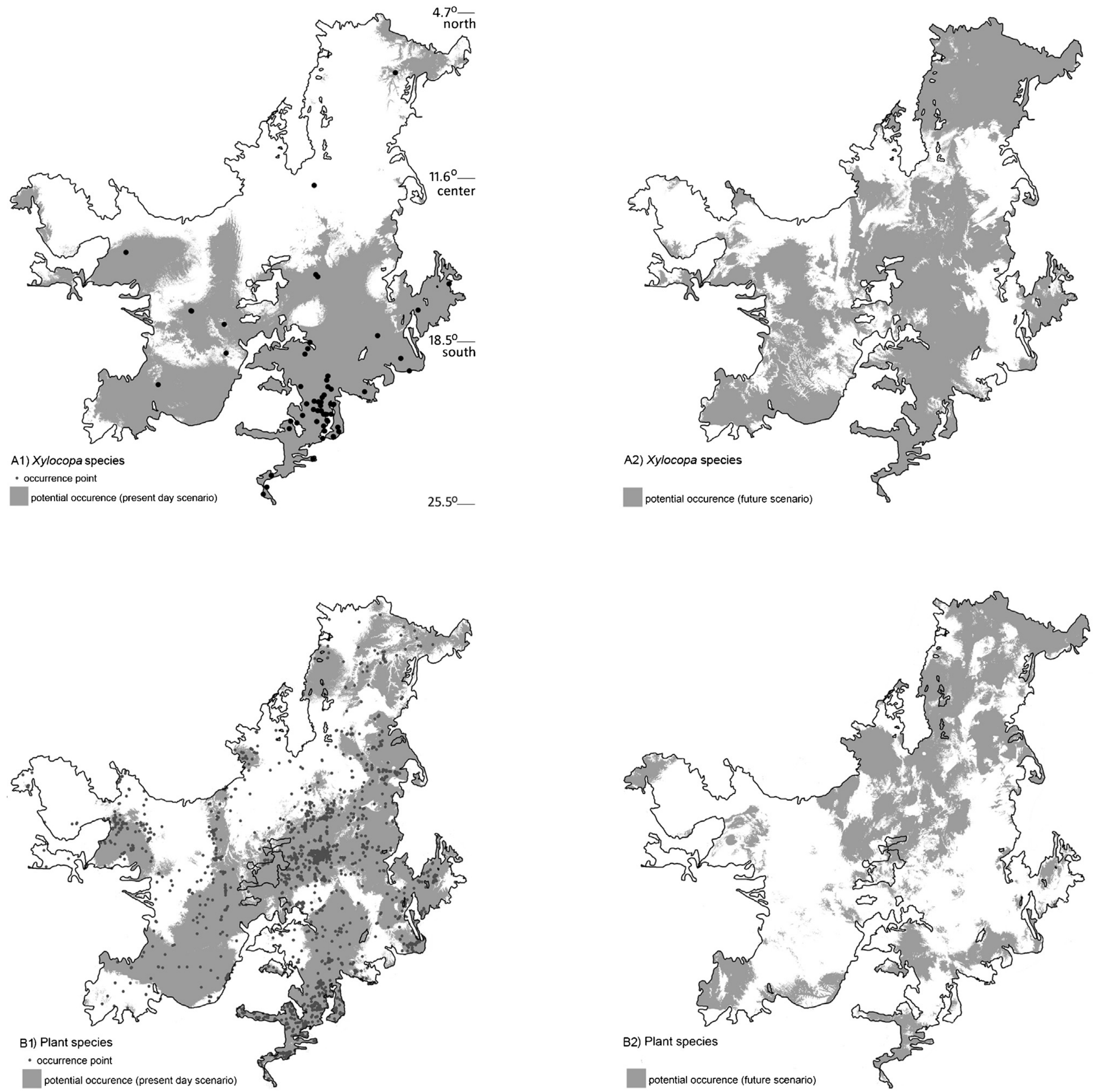

Fig. 2. Potential areas with the highest occurrence probability for (A1) four species of *Xylocopa* at the present day and (A2) future forecast and (B1) 33 plant species at the present day and (B2) future forecast. The four *Xylocopa* species considered were *Xylocopa frontalis*, *Xylocopa grisescens*, *Xylocopa hirsutissima*, and *Xylocopa suspecta*. A moderate scenario for 2050 was used to forecast the future scenario. The list of plant species used for foraging by each *Xylocopa* species can be found in Table 1.

species. Only one of these studies analyzed Brazilian species that are related to agricultural crops, and this study showed a decrease in suitable areas for almost all species (Giannini et al., 2012). In a region of South Africa, a range contraction between 30% and 90% for six bee species under future scenarios of climate change was found (Kuhlmann et al., 2012). In Europe, a potential reduction of occurrence areas for species of *Colletes* was also showed (Roberts et al., 2011).

The shift of the potential occurrence areas in the BTS from south to north should also be considered. Our results showed that, although the total area covered by the four bee species broadened to include most of the BTS in the future, the plant species would occur primarily in the northern areas. This situation represents a potential deficit of foraging resources, particularly for *X. grisescens*, which will remain primarily in the south. In addition, according to our model, *X. hirsutissima* currently occurs primarily in the southern areas and will be severely affected by climate change. In the future, only a small area of distribution will remain for this species. Therefore, although presenting a small relative frequency of flower visitation in the BTS (Yamamoto et al., 2012) it is necessary to consider the preservation of floral resources in these remaining southern areas to protect these two *Xylocopa* species. Other studies have discussed the mismatches in the geographic correspondence of interacting species due to climate change, highlighting the potential disruption of interactions and their consequences (Schweiger et al., 2008; Stralberg et al., 2009). As already noted, systems involving interacting species cannot be addressed by simply analyzing the impact of climate change on each species. Therefore, to protect these species, the resilience of the entire system has to be considered (Gilman et al., 2010).

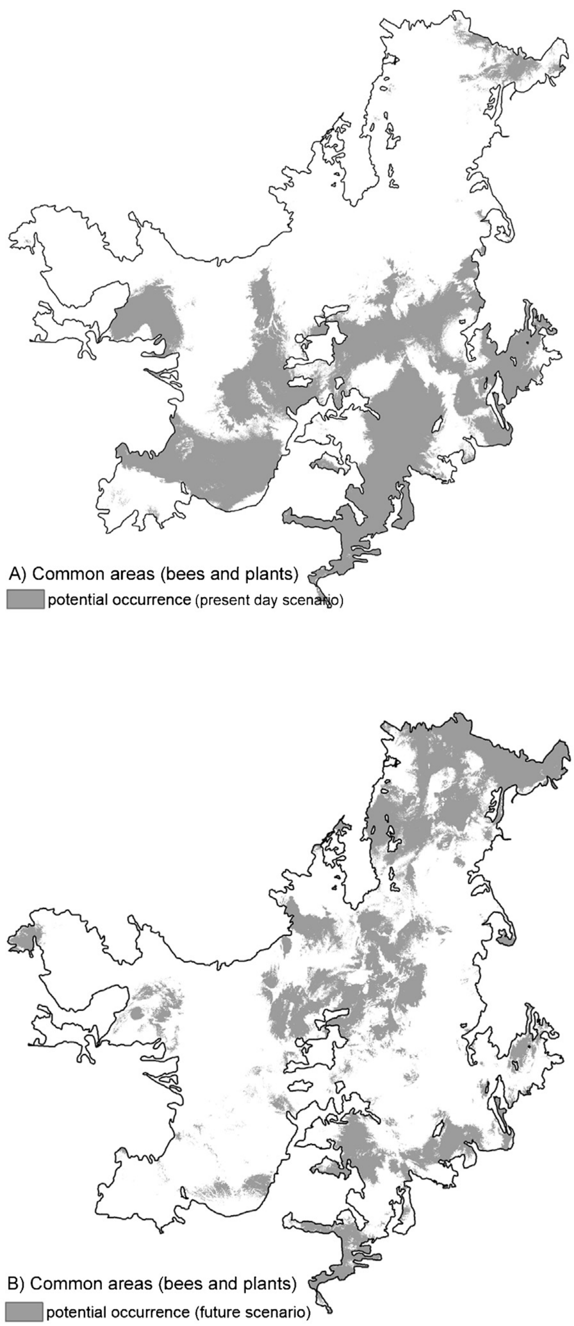

Fig. 3. Common areas with the highest probability of occurrence for *Xylocopa* bees and their forage plant species (A) under the present day scenario and (B) under a moderate future scenario for the year 2050.

The areas remaining in the future for both groups of species (bees and plants), as represented by the vertical line extending from the south to north in the center of the BTS, currently shows different types of vegetation coverage. The southern areas are covered primarily with mosaics of pastures and croplands, whereas the northern areas are covered with this same type of vegetation and also with closed (perhaps natural) vegetation (Bontemps et al., 2010). These potential areas can be considered suitable for the sustainable management of passion fruit crops because the pollinators will find both suitable climate conditions and their forage plants.

The BTS region faces severe threats, primarily as a result of harmful agricultural and livestock practices (Klink and Machado, 2005), and only 8% of the total BTS area is under national protection (MMA, 2010). However these protected areas are few and are not connected, and several other areas were previously proposed with the aim of preserving tree diversity in the face of climate change (Siqueira and Peterson, 2003). Based on the results presented here, new protected areas can be further analyzed aiming to preserve the remaining areas highlighted by the model. The purpose of proposing additional protected areas is to ensure connectivity between the areas of concern. The primary focus of these new areas would be the future distribution areas in the south. These areas would be preserved to protect several plant species as an essential resource for the *Xylocopa* species that will remain in these areas in the future. The central areas located between the southern and northern regions, as highlighted by the modeling, can also be considered to ensure the connectivity of future distribution areas.

In addition, particular agricultural practices can help to protect the essential pollination services for the production of passion fruit. For example, managed areas with the forage plant species analyzed in this study can be placed inside or near passion fruit croplands, especially those that will be more resistant to climate change. A diverse mixture of plant species can be considered, particularly those that bloom at different times and provide a sequence of resources throughout the year, complementing the blooming period of the passion fruit crop. Additionally, if there are natural patches inside the cropland, these can also be managed to include plant species that provide pollen and nectar for the passion fruit pollinators within them or along their borders. Hedgerows can be used to protect the passion fruit crops from winds and the loss of soil humidity (Vaughan and Skinner, 2008) and to provide nest sites for bees (Hannon and Sisk, 2009). Windbreaks and shelter belts provide good sites for nesting structures for bees and can help to reduce the drift of insecticides (Vaughan and Skinner, 2008). These rows can also use the same plant species to provide resources to the *Xylocopa* bees and can serve to connect the patches of managed habitats, thus ensuring the movements of bees between different areas. Standing dead trees may be kept in natural areas to provide nests for the bees, and artificial nests can be placed inside the managed or the natural areas (Vaughan and Skinner, 2008). For example, a *Xylocopa* nesting box was developed by Freitas and Oliveira Filho (2001). The use of this nesting box in a passion fruit crop increased the frequency of *X. frontalis* flower visitation (Freitas and Oliveira Filho, 2003). Trap-nests constructed of bamboo canes were also used for *X. frontalis* and *X. grisescens* (Pereira and Garófalo, 2010). To avoid the effects of sun and rain, it is most appropriate to place these nesting sites under a protective cover (Silva et al., 2012).

5. Conclusions

Passion fruit pollination service in Brazilian Tropical Savannas will be affected in the next future 40 years by climate change. Most plant and bee species will reduce their habitat areas and will shift toward the northern region. However, an extensive area will remain, and this area should be considered for action plans to preserve the pollinator bees and their forage plants. These management practices must be performed in the light of the cumulative scientific knowledge about the impact of habitat and climate changes, particularly in terms of plant–pollinator interactions. In addition, management must consider public policies that incorporate this knowledge, aiming at promoting the economic development of farmers and ensuring the production of food without decreasing biodiversity. A collaborative approach integrating economic, social and environmental issues is of crucial importance to guarantee and improve the pollination service in these times of rapid change.

Acknowledgments

The authors are grateful to Jean Paul Metzger, Paola Marchi and two anonymous referees. Also to FAPESP (04/15801-0, 11/12779-9), CNPq (575069/2008-2), FAPEMIG and Research Center on Biodiversity and Computing (BioComp).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2013.03.003.

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