Volume **32** (2022) 01-08 www://ub.edu.bi/JUB

Understanding the impact of urbanization on the ecology and diversity of insect pollinators for a better biodiversity management in tropical ecosystems

Déogratias Nduwarugiraa[1, 2,*], Lin Mizero[2], Didier Mbarushimana[3], Longin Ndayikeza[2, 3]

[1] Département de Biologie, Faculté des Sciences, Université du Burundi, Bujumbura, BP 2700 Burundi
[2] Centre de Recherche en Sciences Naturelles de l'Environnement (CRSNE)
[3] Office Burundais pour la Protection de l'Environnement (OBPE)
*** Auteur de correspondance: Email / deogratias.nduwarugira@ub.edu.bi**

Reçu: le 02 mars 2022
Accepté pour publication: 25 mars 2022
Publié en ligne pour la première fois: 31 mars 2022

Abstract

Across the world, there is an increased urban expansion leading to the disappearance of ecosystems and disruption of ecological balances. Very little is known about the effects of the transformation of rural landscapes in urban areas on fauna of many African ecosystems. The main objective of the study was to assess the impact of urbanization on insects playing an important role in plant pollination. The case of Bujumbura urbanization, the main town of Burundi, was taken as a model. We collected insect pollinators and their host-plants in two sites located in an urban area and a peri-urban area, respectively. Student paired tests were performed to compare the abundance of the pollinators between the two landscapes. The specific richness of insect pollinators was higher in the peri-urban area than in the urban environment. The preference of the peri-urban area by pollinators could, probably, result from its high richness in plants which may provide them food sources, reproductive sites, and a favorable microclimate. Our research also confirmed that urbanization contributes to the restructuration of local assemblages, with emergence of taxa adapted to the new environment. Understanding the ecological adaptation of pollinators in ecosystems subjected to human transformation may serve as a guide to integrating the management of specific taxa and their habitats, especially in urbanization planning.

Keywords: *Pollination, Biodiversity, Urbanization, Host-plant, Ecosystem.*

Résumé

Partout dans le monde, on assiste à une expansion urbaine accrue entraînant la disparition des écosystèmes et la perturbation des équilibres écologiques. On sait très peu sur les effets de la transformation des paysages ruraux en zones urbaines sur la faune de nombreux écosystèmes africains. L'objectif principal de l'étude était d'évaluer l'impact de l'urbanisation sur les insectes jouant un rôle important dans la pollinisation des plantes. Le cas de l'urbanisation de Bujumbura, la capitale du Burundi, a été pris pour modèle. Nous avons collecté des insectes pollinisateurs et leurs plantes-hôtes dans deux sites situés respectivement en zone urbaine et en zone périurbaine de Bujumbura. Des tests de Student appariés ont été effectués pour comparer l'abondance des pollinisateurs dans les deux paysages. La richesse spécifique des insectes pollinisateurs était plus élevée en zone périurbaine qu'en milieu urbain. La préférence de la zone périurbaine par les pollinisateurs pourrait, probablement, résulter de la grande richesse de ce milieu en plantes pouvant leur fournir des sources de nourriture, des sites de reproduction et un microclimat favorable. Nos recherches ont également confirmé que l'urbanisation contribue à la restructuration des assemblages locaux, avec l'émergence de taxons adaptés au nouvel environnement. Comprendre l'adaptation écologique des pollinisateurs dans les écosystèmes soumis à la transformation humaine peut servir de guide pour intégrer la gestion de taxons spécifiques et de leurs habitats, en particulier dans la planification de l'urbanisation.

Mots clés: *Pollinisation, Biodiversité, Urbanisation, Plante-hôte, Ecosystème.*

1. Introduction

There is a complementarity of ecosystem components, particularly interactions between animal and plant species (Chagnon M., 2008). For instance, by foraging from one flower to another, bees provide a very important service to plants, the pollination (Michener D.C., 2007). Plants benefit from the transport of pollen by bees and in return, the bees benefit from the nectar and pollen. This symbiosis ensures the reproduction and genetic diversity necessary for the evolution of plants, while for insects, the collection of nectar and pollen is essential for their nutrition (Michener D.C., 2007; Rhoné F. *et al.*, 2016; Tooker J.F. *et al.*, 2002). Insufficient pollination is responsible of the decrease in the fruit set rate (transformation of the ovary into fruit), and the fruit deformation or their drop before maturity (Nzigidahera B. & Fofo A., 2010). Nevertheless, famers and researchers are concerned about the decline of pollinators in ecosystems around the world, linked especially to fragmentation and loss of habitats, use of pesticides, invasive species and light pollution (Potts S.G *et al.*, 2010). The fragmentation and loss of habitats are the main factors in biodiversity disappearance, especially in tropical Africa where biodiversity hot spots are being encroached upon by fast-growing cities (Guenat S. *et al.*, 2008). Artificialization and pollution which become more intense in cities harm biodiversity in general and insect pollinators in particular, which lose their food resources as well as their breeding sites (Lemoine G., 2016). The transformation of rural landscapes for urbanization, intensifying road networks and creating industrial zones have resulted in the disappearance of many biotopes and the disruption of ecological balances, particularly between plants and pollinators (Pouvreau A., 1993). Few data on pollinators of some forest and agricultural ecosystems of Burundi have already been provided by Nzigidahera B. & Fofo A. (2010), Ndayikeza L. et al. (2014a, b) and Pauly A. *et al.* (2015). However, very little is known on the local urban pollinators and the effects of actual urbanization on the ecology and diversity of this group. According to the projections, Burundi had an urbanization level of 13% in 2018 that will increase to 27.9% in 2050 (United Nations, 2019). This fast rising demography undoubtedly has repercussions on the structure of the biodiversity of the landscape matrix.

The general objective of the study was to assess the impact of the expansion of the Bujumbura city on pollinator populations to contribute to the safeguard of this biodiversity of capital importance within ecosystems. Concretely, in the study area, the specific objectives of this work were to (i) identify the species of insect pollinators and (ii) identify the plants potentially host to pollinators in the study area.

The results of this study will contribute to improving the database on pollinators of Burundi. They could particularly serve as a guide for the local authority in urban planning by integrating conservation of pollinators, organisms playing a key role in the life and functioning of ecosystems.

2. Material and methods

2.1. Study area

Sampling took place in Bujumbura (3°22′32″S, 29°21′33″E), the capital of Burundi, in the western of the country. It extends on 127 km2, on the shores of Lake Tanganyika, and administratively subdivided into three communes: Muha, Mukaza, and Ntahangwa. According to the national censuses of 1979, 1990 and 2008, the Bujumbura population strongly increased with respectively 168.368; 235.440 and 497.166 inhabitants. Current projections estimate that this population could reach 3.8 million inhabitants by 2050 (ISTEEBU, 2017).

Local climate is characterized by an average annual precipitation of 800 to 1300 mm, with temperatures varying between 23 and 25°C (Bigirimana *et al.*, 2012).

2.2. Sampling design and procedure

Two pollinating insect sampling sites were chosen in the study area:

(1) Site 1 (3°22’28’’S, 29°21’37’’E) located within the National Institute of Public Health (INSP, Burundi) in an urban landscape in the Mukaza commune. The vegetation is mainly representing by fruit trees including avocado trees (*Persea Americana*.), citrus fruits, guava trees (*Psidium guajava*), mango trees (*Mangifera indica*) and ornamental plants such as *Molinga* sp. and *Lantana camara* L. The grassy layer is largely dominated by Acanthaceae, Poaceae (*Brachilaria* sp.), Cyperaceae and Asteraceae (*Bidens pilosa*).

(2) Site 2 (3°21’58’’ S, 29°24’24’’E) situated in a peri-urban landscape in Ntahangwa commune. The vegetation is dominated by herbaceous plants, as well as trees and shrubs like the Lamiaceae (*Ocimum gratissimum*), Fabaceae and Asteraceae (*Bidens pilosa*, *Tithonia diversifolia*), Myrthaceae (*Eucaruptus*), Euphorbiaceae (*Manihot esculenta*), Poaceae (*Hyparrhenia*), Rutaceae (*Citrus*), Rosaceae (*Rubus* sp.), Clasiaceae and Anacardiaceae.

At each sampling site, insect pollinators were sampled using two complementary methods. First, thirty bacs (traps) colored in yellow and filled with water mixed with detergent were placed along a 60 m transect, with 2 m between two consecutive traps. To better understanding the diversity of pollinators and their potential host plants, the insects visiting plants were collected using an entomological net. The use of the entomological net and/or Malaise trap to capture insects is recommended (Durand O. & Coutanceau J.-P., 2015). Thanks to the entomological net method, Kra K.D. et al. (2017) collected a greater number of beetles compared to the use of yellow traps and Barber traps (pitfalls). Moreover, some taxa, particularly the Megachilidae family, are exclusively captured by net because large individuals are able to visualize passive traps (Aguib S., 2014). Sampling took place twice a week, from November 2019 to January 2020. The plant and insect specimens were respectively placed in paper for the herbarium and in tubes containing 80% ethanol for future identification in the lab. Insect specimens were identified microscopically using Picker M. et al. (2004), Marshall S.A. (2006), Eardley C. *et al.* (2010), Ekesi S. & Billah M.K. (2010) and (Marshall S.A. *et al.*, 2017); while the identification of plants potentially host to pollinators was carried out using Troupin G. (1978, 1983, 1985, 1988). Identifications were pursued to the species level whenever possible; otherwise samples were assigned to morphospecies.

2.3. Data analysis

The specific richness and diversity of insect pollinators present in the study area were described with classical diversity indices (Magurran A.E., 1988, 2004): (1°) Chao 1; (2°) Shannon's (eH, where H = Σ pi ln(pi)) and (3°) Simpson's (1/D, where D = Σ pi2), where pi is the proportion of the individuals of species i in the sample; and (4°) Jaccard (J=a/a+b+c) where a is the total number of species present in both samples, b the number of species present only in sample 1, and c the number of species present only in sample 2. Rarefaction curves and diversity indices were calculated with EstimateS v.9.1.0 (Colwell R.K., 2013). We performed Student paired tests to compare the abundance of the insect pollinators recorded in the two study sites. The statistical analyses were carried out using the R version 4.0.2 (R Development Core Team, 2020).

3. Results

3.1. Richness and diversity of insect pollinators in study sites

We recorded a total of 4658 specimens of insect pollinators, representing 40 families, 7 genera and 162 species in the two study sites. None of the two rarefaction curves did not approach a veritable asymptote. Sampling of additional traps might be necessary before a plateau is reached for any site (Fig. 1).

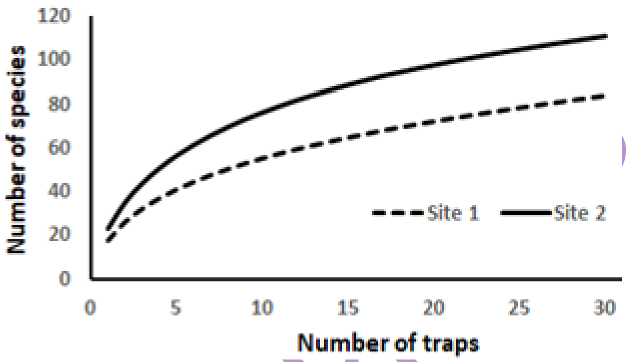

Figure 1. Rarefaction curves for insect pollinators in the two sampling sites

Two orders, *Diptera* and *Hymenoptera*, were the most abundant at the two sampling sites. Seven orders (*Diptera*: 83.28%, *Hymenoptera*: 14.22%, *Coleoptera*: 1.93%, *Lepidoptera*: 0.34%, *Hemiptera*: 0.11%, *Orthoptera* and *Isoptera*: 0.06%) and six orders (*Diptera*: 78.72%, *Hymenoptera*: 18.90%, *Hemiptera*: 1.10%, *Coleoptera*: 0.66%, *Orthoptera*: 0.48%, *Lepidoptera*: 0.28%) were respectively identified at site 1 and site 2. At the family lever, 28 and 35 families were identified at site 1 and site 2, respectively, and the Sarcophagidae, Calliphoridae, Apidae, Haliticidae and Muscidae were most abundant. Halictidae and Apidae were particularly more abundant at site 1 and site 2, respectively. Few Syrphidae were observed at the two study sites. Moreover, the Megachilidae, Lycidae, Arctiidae and Coccinellidae, Nabidae and Silphidae were exclusively collected using the entomological net. Of the 162 species identified during the study, 67 were common to the two sites, 69 specific to site 1 and 26 specific to site 2. The species Dolichopodidae sp.1, Dolichopodidae sp.2, Calliphoridae sp.4 and Lipotriches sp.3 dominated at site 1 while Calliphoridae sp.1, Sarcophagidae sp.1, Sarcophagidae sp.3, *Apis mellifera* L., Sarcophagidae sp.2, Calliphoridae sp.7 dominated at site 2 (Table S1-2).
Overall, it was noted that the median specific richness of the insect pollinators was higher in the site 2 than in site 1, with 23 and 18 species, respectively. Student paired tests confirmed significant differences in specific richness between the two sites (t=5.61, df= 58, P<0.001). Nevertheless, the specific diversity is almost the same for the two sites but they showed a weak similarity in species composition (Table 1, Fig.2).

Table 1. Estimated (Chao 1) species richness and diversity statistics for the two study sites.

Site	Chao 1	Shannon	Simpson	Jaccard
Site 1	120	2.93	0.91	0.41
Site 2	149	2.86	0.88	

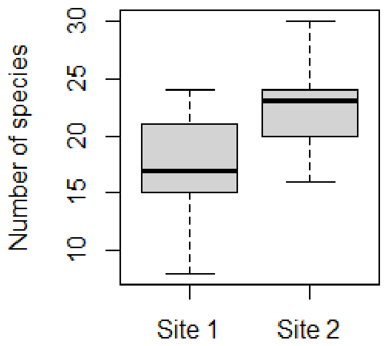

Figure 2. Boxplots showing the median number of species (heavy horizontal lines in the boxes) of insect pollinators in sampling sites. The upper and lower edges of the boxes represent the first and third quartiles.

3.2. Interaction plants – insect pollinators in the study sites

Thirty species of insect potentially pollinating plants were collected from the two study sites. Five species were only observed at site 1 versus 12 species at site 2. In addition, of all pollinators recorded, the honeybee, *Apis mellifera*, seemed to be more active at the study sites. It was observed on 13 plant species at site 2 versus 6 at site 1, respectively. Other abundant species were *Ceratina* sp.2, *Ceratina* sp.3, *Lipotriches hylaoide*s, *Lipotriches* sp.4, Chrysomelidae sp.6, *Toxomerus floralis*, *Fabricius Eristaloides quinquelineatus*, *Eritalinus* sp., Muscidae sp.10, *Paragus borbonicus* and Rhinophoridae sp.1. Twenty-nine plant species visited by insect pollinators were observed in the two study sites, with 10 species at site 1 against 17 at site 2. *Ocimum gratissimum*, *Stylosanthes biflora* and *Stachytarpheta jamaicensis* were particularly more attractive to insect pollinators, with respectively 13; 11 and 9 species. Also, five to seven species of insect pollinators were recorded on *Stachytarpheta jamaicensis*, *Sesamum angustifolium*, *Kilinga bulbosa*, *Bidens elliotii* and *Psidium guajava*.

4. Discussion

4.1. Richness and diversity of insect pollinators in study sites

One hundred and sixty-two species of insect pollinators spread over 40 families and seven orders were recorded in the study area. *Diptera* and *Hymenoptera* were particularly more abundant. In general, *Diptera*, *Hymenoptera*, *Coleoptera* and *Lepidoptera* are naturally better represented in ecosystems and they are also among the main pollinators in the world (Desaegher J., 2017; Das B.J. *et al*., 2018). Predominance of Diptera in pollinating insects was also noted by Chloé P. *et al*. (2017) in Martinican fruit agroecosystems. The families of Sarcophagidae, Calliphoridae, Apidae, Haliticidae and Muscidae were more abundant in both study sites. The abundance of Sarcophagidae and Calliphoridae in our study area could be particularly explained by their ecology requiring an open and warm environment favorable to spawning (Marshall S.A., 2006). In addition, some of their species are indicators of urban habitats (Fremdt H. & Amendt J., 2014). Moreover, species of those families are predominantly domestic (Charabidze D., 2012). Halictidae were more represented at site 1 when Apidae dominated at site 2. Ropars L. *et al*. (2018) also noted an abundance of Halictidae during a study on the diversity of bees from the Paris city. These bees prefer well-sunny habitats and nest on the ground (Vereecken N. *et al*., 2009). They therefore have positive affinities to urbanization unlike the Apidae (Desaegher J., 2017). Few Syrphidae were recorded at the two sampling sites. This result corroborates that of Sinzinkayo E. et al. (2016) who noted a low abundance of this family in a biotope of Bujumbura city. Without a variety of food sources, bees and hoverflies do not find the quantity of nectar and pollen necessary for their physiological functioning (Michener D.C., 2007). The site 2 displayed a high specific richness of insect pollinators compared to the site 1. Indeed, the site 2 sheltered many species plants compared to the site 1, and this is favorable to the establishment of several pollinators, especially wild bees (Somme L. *et al*., 2011). The results of our study therefore highlight that the creation of new quarters and other infrastructures in our study area have favored the restructuring of the local pollinator communities with emergence of taxa adapted to the new environment.

4.2. Relation plants - pollinators in study sites

The peri-urban landscape was more diversified in plant species than the urban environment. Plant diversification influences the structure of pollinator communities (Lichtenberg *et al*., 2017). This area was dominated by fallow lands and crop fields, compared to the urban landscape located in zone with impermeable surfaces (roads, buildings, etc.) that implies a specific floristic composition. This observation corroborates the result of Bossu A. *et al*. (2014) during their research on pollinators in two areas of France. The result of our study suggests that the unavailability of floral resources in the urban environment would have led pollinators to migrate to the nearby rural lands. Flower diversity particularly attracts communities of hoverflies and bees (Warzecha D. *et al*., 2018). Moreover, the high intensity of artificial light in cities would affect the physiology of plants, in particular their flowering and fruit development with implications for faunal diversity (Briggs W.R. & Christie J.M., 2002), especially pollinators whose visit frequency would therefore be low due to the insufficiency of plants able of providing the necessary food resources (Le Féon V., 2010). In general, urban infrastructures, especially the height of the buildings, would impede pollinator dispersion (Kevin J.G., 2010). The present study revealed that three plant species, *Ocimum gratissimum*, *Stylosanthes biflora* and *Tithonia diversifolia* (only observed in the peri-urban area), and *Stachytarpheta jamaicensis* (founded in the urban area) seemed to be more attractive to foraging insects. This would be linked to their production of nectar and pollen needed by pollinators for their own survival and that of their offspring (Habakaramo M.P. *et al*., 2015). The high attraction of insects by essential oils produced by *O. gratissimum* was reported by Yarou

B.B. (2018) who identified 52 families of insects on this plant. Also, attraction of *Stylosanthes biflora* to pollinators has been reported by Daniels J.C. *et al*. (2014) in Florida. Moreover, Abdullahi G. *et al*. (2011) found that *T. diversifolia* was among the plants most visited by bees in Mubi region in the Sudanese savannah of Nigeria. The attracting potential of *T. diversifolia* to insect pollinators was also obseved by Donatti-Ricalde M.G. *et al*. (2018) in Rio de Janeiro. Also, Lakshmi P.V. & Raju A.J.S. (2011), Ballantyne G. & Willmer P. (2012) and Pieris P.U.S. (2016) have noted a great attraction of *S. jamaicensis* to butterflies and bees. Honey bee, *Apis mellifera*, was the most active of all insect foragers observed in the study sites. Ndayikeza L. *et al*. (2014b) also observed that this species visited a wide range of plants compared to other foragers in natural and agricultural ecosystems in Burundi. The results of our study confirm that urbanization may contribute to the loss of plants playing an important role in pollination. Specific measures for conservation and management of pollinator habitats should be taken during urbanization planning.

5. Conclusion

he results of this study confirmed that urbanization conducted to restructuring of plant and pollinator communities. In particular, urbanization contributes to emergence of insect taxa characteristic of urban landscapes, such as the families of Sarcophagidae and Calliphoridae, whereas the peri-urban zone seems to attract the families of Syrphidae and Apidae. The specific richness of pollinating insects is higher in peri-urban areas than in urban areas, probably due to the availability of food resources, nesting sites and a favorable microclimate. Furthermore, the presence of plants more attractive to pollinators and of medicinal importance such as *O. gratissimum*, *S. biflora*, *Tithonia diversifolia* and *S. jamaicensis* in peri-urban environment suggests that particular measures for conservation of some plant species should be taken, especially through the creation of urban gardens, when elaborating urbanization plans.

Acknowledgments

Our thanks go to the Burundian Office for the Conservation of the Environment (OBPE, Burundi) for making our research activities possible. We also thank the he anonymous reviewers. We are indebted to the Royal Belgian Institute of Natural Sciences for its financial support during field activities.

References

[1] Abdullahi G., Sule H., Chimoya I.A., Isah M.D. (2011) Diversity and relative distribution of honeybees foraging plants in some selected reserves in Mubi region, Sudan savannah ecological zone of Nigeria. *Adv Appl Sci Res*, 2(5), 388–395.

[2] Aguib S. (2014) Biogéographie et monographie des Megachilidae (Hymenoptera : Apoide) dans le nord-est algérien. PhD dissertation, University of Constantine 1, Constantine.

[3] Ballantyne G., Willmer P. (2012) Nectar theft and floral ant-repellence: A link between nectar volume and ant-repellent traits? *Plos One*, 7(8), 1–10.

[4] Bigirimana J., Bogaert J., De Cannière C., Bigendako M.J., Parmentier I. (2012) Domestic garden plant diversity in Bujumbura, Burundi: Role of the socio-economical status of the neighborhood and alien species invasion risk. *Landscape Urban Plan*, 107(2), 118–126.

[5] Bossu A., Manel S., Marco A., Carrère M. (2014) Composition spéficique et fonctionnelle comparée de la flore spontanée des jardins privatifs d'un village de Luberon (Lauris, Vaucluse) et d'une grande agglomération (Marseille, Bouches-du-Rhône). *Courrier Scientifique du Parc Naturel Régional du Luberon et de la Réserve de Biosphère Luberon-Lure*, 12, 88–106.

[6] Briggs W.R., Christie J.M. (2002) Phototropins 1 and 2: Versatile plant blue-light receptors. *Trends Plant Sci*, 7(5), 204–210.

[7] Chagnon M. (2008) Causes et effets du déclin mondial des pollinisateurs et les moyens d'y remédier. Fédération canadienne de la faune, Québec.

[8] Charabidze D. (2012) La biologie des insectes nécrophages et leur utilisation pour dater le décès en entomologie médico-légale. *Annales de la Société entomologique de France*, 48(3-4), 239–252.

[9] Chloé P., Dumbardon-martial E., Singh C. (2017) Utilisation des bols colorés en Martinique (Antilles françaises) : quelles possibilités pour l'inventaire et le suivi des insectes pollinisateurs des agrosystèmes fruitiers ? *Naturae*, 11, 1–16.

[10] Colwell R.K. (2013) EstimateS, version 9.1.0. University of Connecticut, [online] URL: http://viceroy.eeb.uconn.edu/estimates/index.html

[11] Daniels J.C., Schaefer J., Huegel C.N., Mazzotti F.J. (2014) Butterfly gardening in Florida 1. *IFAS/Wec*, 22, 1–23.

[12] Das B.J., Paul K., Nabanita B., Binoy K.B. (2018) Diversity study of insect pollinators of RABI crops cultivated in surrounding areas of Barpeta Town in Assam India. *IJRAR*, 5(4), 172–177.

[13] Desaegher J. (2017) Urbanization effects on floral morphology and plant-pollinator relationships. PhD dissertation, Université Paris-Saclay, Paris.

[14] Donatti-Ricalde M.G., Sousa W.B., Ricalde M.P., Silva A.C., Abboud A.C.S. (2018) Potencial atrativo de Tithonia diversifolia (Hemsl) A. Graye Tithonia rotundifolia (Mill) S. F. Blake (Asteraceae) para utilização em controle biológico conservativo. *Cadernos de Agroecologia*, 13(1), 1–6.

[15] Durand O., Coutanceau J.-P. (2015) Niveau de connaissance sur le groupe des Coléoptères (Coccinellidae). CPIE Loire Anjou, Mayenne Nature Environnement, 9p.

[16] Eardley C., Kuhlmann M., Pauly A. (2010) Les genres et les sous-genres d'abeilles de l'Afrique subsaharienne. Abc Taxa, Brussels.

[17] Ekesi S., Billah M.K. (2010) Un guide pratique pour la gestion des mouches de fruits (Tephritidae) d'importance économique en Afrique. 2ème édition. ICIPE, Nairobi.

[18] Guenat S., Kunin W.E., Dougill A.J., Dallimer M.

(2018) Effects of urbanization and management practices on pollinators in tropical Africa. *J Appl Ecol*, 56, 214–224.

[19] Kevin J.G. (2010) Urban ecology. Cambridge university press, Cambridge.

[20] Fremdt H., Amendt J. (2014) Species composition of forensically important blow flies (Diptera: Calliphoridae) and flesh flies (Diptera: Sarcophagidae) through space and time. *Forensic Sci Int*, 236, 1–9.

[21] Habakaramo M.P., Ntahobavuka H.H., Kabonyi N.C. (2015) Enquêtes ethnomellisologiques et étude des différents produits de la ruche de l'île d'Idjwi (Sud-Kivu/RDC). *IJISR*, 19(1), 75–84.

[22] ISTEEBU (2017) Projections démographiques 2010-2050. Niveau national et provincial. Service des Etudes et Statistiques Démographiques, Bujumbura.

[23] Kra K.D., Kwadjo K.E., Douan B.G., Doumbia M., Kouamé K.L. (2017) Use of two methods to assess beetle abundance and diversity in different habitats. *IJIAS*, 20(4), 1078–1084.

[24] Lakshmi P.V., Raju A.J.S. (2011) Psychophily in *Stachytarpheta jamaicensis* (L.) Vahl. (Verbenaceae). *Curr Sci India*, 100(1), 88–95.

[25] Le Féon V (2010) Insectes pollinisateurs dans les paysages agricoles : approche pluri-échelle du rôle des habitats semi-naturels, des pratiques agricoles et des cultures entomophiles. PhD dissertation, Université Rennes 1, Rennes.

[26] Lemoine G. (2016) Flores et pollinisateurs des villes et des friches urbaines. Entre nature temporaire et biodiversité en mouvement. *Bulletin de la Société Botanique du Nord de la France*, 69, 103–116.

[27] Lichtenberg E.M., Kennedy C.M., Kremen C., Batáry P., Berendse F., Bommarco R., …, Williams N.M. (2017). A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. *Global Change Biol*, 23(11), 4946–4957.

[28] Magurran A.E. (1998) Ecological diversity and its measurement. Princeton University, New Jersey.

[29] Magurran A.E. (2004) Measuring biological diversity. Blackwell Publishing Company, Malden.

[30] Marshall S.A. (2006) Insects : Their natural history and diversity, with a photographic guide to insects of Eastern North America. Buffalo New York, New York.

[31] Marshall S.A., Kirk-Spriggs A.H., Muller B.S., Paiero S.M., Yau T., Jackson M.D. (2017) Key to diptera families - adults. *Suricata*, 4, 267–355.

[32] Michener D.C. (2007) The bees of the world. 2nd Edition. The Johns Hopkins University Press, Baltimore.

[33] Ndayikeza L., Nzigidahera B., Mpawenimana A., Habonimana B. (2014a) Abondance et distribution des abeilles du genre Xylocopa Latreille, 1802 (Hymenoptera : Apoidea) du Burundi. *Bull Sc Inst Nat Env Conser Nat*, 11, 38–48.

[34] Ndayikeza L., Nzigidahera B., Mpawenimana A., Munyuli T. (2014b) Dominance *d'Apis mellifera* L. (Hymenoptera , Apoïdea) dans les écosystèmes naturels et les agro-écosystèmes du Burundi : risque d ' érosion de la faune des abeilles sauvages. *Bull Sc Inst Nat Env Conser Nat*, 13, 72–83.

[35] Nzigidahera B., Fofo A. (2010) Protégons les pollinisateurs des écosystèmes forestiers en faveur des écosystèmes agricoles au Burundi. OBPE, Bujumbura.

[36] Pauly A., Nzigidahera B., Eardrey C., Ndayikeza L., Mpawenimana A., Habonimana B. (2015) Les abeilles du genre *Xylocopa* Latreille (Hymenoptera : Apoidea : Apidae) au Burundi, de bons pollinisateurs des légumineuses. *Belg. J. Entomol*, *27*, 1–27.

[37] Picker M., Griffiths C., Weaving A. (2004) Field guide to insects of South Africa. 2nd edition. Struik, Cape Town.

[38] Pieris P.U.S. (2016) Study on butterfly visitation patterns of Stachytarpheta jamaicensis as a beneficial plant for butterfly conservation. *International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering*, 10(2), 74–77.

[39] Potts S.G., Biesmeijer J.C., Kremen C., Neumann P., Schweiger O., Kunin W.E. (2010) Global pollinator declines: Trends, impacts and drivers. *Trends Ecol EvoL*, 25(6), 345–353.

[40] Pouvreau A. (1993) Les Bourdons pollinisateurs menacés. *Courrier de l'environnement de l'INRA*, 19, 63–70.

[41] R Development Core Team (2015) R, version 3.1.3. Foundation for Statistical, [online] URL: http at http://www.R-project.org/

[42] Rhoné F., Maire E., Odoux J.F., Guillerme S., Laffly D., Rhoné F., Maire E., Odoux J.F., Guillerme S., Briane G. (2016) La composante ligneuse : un élément clé pour l'apport de ressources alimentaires aux colonies d'abeilles domestiques (Apis mellifera L.) en contexte paysager agricole. *OpenField*, 1–9.

[43] Ropars L., Dajoz I., Geslin B. (2018) La diversité des abeilles parisiennes. *Obervatoire des Abeilles*, 7, 14–19.

[44] Sinzinkayo E., Nzigidahera B., Nasasagare R.P. (2016) Diversité et écologie des Syrphidae (Diptères:Syrphoidea) pollinisatrices du Burundi. *Bull Sc Inst Nat Env Conser Nat*, 2, 34–47.

[45] Somme L., Van Rossum F., Mairesse J. (2011) Influence de la restauration et de l'entretien de milieux tourbeux sur les communautés de pollinisateurs en Lorraine belge. *Parcs et Réserves*, 71(3), 4–11.

[46] Tooker J.F., Reagel P.F., Hanks L.M. (2002) Nectar sources of day-flying Lepidoptera of Central Illinois. *Ann Entomol Soc Am*, 95(1), 84–96.

[47] Troupin G. (1978) Flore du Rwanda. Spermatophytes. Volume 1. Musée Royale de l'Afrique Centrale, Tervuren.

[48] Troupin G. (1983) Flore du Rwanda. Spermatophytes. Volume 2. Musée Royal de l'Afrique Centrale, Tervuren.

[49] Troupin G. (1985) Flore du Rwanda. Spermatophytes. Volume 3. Musée Royale de l'Afrique Centrale, Tervuren.
[50] Troupin G. (1988) Flore du Rwanda. Spermatophytes. Volume 4. Musée Royale de l'Afrique Centrale, Tervuren.
[51] United Nations (2019) World urbanization prospects : The 2018 Revision (ST/ESA/SER.A/420). Department of Economic and Social Affairs, Population division, New York.
[52] Vereecken N., Genoud D., DufrêNe É., Vaissière B. (2009) Une biodiversité étonnante. *Le Monde des Abeilles*, 1014, 26–28.
[53] Warzecha D., Diekötter T., Wolters V., Jauker F. (2018) Attractiveness of wildflower mixtures for wild bees and hoverflies depends on some key plant species. *Insect Conserv Diver*, 11(1), 32–41.
[54] Yarou B.B. (2018) Bioefficacité d'Ocimum spp. (Lamiaceae) pour une gestion intégrée des ravageurs en cultures maraîchères. PhD dissertation, Université de Liège, Gembloux.40.

Supplementary information

Table S1. Abundance of families of insect pollinators in the sampling sites (with at least ten individuals, NI: number of individuals, RA: relative abundance)

	Site 1		Site 2	
Families	NI	RA (%)	NI	RA (%)
Sarcophagidae	593	33.73	1116	38.47
Calliphoridae	417	23.72	747	25.75
Apidae	84	4.78	390	13.45
Muscidae	30	1.71	129	4.45
Dolichopodidae	268	15.24	76	2.62
Anthomyiidae	46	2.62	55	1.90
Sphecidae	12	0.68	49	1.69
Syrphidae	32	1.82	44	1.52
Tachnidae	4	0.23	40	1.38
Ichneumonidae	15	0.85	37	1.28
Diopsidae	20	1.14	35	1.21
Halictidae	87	4.95	24	0.83
Cicadellidae	1	0.06	19	0.66
Vespidae	15	0.85	18	0.62
Chrysomelidae	29	1.65	13	0.45
Stratiomyidae	47	2.67	13	0.45
Acrididae	1	0.06	11	0.38
Tenthredinidae	29	1.65	8	0.28

Table S2. Abundance of species of insect pollinators in the sampling sites (with at least twenty-five individuals, NI: number of individuals, RA: relative abundance)

	Site 1		Site 2	
Species	NI	RA (%)	NI	RA (%)
Calliphoridae sp.1	191	10.86	534	18.41
Sarcophagidae sp.1	278	15.81	519	17.90
Sarcophagidae sp.3	191	10.86	315	10.86
Apis mellifera	38	2.16	292	10.07
Sarcophagidae sp.2	90	5.12	221	7.62
Calliphoridae sp.7	94	5.35	115	3.97
Dolichopodidae sp.2	202	11.49	47	1.62
Muscidae sp.1	6	0.34	44	1.52
Muscidae sp.7	4	0.23	44	1.52
Neomintho celeris	4	0.23	40	1.38
Calliphoridae sp.3	33	1.88	34	1.17
Ceratina sp.1	21	1.19	34	1.17
Ceratina sp.2	9	0.51	30	1.03
Dolichopodidae sp.1	66	3.75	29	1.00
Sarcophagidae sp.5	2	0.11	29	1.00
Calliphoridae sp.6	0	0.00	25	0.86
Eutrichota sp.	41	2.33	19	0.66
Sarcophagidae sp.7	32	1.82	18	0.62
Calliphoridae sp.4	86	4.89	8	0.28
Lipotriches sp.3	33	1.88	6	0.21
Stratiomyidae sp.1	27	1.54	6	0.21