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Modelling the geographical distribution of plant species reported as anti-malaria and mosquito repellents in Burundi

[1]NSABIMANA C., [3*]HAVYARIMANA C., [1]MANIRAKIZA J M V., [1]NDAYIZEYE G., [1]IRAMPAGARIKIYE R., [1,2]MASHARABU T

[1]Research Centre in Natural and Environmental Sciences, University of Burundi, P.O. Box 2700 Bujumbura, Burundi

[2]Biology Department, Faculty of Sciences, University of Burundi, P.O. Box 2700 Bujumbura, Burundi

[3]Center for Expertise, Research and Training in Environment and Sustainable Development (CERFED), Bujumbura, Burundi

*Corresponding author: celestinhavy@gmail.com

Abstract

The conservation and sustainable management of plant species require knowledge of their potential distribution areas and of the factors driving this distribution. A study modeling the distribution of ten flagship plant species reported as anti-malaria and mosquito repellents in Burundi was carried out, with a view to contributing to the establishment of conservation priorities in Burundi, which could also be a reference for other countries. The study was conducted in the four phytogeographic districts of Burundi. It was based on 98 samples from a field data collection on anti-malaria and mosquito repellent plants from Burundi and plant specimens kept at the University of Burundi Herbarium. Potential distribution areas were determined using the Inverse Distance Weighting (IDW) spatial interpolation tool in ArcGIS 10.5 software. The geographic distribution and the ecological factors likely to influence this distribution were determined. The spatial interpolation show that the ten plant species reported as antimalarial and/or mosquito repellent in Burundi can be predicted in all the phytogeographic districts of Burundi. According to the available literature, seven of the ten species belong to the category of widely distributed species. The study shows that there are some differences in terms of distribution especially in the Mosso-malagarazi district. This could be explained by ecological conditions, typical of the lowlands. The distribution models obtained in this study will guide the sustainable plants management in Burundi and elsewhere. In order to increase the production of essential oils and phytochemicals, we recommend the use of these models to identify potential growth sites of the ten anti-malaria and mosquito repellent plant species.

Keywords: *potential distribution area; spatial interpolation; species distribution factors; anti-malarial plant; mosquito repellent plants*

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Introduction

Most approaches developed to predict the geographic distribution of species are based on the concept of ecological niche and its modeling (Mahamoud and Akpo, 2018). Species distribution models have been used for years to predict the potential range of a species and identify the factors that determine that distribution (Kumar and Stohlgren, 2009). Some models are valid on a large scale, such as the "Maxent" model, which is based on maximum entropy (Phillips *et al.,* 2006) and calculates the effective niche and the probability of occurrence of a given species. Other models that can be used at large and small scales include the Kigreage and inverse distance weighting (IDW) models. This inverse distance weighting method has been used in several research studies to predict the distribution of plant species (Boman *et al.,* 1995; Dirks *et al.,* 1998; Roberts, 2001) and has consistently been ranked as one of the best techniques for modeling the geographic distribution of plants and other features of interest such as soil fertility (Gotway *et al.,* 1996).

The present study is a contribution to the modeling of the geographical distribution of ten plant species most reported as antimalarial and mosquito repellent in Burundi (Havyarimana, 2020). These are the species *Gymnanthemum amygdalinum* (Delile) Sch. Bip. ex Walp., *Tetradenia urticifolia* (Baker) Phillipson, *Plectranthus barbatus* Andrews, *Solanecio mannii* (Hook.f.) C. Jeffrey, *Phytolacca dodecandra* L'Hér., *Dodonaea viscosa* Jacq., *Senna didymobotrya* (Fresen.) H. S. Irwin & Barneby, *Sesbania sesban* (L.) Merr., *Erigeron sumatrensis* Retz. et *Markhamia lutea (Benth.) K. Schum*, selected due to the lack of baseline data on their geographic distribution to facilitate the establishment of conservation priorities in Burundi, which could also be a reference for other countries.

The study had a threefold objective: (i) to contribute to the mapping of the spatial distribution of the ten antimalarial and mosquito repellent plant species in Burundi, (ii) to model their geographical distribution to highlight their potential distribution areas and (iii) to determine the factors that may influence the geographical distribution of these species. The results of the study will allow conclusions to be drawn about the knowledge of the potential distribution areas of the ten antimalarial and mosquito repellent plant species in Burundi and an understanding of the factors that may influence their geographic distribution in order to inform decisions about extension programs aimed at increasing the raw materials used in essential oil extraction units and the conservation of these species.

Materials and methods

Study area

The study was conducted in Burundi, a country located between 28°58' and 30°53' East longitude and between 2°15' and 4°30' South latitude. It is bordered by Rwanda to the north, the Democratic Republic of Congo to the west and Tanzania to the south and east. It covers an area of 27834 km^2 of which about 2000 km^2 are occupied by the Burundian part of Lake Tanganyika (Nzigidahera, 2012). The Burundian vegetation is part of the Afrotropical ecozone, and in particular, of the highland forest ecoregion. However, human action has sustainably reduced the extent of forests for agriculture (Deltares, 2020). The country was once covered with forests, but these have been decimated by the search for arable land and pasture, the production of lumber and firewood, and the production of charcoal to meet the needs of the cities (Ndabaneze, 1988).

Located in the heart of Africa, Burundi is indeed subject to diverse phytogeographic influences (Figure 1). The phytogeographic districts as described by Ndabaneze (1983) in (Ndabaneze, 1988) were considered as homogeneous units of the study area.

Data collection and map production

The geographical coordinates of reference for the distribution of the ten species of anti-malaria and mosquito repellent plants were collected during the field missions carried out for this study. Samples of herbarium specimens collected in the field were complemented with data housed at the Herbarium of the University of Burundi for herbarium specimens from previous work.

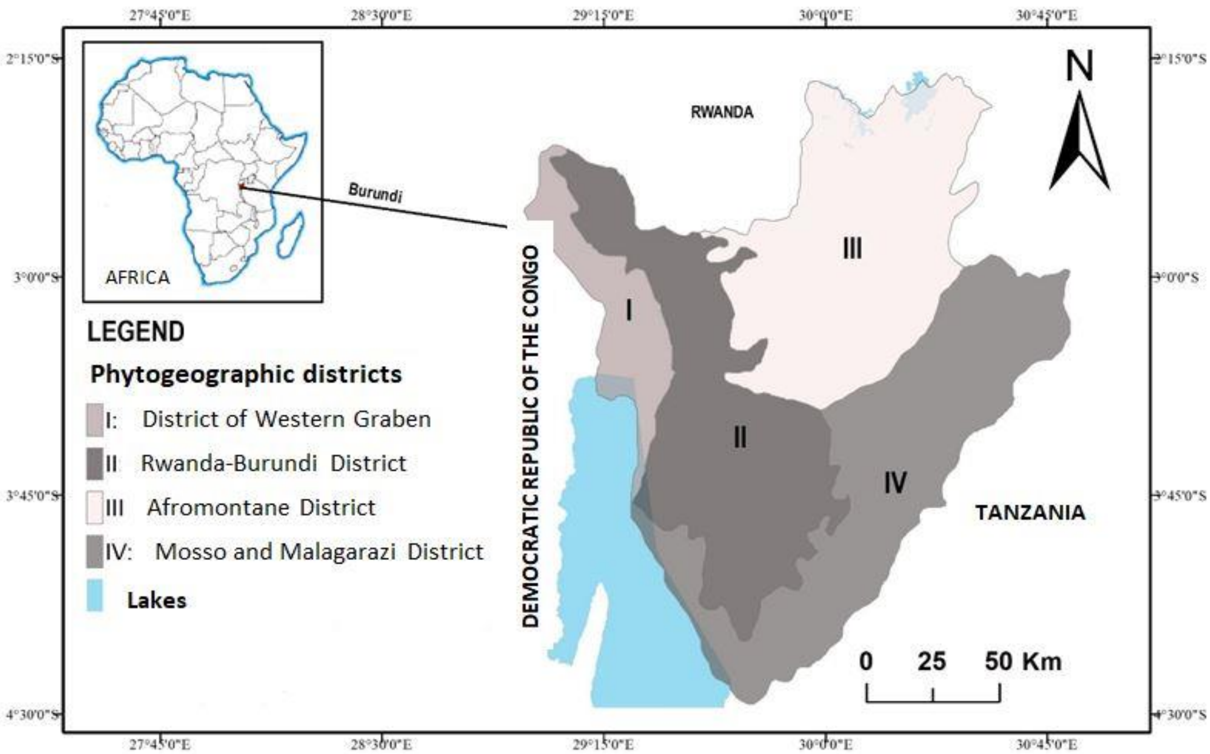


Figure 1. Study area: Phytogeographic regions of Burundi modified from the Ndabaneze (1988) phytogeographic model (I: Western Graben District, II: Rwanda-Burundi District, III: Afromontane District, IV: Mosso and Malagarazi District)

Data visualization and map production were performed using ArcGIS 10.5 software. To determine the potential distribution of each of the anti-malarial and mosquito repellent plant species, we used the Inverse Distance Weighted (IDW) spatial interpolation tool to estimate the prediction areas for each species. This technique interpolated the unsampled areas as follows (Shekhar & Xiong, 2008):

$$z_j = \frac{\sum_i \frac{z_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}}$$

Where, Zj is the estimated value for point Z at location j, dij is the distance from point i to unknown point j, Zi is the value of known point i, and n a user defined exponent. Note that the value of n used in this work is 2.

Analysis of the geographical distribution and its factors

The geographic distribution analysis was performed by comparing the results obtained with the Ndabaneze (1988) model to the phytogeographic subdivisions defined by White (1993) which are generally considered the most recent phytogeographic subdivisions of Africa and the most used in phytogeographic studies (Linder and Rudall, 2005; Ndayishimiye, 2011; Olson *et al.,* 2001).

Factors that may influence the geographic distribution of the ten flagship anti-malarial and mosquito repellent species were determined by consulting the available literature on diaspora spread patterns with reference to the classification of (Dansereau and Lems, 1957), Raunkier's (1934) biological types (Masharabu, 2011; Mouton, 1966), and the habitats of plant species (Havyarimana, 2020; Melly *et al.,* 2020).

Results

Geographical distribution maps

The study produced true geographical distribution maps using occurrence data for each of the 10 plant species reported as antimalarial and mosquito repellent in Burundi and geographical distribution models. The overall distribution map shows that these species are generally present in all phytogeographical districts of Burundi (Figure 2). However, some species are absent in certain parts of the phytogeographical districts of Burundi.

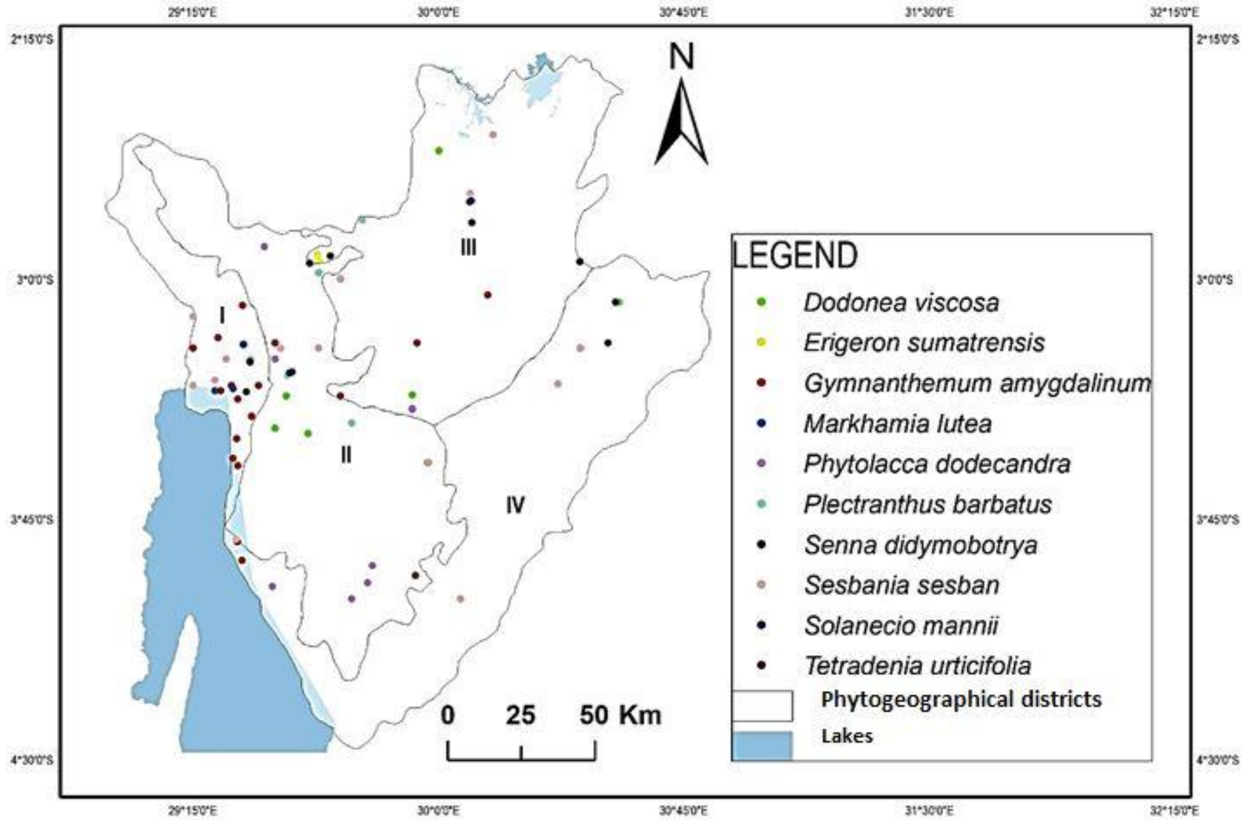
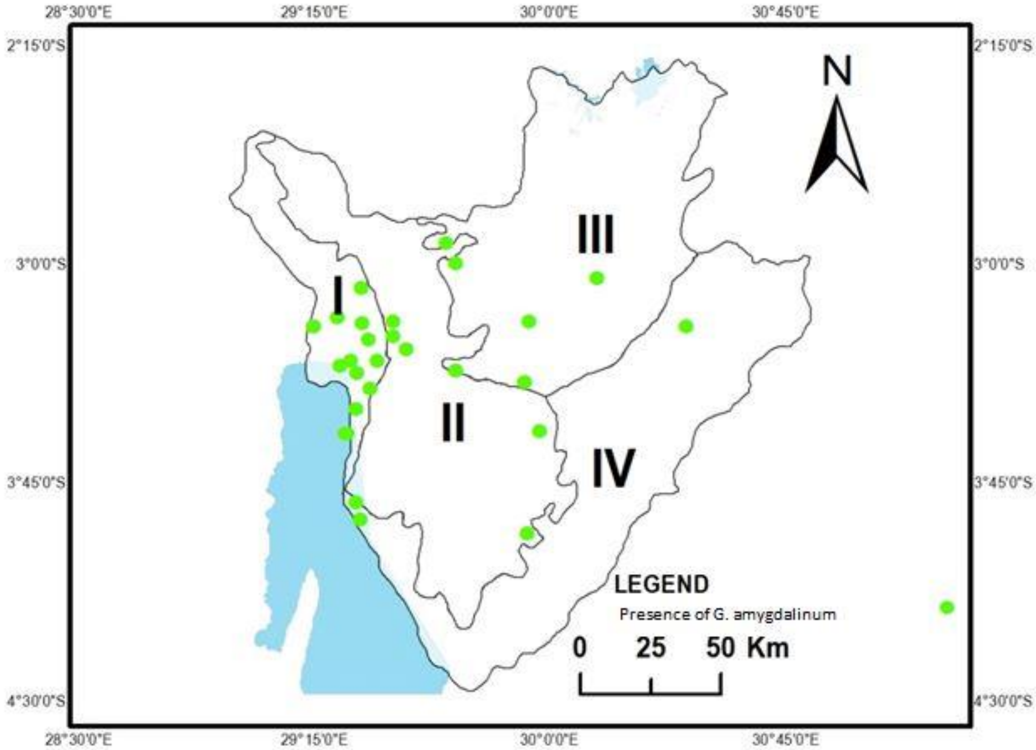


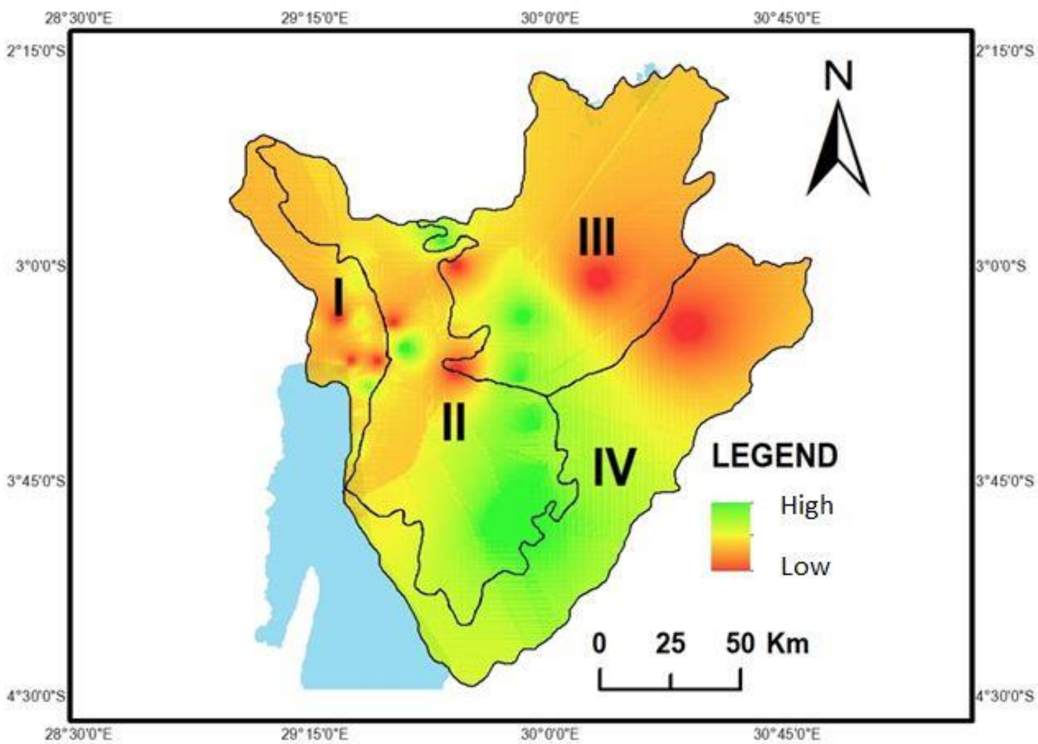
Figure 2. Actual distribution of the 10 anti-malaria and anti-mosquito flagship species in the phytogeographic districts of Burundi (I: Western Graben District, II: Rwanda-Burundi District, III: Afromontagnard District, IV: Mosso and Malagarazi District)

The actual occurrence points of the ten species (Figure 3A-10A) show also that they are generally present in all phytogeographical districts of Burundi. Each of the species *Gymnanthemum amygdalinum, Tetradenia urticifolia, Plectranthus barbatus, Sesbania sesban, Solanecio mannii* and *Dodonea viscosa* is represented by at least one sample in each phytogeographical district of Burundi, but it should be noted that *Gymnanthemum amygdalinum* is the most represented species. On the other hand, some species do not have representative samples in all the phytogeographical districts of Burundi. The species *Senna didymobotrya* is not represented in the Western Graben and Mosso-Malagarazi districts. The species *Markhamia lutea* and *Phytolacca dodecandra* are not represented in the Mosso and Malagarazi districts, while the species *Erigeron sumatrensis* is absent in the Afromontane and Mosso and Malagarazi Districts.

Regarding the potential spatial distribution of the ten species (Figure 3B-10B), the results of the spatial interpolation show that these species can be predicted in all the phytogeographical districts of Burundi despite the low representativeness of some species.

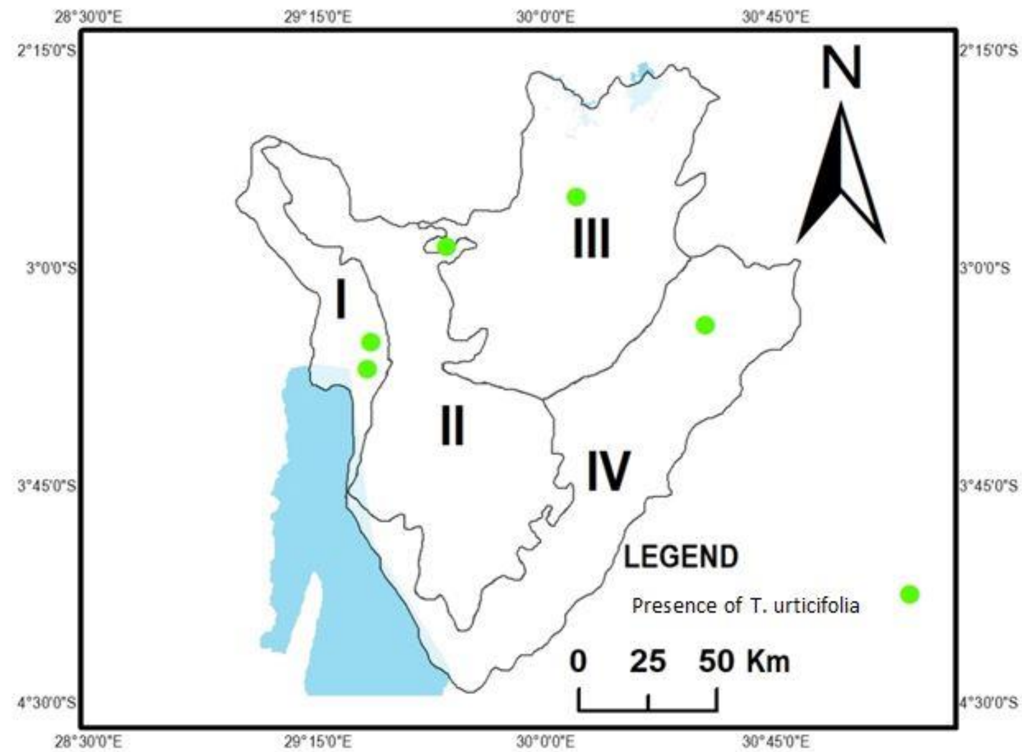


A

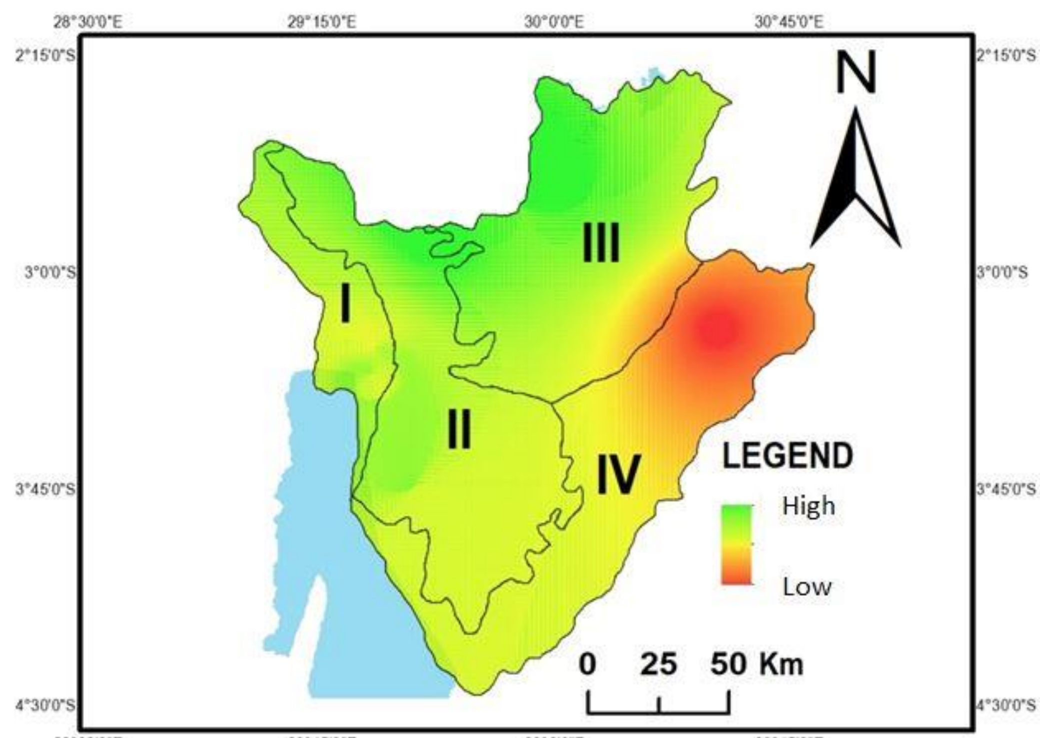


B

Figure 3. Potential distribution map (B) obtained by inverse distance weighting (IDW) using the real presence points of Gymnanthemum amygdalinum (A) in Burundi

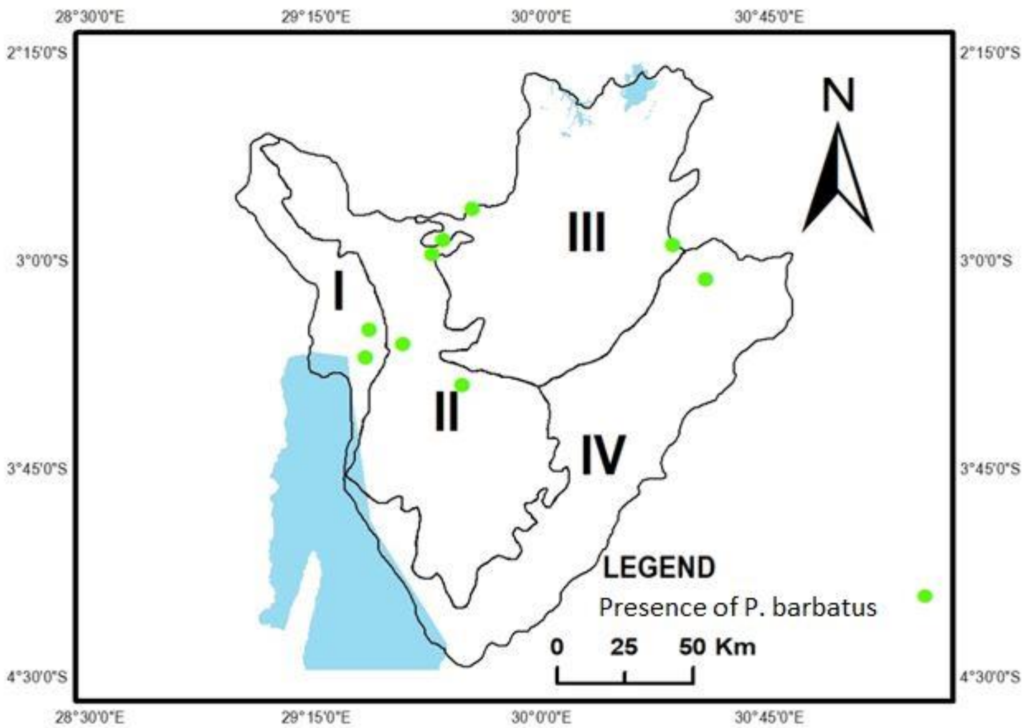


A

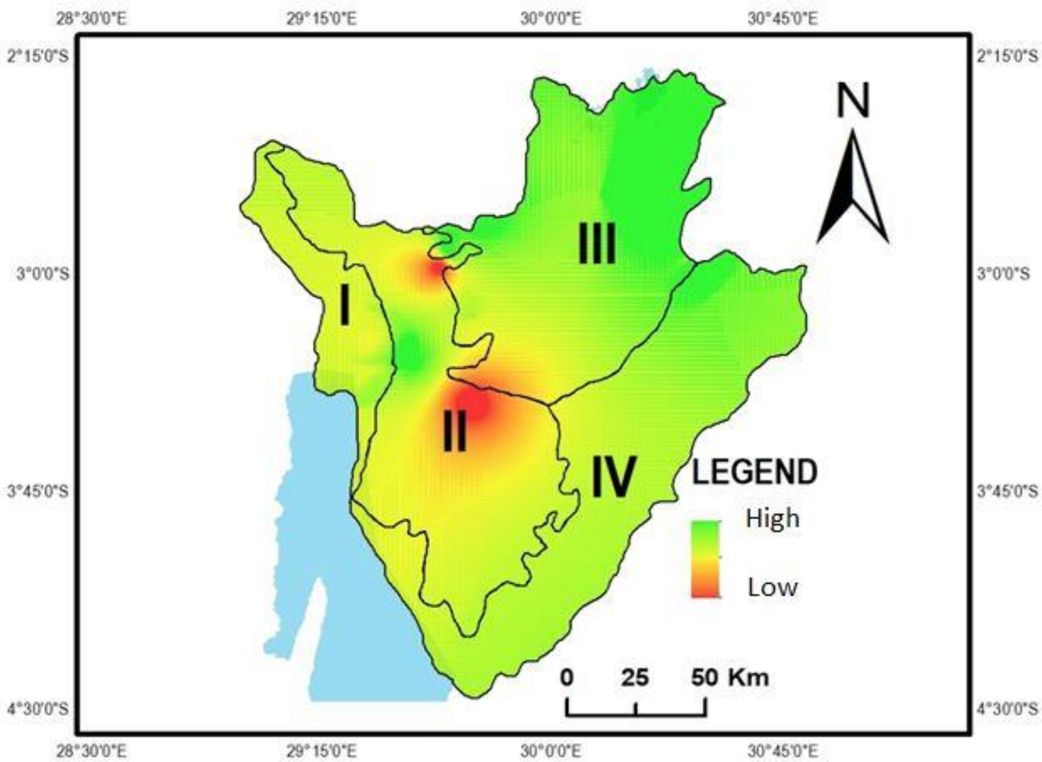


B

Figure 4. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Tetradenia urticifolia (A) in Burundi



A



B

Figure 5. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Plectranthus barbatus (A) in Burundi

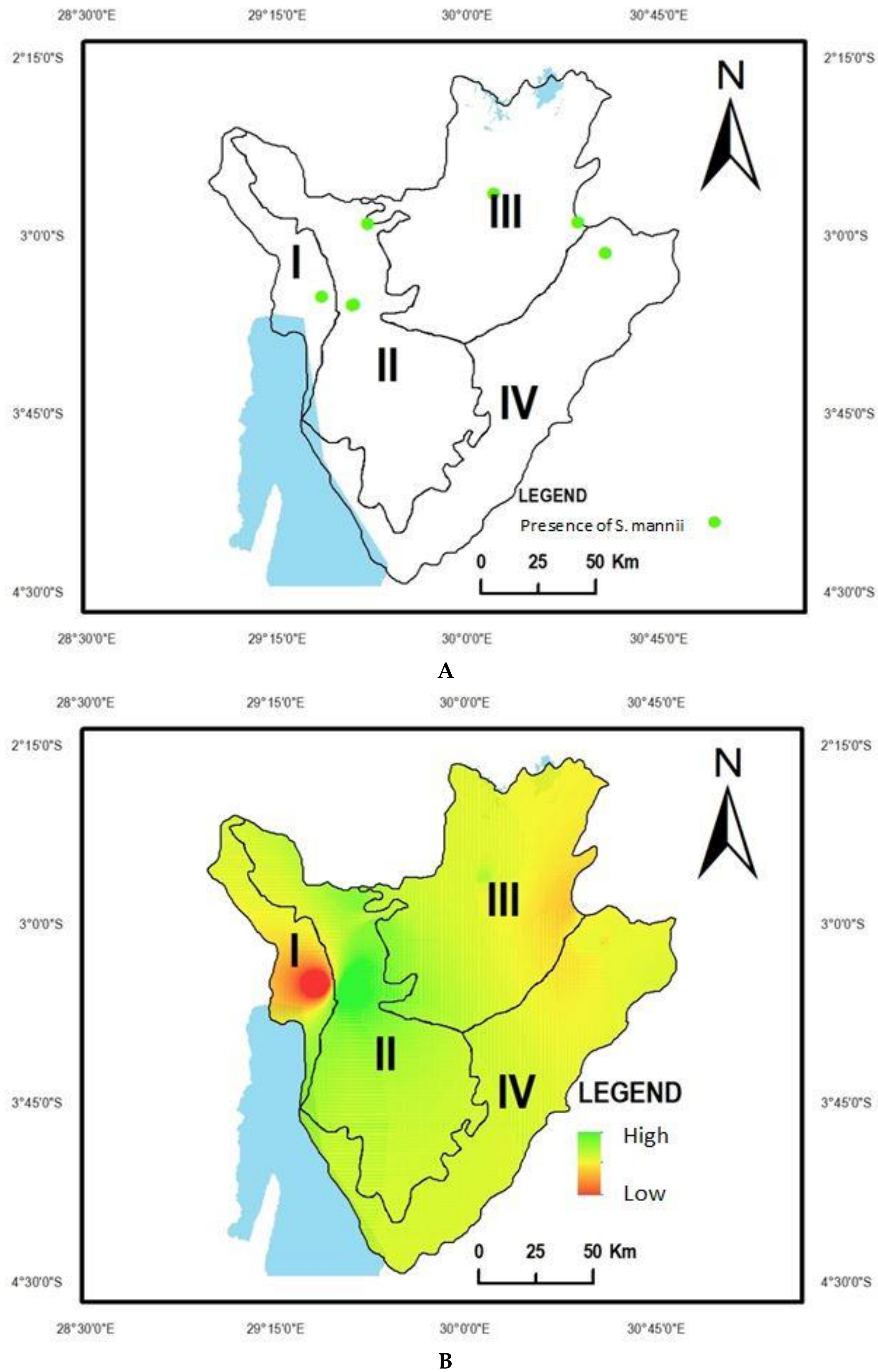
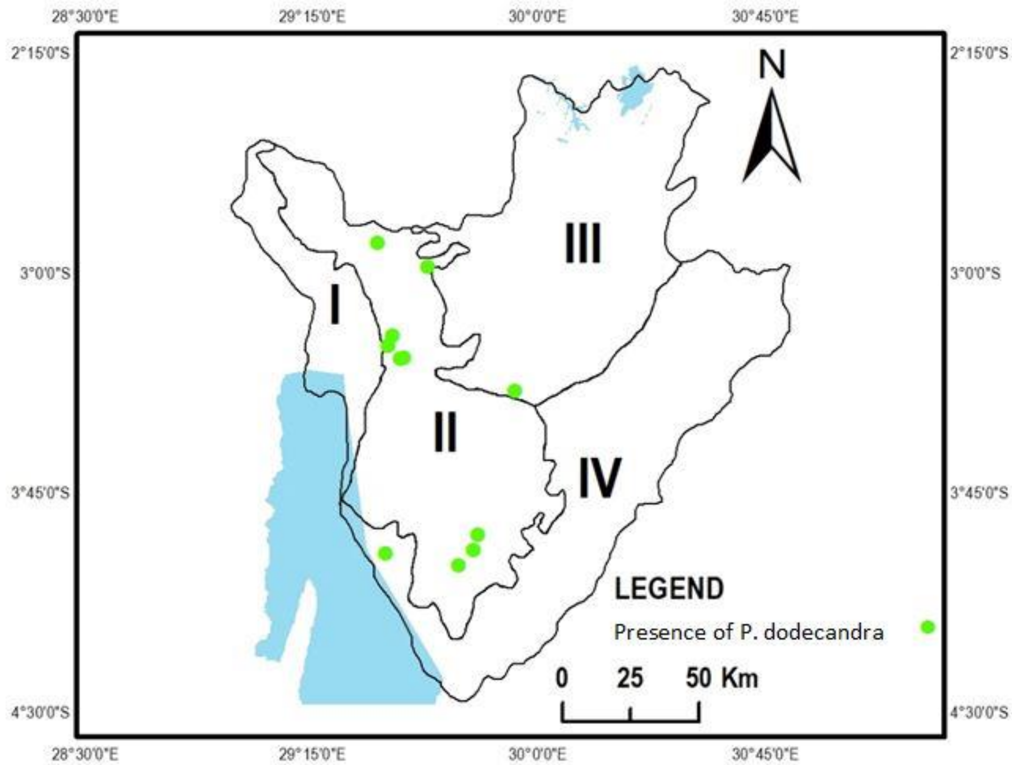
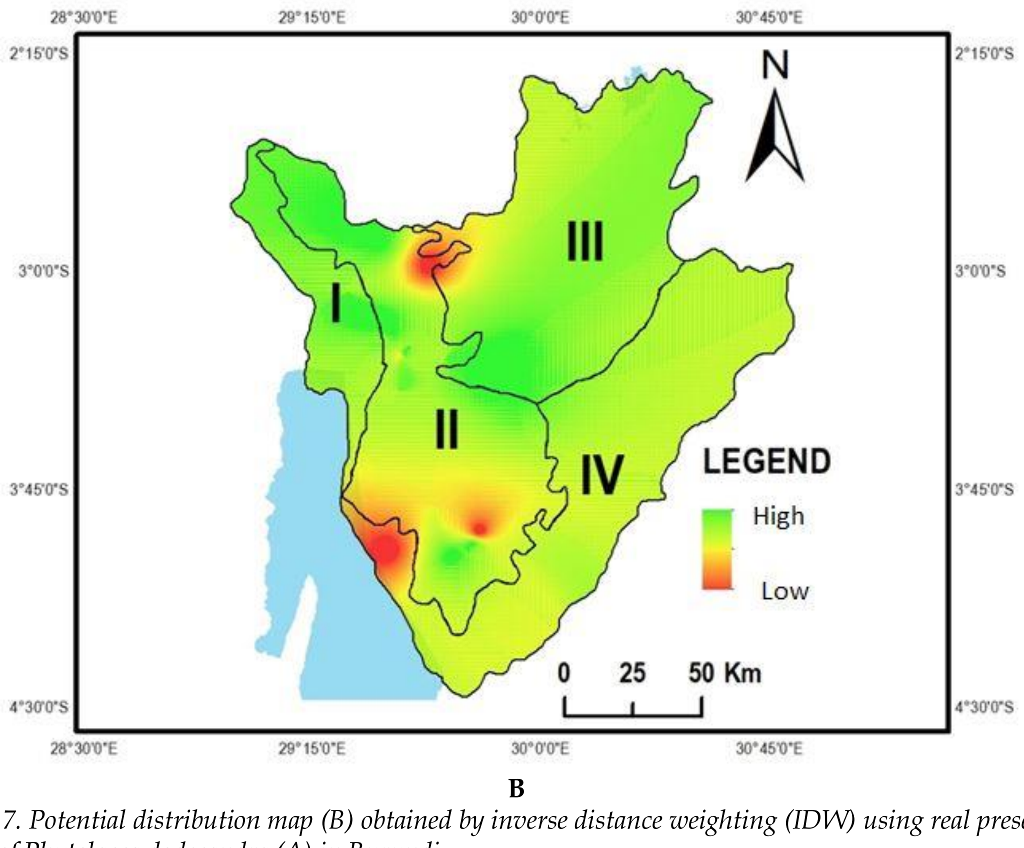


Figure 6. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Solanecio mannii (A) in Burundi

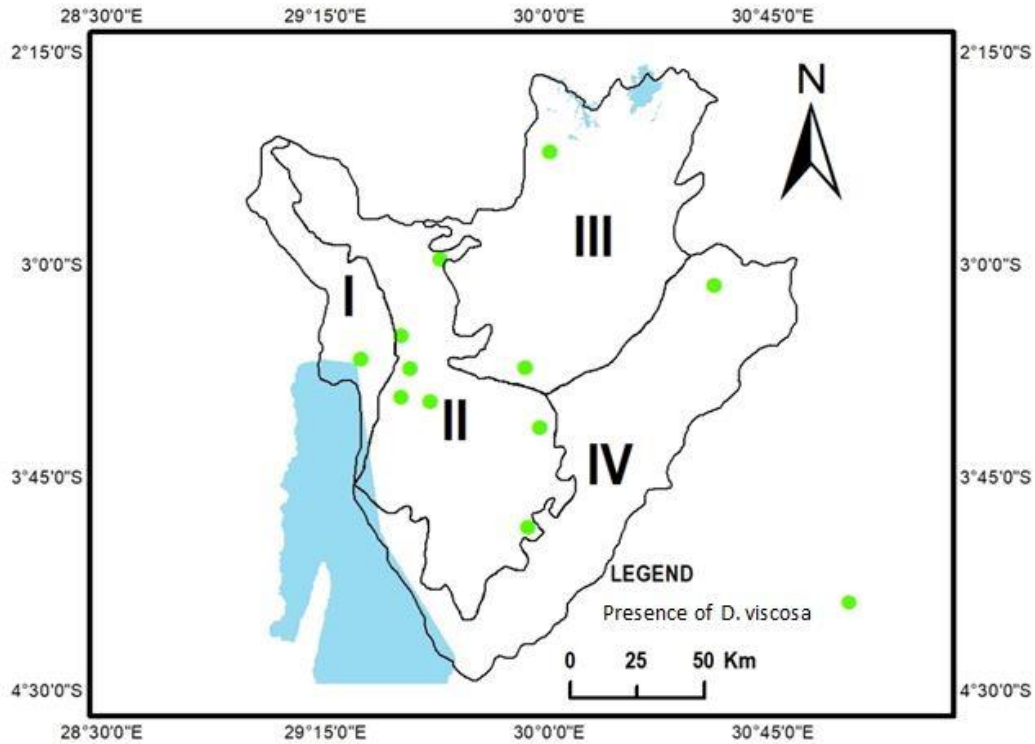


A

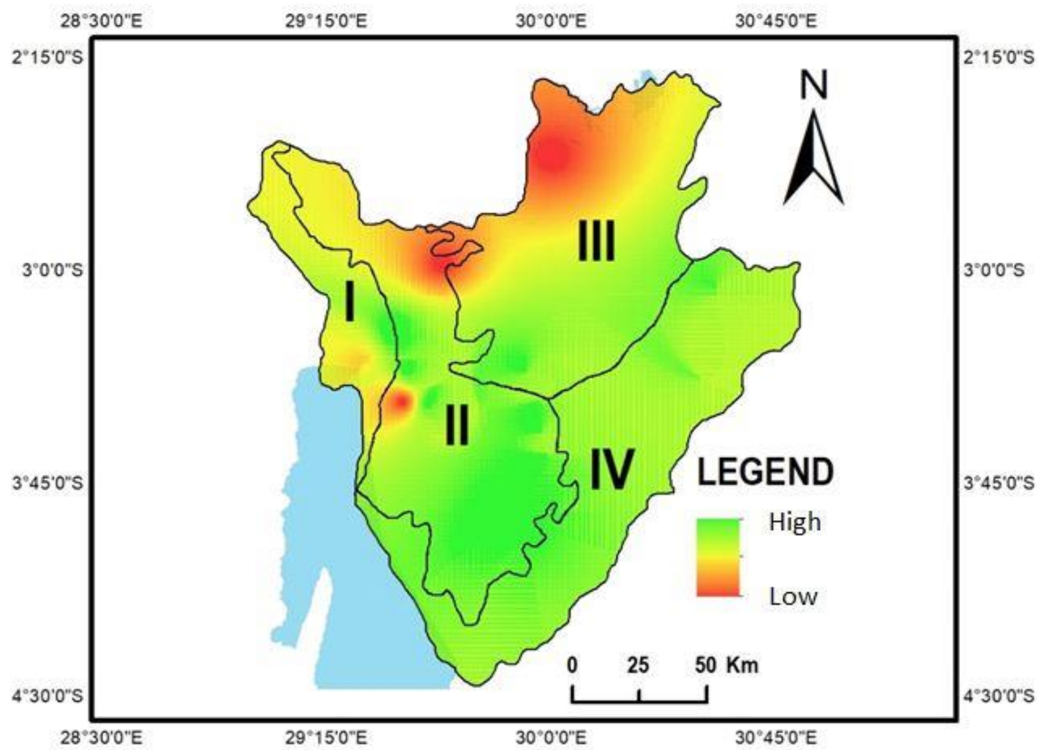


B

Figure 7. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Phytolacca dodecandra (A) in Burundi

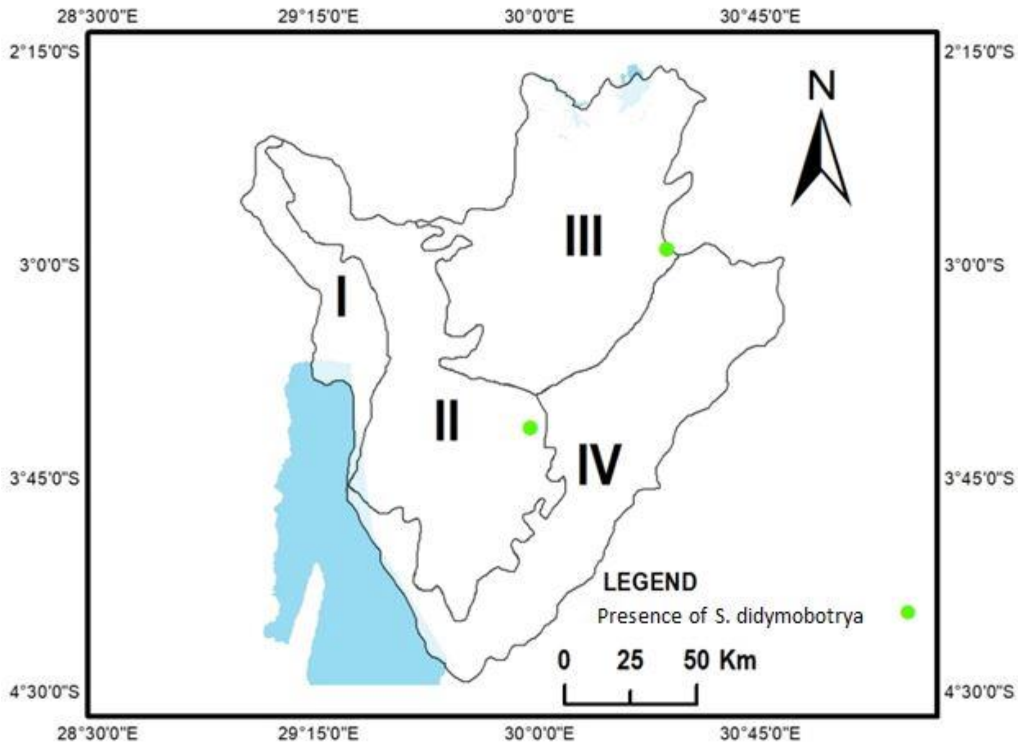


A

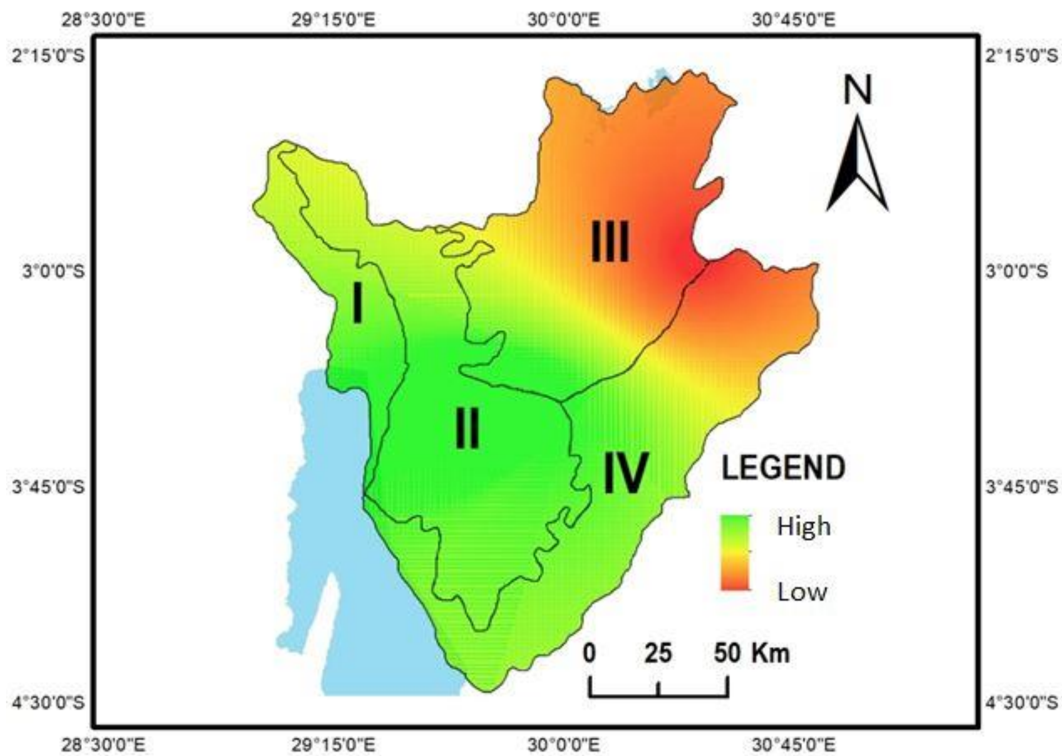


B

Figure 8. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Dodonea viscosa (A) in Burundi

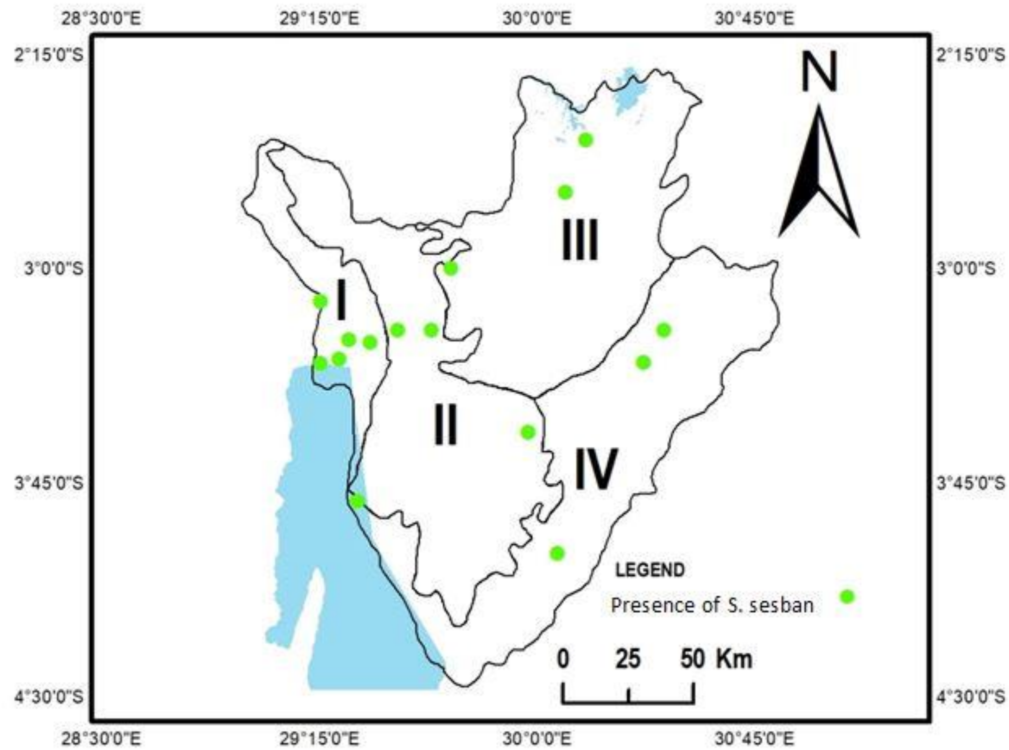


A

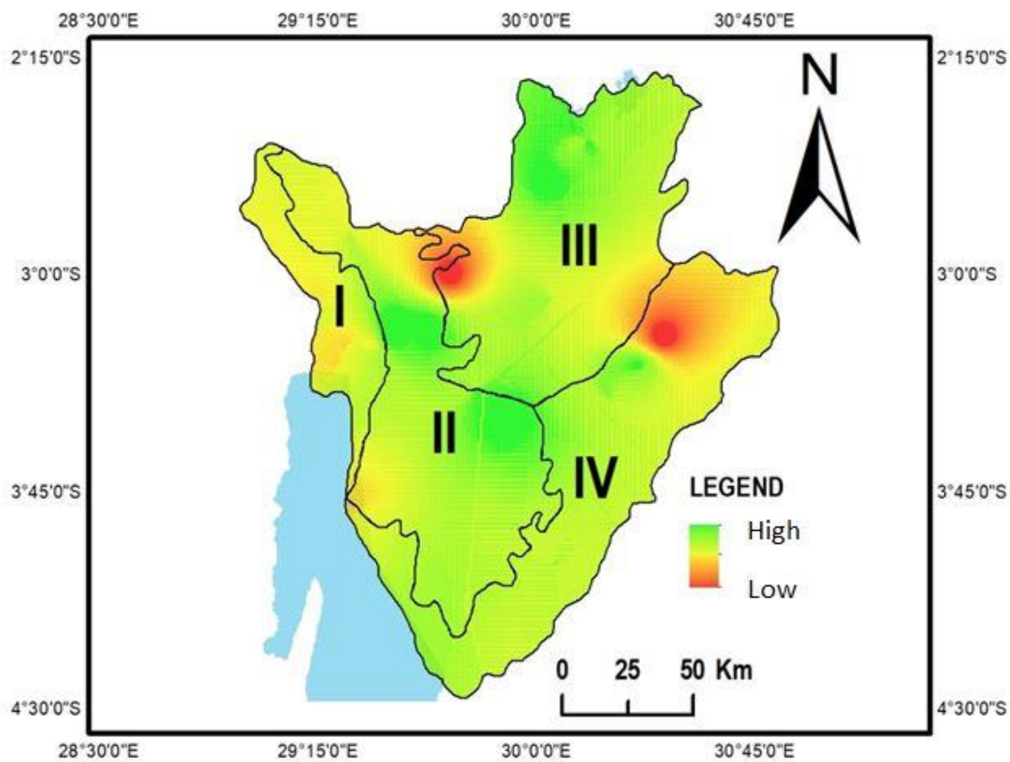


B

Figure 9. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of <u>Senna</u> <u>didymobotrya</u> (A) in Burundi



A



B

Figure 10. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Sesbania sesban (A) in Burundi

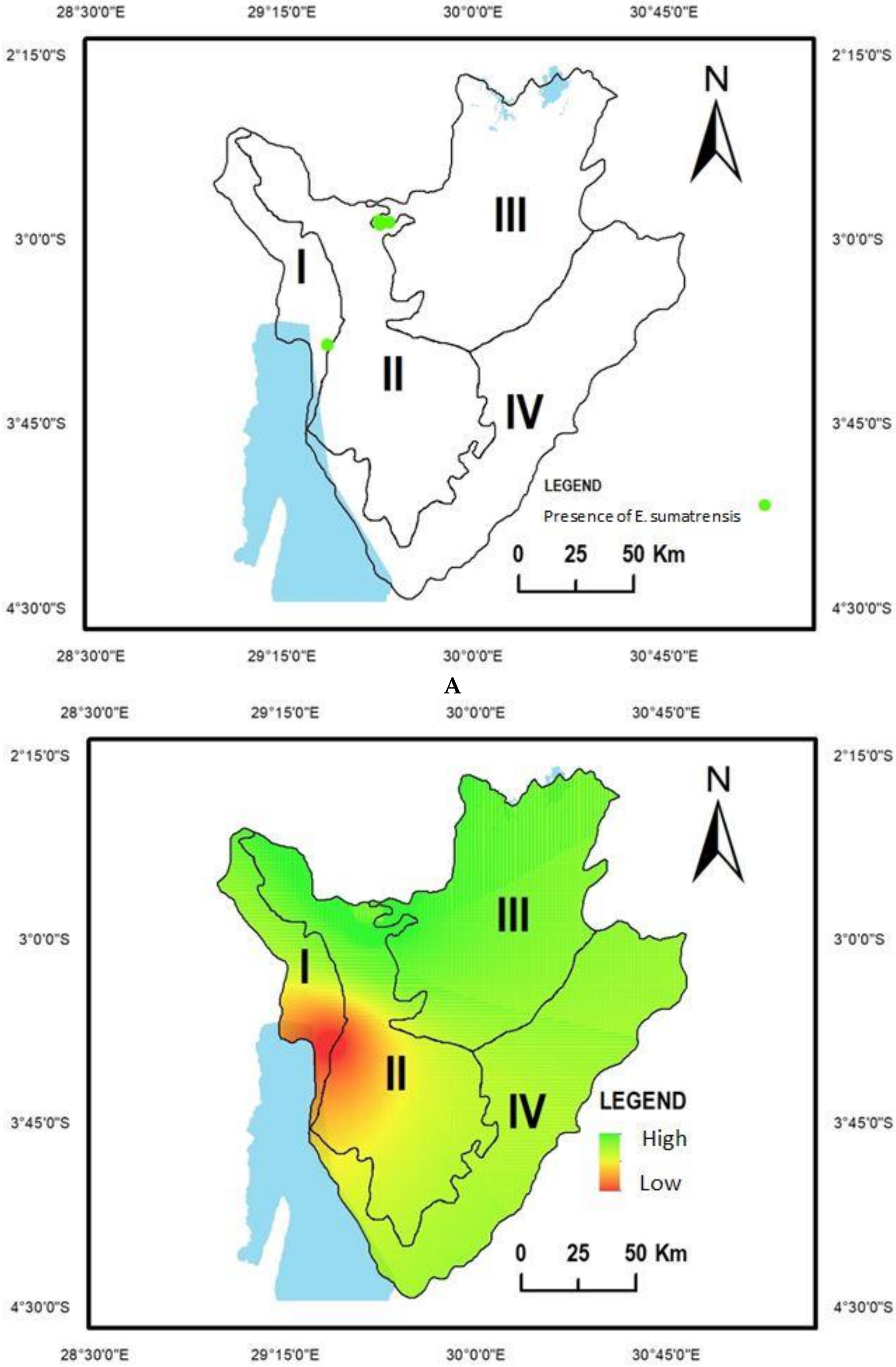
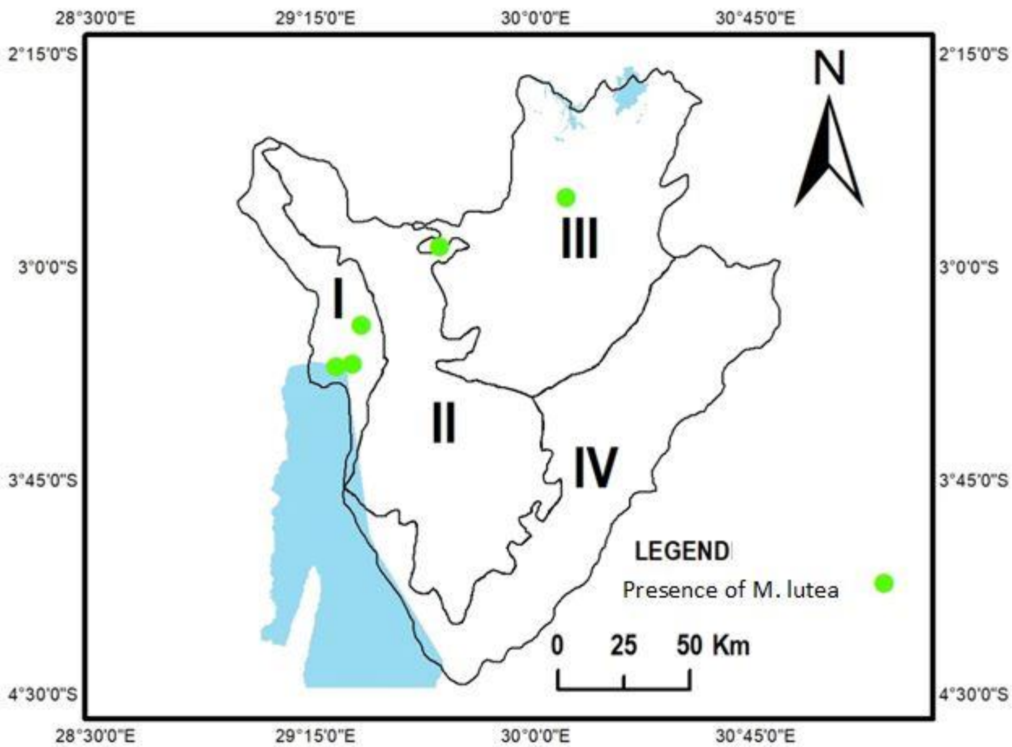
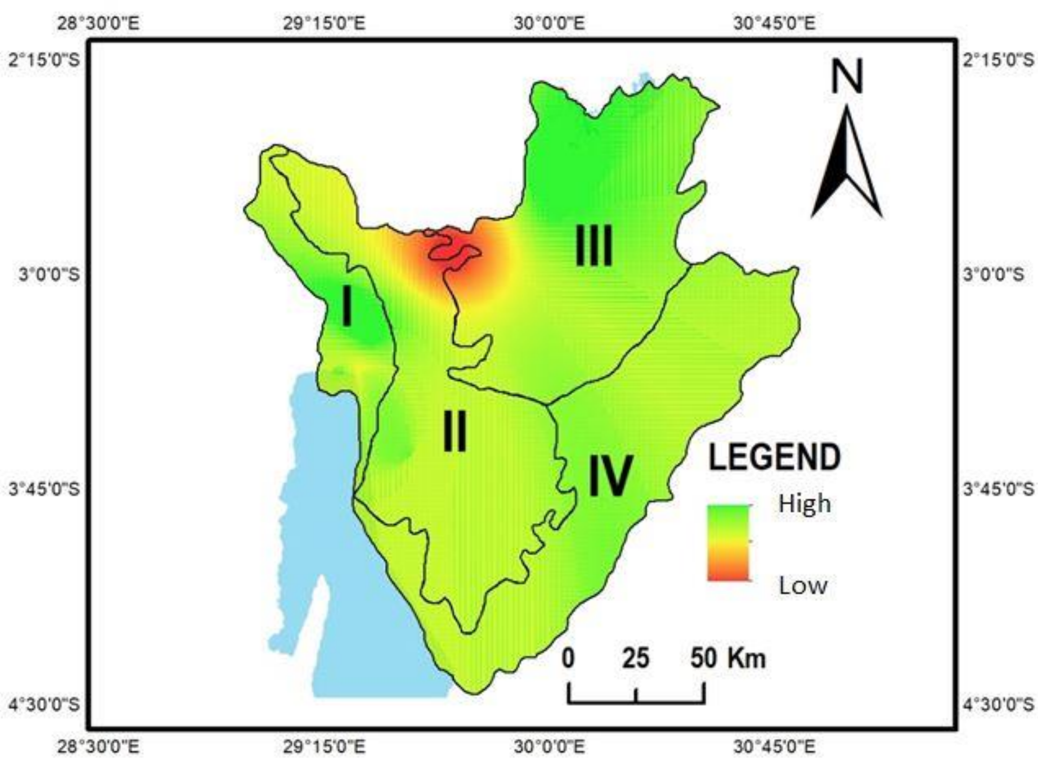


Figure 11. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of *__Erigeron__* *__sumatrensis__* *(A) in Burundi*



A



B

Figure 12. Potential distribution map (B) obtained by inverse distance weighting (IDW) using real presence points of Markhamia lutea (A) in Burundi

Geographical distribution based on literature

Although the exact distribution of plants can only be understood on a very large scale, regional and zonal scales, but also local scales can directly influence the geography of vegetation (Alexandre *et al.,* 1998). The establishment of the phytogeographical distribution (PD) allowed us to classify the 10 species considered in the phytogeographic subdivisions by considering the White's classification (1993).

According to this classification we distinguish 1 pantropical species, 1 African multi-regional species, 4 afrotropical species, 1 omni-Sudanese-Zambezian species, 1 paleotropical species, 1 Sudanese-Zambezian species with Eastern Ethiopian and Zambezian dominance and 1 Sudanese-Zambezian-Guinean linkage species.

Table 1. *Phytogeographical distribution of ten flagship plant species reported as antimalarial and mosquito repellent in Burundi according to White's classification (1993)*

Family	Species	DP
Asteraceae	*Erigeron sumatrensis* Retz.	Pan
	*Gymnanthemum amygdalinum (*Delile) Sch. Bip. ex Walp.	Plur-Afr
	Solanecio mannii (Hook.f.) C.Jeffrey	Afr-Trop
Bignoniaceae	*Markhamia lutea* (Benth.) K. Schum.	Afr-Trop
Fabaceae	*Senna didymobotrya* (Fresen.) H. S. Irwin & Barneby	SZ
	Sesbania sesban (L.) Merr.var. nubica Chiov.	Pal
Lamiaceae	*Plectranthus barbatus* Andrews	Afr-Trop
	Tetradenia urticifolia (Baker) Phillipson	Afr-Trop
Phytolaccaceae	*Phytolacca dodecandra* L'Hér.	SZ(EOZ)
Sapindaceae	*Dodonaea viscosa* Jacq.	LSZ-G

Pan: Pantropical species; Plur-Afr: African multi-regional species; Afr-Trop: Afrotropical species; SZ: Omni-Sudanese-Zambezi species; Pal: Paleotropical species; SZ(EOZ): Sudan-Zambezi species with Eastern Ethiopian and Zambezi dominance; LSZ-G: Sudanese-Zambézian and Guinean link species.

Table 2. Species- and habitat-specific distribution factors from the literature review

Species	**TB**	**TD**	**Habitats**
Erigeron sumatrensis Retz.	T	Pogo	Along roads and highways, abandoned arable land and field margins (Vladimirov, 2009); Fallows, fields, gardens (Havyarimana, 2020).

Gymnanthemum amygdalinum (Delile) Sch. Bip. ex Walp.	P	Pogo	Disturbed cultivated area, hillside, bush (Melly *et al.,* 2020); Fields, gardens, fallow land (Havyarimana, 2020)
Solanecio mannii (Hook.f.) C.Jeffrey	T	Pogo	Margins of dry or evergreen forest, secondary forest, riparian forest, on rocky slopes in the bush (Melly *et al.,* 2020); Fields, fallows, gardens (Havyarimana, 2020)
Markhamia lutea (Benth.) K. Schum.	P	Ptéro	Little disturbed forests, fields (Havyarimana, 2020)
Senna didymobotrya (Fresen.) H. S. Irwin & Barneby	P	Ballo	Bushes (Melly *et al.,* 2020); Fields, little disturbed forests, fallow lands (Havyarimana, 2020)
Sesbania sesban (L.) Merr.var. nubica Chiov.	P	Ballo	Low disturbance forests, fields, gardens, fallow lands (Havyarimana, 2020), Forests (Ndayishimiye, 2011)
Plectranthus barbatus Andrews	Ch	Scléro	Bushes, rocky meadows (Melly *et al.,* 2020); Low disturbance forests, fields, fallows (Havyarimana, 2020)
Tetradenia urticifolia (Baker) Phillipson	Ch	Scléro	Fields, fallows, gardens (Havyarimana, 2020); Rocky slopes (Melly *et al.,* 2020)
Phytolacca dodecandra L'Hér.	P	Ballo	Low disturbance forests (Havyarimana, 2020)
Dodonaea viscosa Jacq.	P	Ptéro	Little disturbed forests, savannahs, fallows (Havyarimana, 2020)

P: Phanerophytes Pogo: Pogonochores Sclero : sclerochores
Ch: Chamephytes Ptero : pterochores TB : Biological types
T: Therophytes Ballo : Ballochores TD : Type of diaspore

With respect to factors that may influence geographic distribution, species-specific factors such as biological type and diaspore type as well as ecological factors such as species habitat are considered in this study (Table 2). The most dominant biological type is the phanerophyte type (6 species). The therophyte (2 species) and champephyte (2 species) types are represented by the same number of species. In relation to the diaspore types, pogonochores (3 species) and ballochores (3 species) are represented by the same number of species, as are pterochores (2 species) and sclerochores (2 species).

Discussion

Geographical distribution maps

The geographical distribution maps obtained in this study show that the ten antimalarial and mosquito repellent species reported in Burundi are generally distributed in the Phytogeographic subdivision of Burundi. Considering the districts of Ndabaneze (1988), some deviations in distribution are noticeable especially in the Mosso and Malagarazi districts. These differences can be explained by the ecoclimatic characteristics specific to this area, which differentiate it from other phytogeographic regions of Burundi. The Moso depression is like a plain stretched along the Tanzanian border and drained by the Malagarazi, Rumpungwe and their tributaries (Bukuru and Rufuguta, 2013). This region has an ecology characteristic of the Zambezi zone (White, 1993) characterized by open forests, gallery forests, savannas and the Malagarazi swamp.

The potential distribution of G. amygdalinum shows that it is widely distributed in the southern part of Rwanda-Urundi district, in part of Malagarazi district especially in Makamba Province. It is also widely distributed in the Afromontane district, especially in the provinces of Gitega and Karusi. Our model also shows that the species *Gymnanthemum amygdalinum* is absent in a large part of the southern part of the Rwanda-Urundi district. This could be a result of the low representativeness of the actual presence points of the species. On the other hand, previous work has shown that the species grows in a style common to ecological zones in Africa, although it is sensitive to drought (Bonsi *et al.*, 1995) *in* (WAHO, 2013). As this low representativeness is noticed in most of the species studied, the models produced have limitations with respect to the potential distribution of the species. For the species *T. urticifolia*, it is mainly in the Afromontane district that shows the high occurrence, the northern part of the Rwanda-Urundi district, but also in the Graben district notably in Bubanza Province. Subsequently, the species P. barbatus when it, the high occurrence is manifested in the district Afromontane but also in the northern part of the Malagarazi.

Concerning the species S. didymobotrya, it reveals the strong occurrence in particular in more than three quarters of the whole territory because it is only in the North especially the pressures of the North and a small part of the depressions of the East in its northern termination where one notes the very weak occurrence tending even towards the absence. The species S. sesban as for it shows the strong occurrence in the center in and center East that is to say in the provinces of Gitega, Muramvya, Rutana and Kayanza, that is in a zone overlapping all the districts. However, it is also widely distributed in the northern part of the northern depressions, especially in the provinces of Kirundo and Muyinga. The species S. manii does not show any particular contrast of occurrence except in a small area within the Rwanda-Urundi District more precisely in the Kibira Park. P. dodecandra, on the other hand, generally shows high occurrence in the rest of the districts except in Mosso-Malagarazi District where it shows medium occurrence. Contrary to some works (WAHO, 2013) which showed that *Phytolacca dodecandra* species is encountered in forest, forest edge, riparian forest, thickets, wetter groves, along cropland fences and around houses, on mountain slopes and in open fields at 1500-3000 m altitude, the potential distribution model produced in this work shows that this species can be predicted even in low altitudes (<1000 m). The Viscosa species when it shows a high occurrence in the southern part of Rwanda-Urundi and Mosso-Malagarazi districts. As for E. sumatrensis, it is strongly distributed in the North and North-West, moderately distributed in Mosso-Malagarazi and weakly distributed in the West. Finally, M. lutea is moderately distributed everywhere but is strongly distributed in the northern depressions.

Finally, we note that the districts of Rwanda-Urundi, Afromontagnard but also Mosso-Malagarazi is the districts of high occurrence for all species studied, this coincides with the areas containing most of the protected areas and parks (Ndayishimiye, 2011) in other areas, we note that these are highly anthropized areas where the need to focus efforts of domestication or conservation.

Geographical distribution and its factors

This study shows that seven of the ten species reported as antimalarial and/or mosquito repellent in Burundi belong to the category of widely distributed species. These include the species *Erigeron sumatrensis* Retz., *Gymnanthemum amygdalinum* (Delile) Sch. Bip. ex Walp., *Solanecio mannii* (Hook.f.) C. Jeffrey, *Markhamia lutea* (Benth.) K. Schum., *Sesbania sesban* (L.) Merr.var. nubica Chiov, *Plectranthus barbatus* Andrews and *Tetradenia urticifolia* (Baker) Phillipson. Les trois espèces restantes notamment *Senna didymobotrya* (Fresen.) H. S. Irwin and Barneby, *Phytolacca dodecandra* L'Hér. and *Dodonaea viscosa* Jacq. are linkage species and therefore are not widely distributed.

The biological types represented in the species studied are phanerophytes, therophytes and chamephytes. The available literature on the distribution of species according to their biological types shows that phanerophytes are dominant in the peripheral fallows of Bururi and Kigwena forests and that the chamephytic trend is observed in the Imbo plain while therophytes are more observed in the savannahs of Ruvubu (Bangirinama *et al.,* 2011). The study of diaspora types shows the dominance of pogonochores and ballochores in the plants studied. However, previous work has shown that on a small scale, species may not occupy the entire space of their ecological niche, simply because of the vagaries of the evolution of the flora and fauna associated with their spread (Génin, 1995).

Diaspora dispersal patterns are very important in terms of geographic distribution because a species can only expand its range when individuals are able to disperse to a new region and then tolerate the new abiotic and biotic conditions encountered (Silva, 2016). On the other hand, the habitats of these species are varied. They are encountered in minimally or heavily anthropized habitats typically disturbed cultivated areas, secondary bush forests, fields, gardens, and fallow lands (Bangirinama *et al.,* 2011; Havyarimana, 2020; Melly *et al.,* 2020). The presence of these species in a variety of environments is an important indicator of their potential for development over a large part of the country. Because each conservation issue is unique to the environment and the people who manage and use the space (Marage, 2006), it is important to consider the conditions in each locality.

Conclusion and recommendations

This study of the geographical distribution of ten key plant species reported as antimalarial and mosquito repellent in Burundi highlighted areas of high and low occurrence. The results show that the potential distribution areas of these species are generally wide. Differences in distribution in some parts of Burundi are due to ecological conditions in certain districts. The species that were the subject of this study are present in multiple and varied environments, and have the potential to be cultivated throughout the country. However, additional studies will have to be conducted before the initiation of cultivation programs. In perspective, the distribution models obtained in this study can be used to predict potential sites for the cultivation of endangered species or in case of programs aiming at increasing the production of vegetable matter, especially for vegetable oil extraction units. This is also of interest for the management and development of plant resources in an environmental context marked by strong anthropic pressure and climate change.

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