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Akoda Kossi Amevivi[1, 2]
https://orcid.org/0009-0007-3526-2966

Wouyo Atakpama[2, 3]
https://orcid.org/0000-0001-7041-918X

Kourouma Koura[1]
https://orcid.org/0000-0002-2243-3152

Nounagnon Gérard Gouwakinnou[4]
https://orcid.org/0000-0002-3595-9831

Komlan Batawila[2]
https://orcid.org/0000-0003-2781-3063

Jean Cossi Ganglo[1]
https://orcid.org/0000-0003-4212-6448

SPATIAL DISTRIBUTION AND CONSERVATION STRATEGY OF THE *ADANSONIA DIGITATA* L. IN THE CONDITIONS OF CLIMATE CHANGE AND PARASITISM BY *ANALEPTES TRIFASCIATA* F. IN TOGO

[1] Forest Sciences Laboratory (LSF), Department of Environmental Planning and Management, Faculty of Agricultural Sciences, University of Abomey-Calavi (UAC), 01 BP 526, Cotonou, Benin
[2] Laboratoire de Botanique et Ecologie Végétale (LBEV), Département de Botanique, Faculté des Sciences (FDS), Université de Lomé (UL), 01 BP 1515, Lomé 1, Togo
[3] West Africa Plant Red List Authority (WAPRLA), IUCN Species Survival Commission, Rue Mauverney 28, 1196 Gland, Switzerland
[4] Laboratory of Ecology, Botany and Plant Biology (LEB), Faculty of Agronomy, University of Parakou (UP), 03 BP 125, Parakou, Benin

Abstract

Baobab (*Adansonia digitata* L.) is a multiple-use species of high socio-economic importance in tropical Africa. It faces anthropogenic, climatic and parasitic pressures that are likely to affect its sustainability. This study provides new elements for more effective baobab management in the context of climate and global change in Togo. Specifically, it aims to: (i) determine the impact of climate change on the spatial distribution of *A. digitata* and *A. trifasciata*, and (ii) identify priority areas for the conservation and sustainable use of *A. digitata* co-products in the face of climate change and parasitism in Togo. The algorithm based on the maximum entropy of the baobab was developed in order to model potential habitats. Modelling was based on 17 environmental variables and occurrences of *A. digitata* and its parasite, *Analeptes trifasciata* in West Africa. The algorithm of maximum entropy (MaxEnt) was used. Forecasts were performed for SSP 126 and SSP 585 scenarios. Habitats were prioritised for conservation by combining current and future models using Zonation software. Currently, *A. digitata* and to *A. trifasciata* are predicted to occupy about 80.1 % and 91 % of the Togolese territory, respectively. By 2055, about 50 % of the highly favourable habitat for *A. digitata* will have been lost due to unfavourable habitat. This decline is greater in the SSP 585 scenario than SSP 126 scenario. It is recommended to implement an integrated pest management strategy and to introduce *A. digitata* in the most favourable areas, considering the spatial distribution of the parasite. Conservation of *A. digitata* must take into account areas suitable for its growth, development and reproduction. In situ conservation in agroforestry systems and home gardens should be promoted for the sustainable use of *A. digitata* by-products in Togo.

Keywords: *Adansonia digitata* L., *Analeptes trifasciata* F., habitat, sustainable management, Togo

ROZMIESZCZENIE PRZESTRZENNE I STRATEGIA OCHRONY *ADANSONIA DIGITATA* L. W WARUNKACH ZMIAN KLIMATYCZNYCH I PASOŻYTNICTWA ZE STRONY *ANALEPTES TRIFASCIATA* F. W TOGO

Abstrakt

Baobab (*Adansonia digitata* L.) jest wielofunkcyjnym gatunkiem o dużym znaczeniu społeczno-gospodarczym w tropikalnej Afryce. Roślina ta stoi w obliczu antropogenicznej, klimatycznej i pasożytniczej presji, która prawdopodobnie wpłynie na jej długoterminowe przetrwanie. Niniejsza praca dostarcza nowych elementów do bardziej efektywnego zarządzania baobabem w kontekście zmian klimatycznych i globalnych w Togo. W szczególności: (i) zidentyfikowano obecne potencjalne siedliska *A. digitata* i jego pasożyta *A. trifasciata*; (ii) oszacowano wpływ zmian klimatycznych na przestrzenne rozmieszczenie *A. digitata* i *A. trifasciata*; oraz (iii) określono priorytetowe siedliska dla ochrony i zrównoważonego użytkowania *A. digitata* w obliczu zmian klimatycznych i ataków pasożyta *A. trifasciata* w Togo. Modele zostały uruchomione na podstawie 17 zmiennych środowiskowych i punktów występowania *A. digitata* i *A. trifasciata* w Afryce Zachodniej, przy użyciu algorytmu maksymalnej entropii (MaxEnt). Prognozy przeprowadzono w ramach scenariuszy SSP 126 i SSP 585. Siedliska chronione zostały uszeregowane priorytetowo poprzez połączenie obecnych i przyszłych modeli przy użyciu oprogramowania Zonation. Przewiduje się, że około 80,1 % terytorium Togo jest obecnie bardzo korzystne dla *A. digitata* i 91 % dla *A. trifasciata*. Do 2055 roku około 50 % bardzo korzystnych siedlisk dla *A. digitata* zostanie utraconych na rzecz niekorzystnych siedlisk. Spadek ten jest większy w przypadku scenariusza SSP 585. Zaleca się wdrożenie zintegrowanej strategii ochrony przed szkodnikami. Sugerowana jest strategia ochrony in situ dla *A. digitata* uwzględniająca obszary priorytetowe. Należy zachęcać do ochrony circa-situ w systemach rolno-leśnych i ogrodach przydomowych.

Słowa kluczowe: *Adansonia digitata* L., *Analeptes trifasciata* F., siedlisko, zrównoważone zarządzanie, Togo

1. INTRODUCTION

Baobab (*Adansonia digitata* L.) is an integral part of many agricultural systems in sub-Saharan Africa. It is undemanding of soil quality, but prefers limestone and deep, well-drained soils [1]. Baobab by-products have the potential to improve nutrition, thereby enhancing food security and promoting rural development [2, 3]. This plant is important for the local population. It plays an important role in maintaining the microclimate. Despite its benefits and services, *A. digitata* is under severe pressure. A reduction in *A. digitata*'s range would result in cultural, religious, food and ecological disruption. The pressures on baobab are anthropogenic, climatic and parasitic. Urbanization, population explosion, agriculture and increasing use of the various parts of the plant are the main anthropogenic threats [3, 4]. The diversified and widespread use of the by-products coming from this species is exerting strong pressure on the latter [3]. In addition to these anthropogenic pressures, there are also parasitic and climatic pressures [5–7]. These are no longer the least of the impacts. Increased frequency, intensity and severity of droughts, floods and heatwaves, as well as continued sea-level rise, will increase food security risks in vulnerable regions [8]. Temperatures will rise moderately to strongly by +1.5°C to +2°C, with little or no adaptation by humans, animals, plants, etc. [9]. In Africa, more than half of the oldest trees have died completely, especially the oldest or largest trunks since 2005 [10]. Years of drought and rising temperatures could prevent them from recovering after flowering or losing their leaves [10]. Several pests such as aphids, mealybugs, mites and moths attack *A. digitata* plants. The main host plants of *Analeptes trifasciata* in West Africa are reported to be Bombacaceae, especially *Bombax costatum* Pellegr & Vuillet, *A. digitata* and *Ceiba pentandra* (L.) Gaertn [11]. This parasite cuts the branches and/or stems by chewing them at the base. Studies on the climatic conditions that determine the presence of the species show that there are three subpopulations in Togo [12]. However, knowledge of how changing of climatic conditions will affect the species' habitat in the future remains incomplete. The combined effects of climate change and pests on its distribution are also unknown. This study provides new elements for more efficient management of the baobab in the context of climate and global changes. It aims to address three main issues. What are the current and future spatial distributions of *A. digitata* and its parasite *A. trifasciata* in Togo? How do climate change and the *A. trifasciata* parasite affect the spatial distribution of *A. digitata*? What are the priority habitats for the conservation and sustainable use of the baobab in Togo? The answers to these questions may help to develop sustainable management strategies for *Adansonia digitata* in the context of climate change and parasitism.

2. LITERATURE REVIEW

2.1. Study Area

Togo, a country in West Africa, stretches from the 6th to the 11th parallel north. It is approximately 650 km long (Fig. 1) with an area of 56,600 km². The population was estimated at approximately eight (8) million in 2022 [13]. The relief is not very rugged, with the exception of the Atakora mountain range, which crosses the country. Some of its peaks in the southern part exceed 900 m. The hydrographic network is made up of several rivers. The most important are: the Oti, the Mono, the Zio and the Haho. The climate is intertropical overall. However, it varies considerably from south to north, dividing the country into two climatic regimes, the boundary of which is at the latitude of Blita. There are several

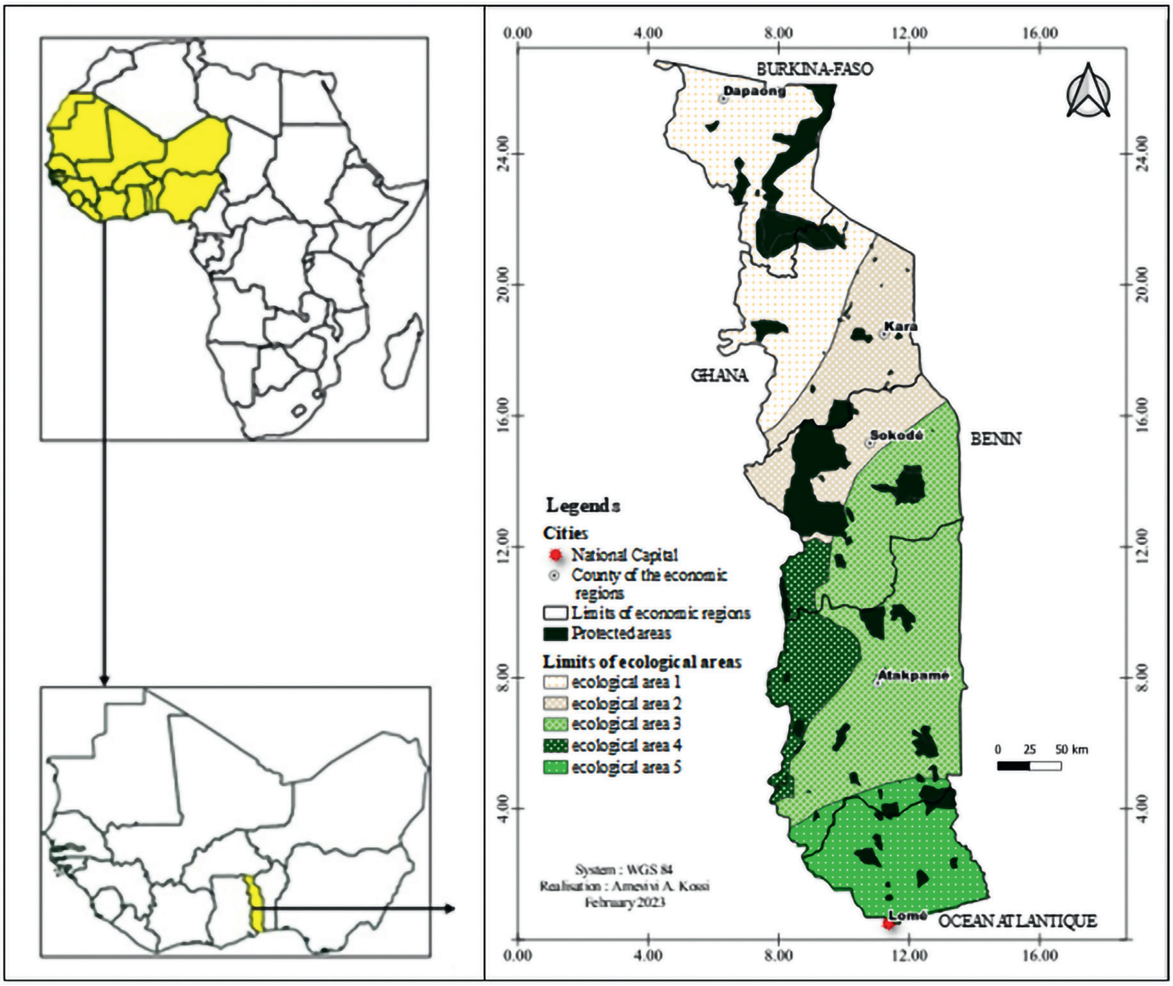

Fig. 1. Subdivision of economic regions and ecological zones of Togo

Ryc. 1. Podział na regiony ekonomiczne i strefy ekologiczne w Togo soil types, including: tropical ferruginous soils; poorly developed soils; vertisols; ferrallitic soils and hydromorphic soils in Gley [14]. The majority of Togo is covered by savannahs [15]. There are five [5] ecological zones (Fig. 1) defined on the basis of relief and floristic affinities [16]. The northern part of the country corresponds to the northern plains (zone I). The main vegetation type is that of the Sudanian savannahs, dominated by thorny plants [17]. These are largely replaced by agroforestry parks with the African locust bean (*Parkia biglobosa* (Jacq.) R.Br. ex G.Don), shea butter tree (*Vitellaria paradoxa* CF Gaertn.), roast palm trees (*Borassus aethiopum* Mart.), tamarind tree *(Tamarindus indica* L.), the African baobab *(Adansonia digitata*) [4, 8–20]. The northern mountain zone (zone II) is an area of dense dry forests, open forests and diverse savannahs [21, 22]. Ecological zone III corresponds to the vast of plains in the centre of the country. Guinea's savannas dominate this zone [15]. There are also open forests [23] and dense dry forests. These are mostly found in protected areas [24]. Ecological zone IV corresponds to the southern part of the Togo mountains. It consists of Guinean savannahs and dense semi-deciduous forests [25]. The original formations of this area are almost degraded. They have been converted into agroforests for coffee, cocoa and fruits [26–29]. Southern Togo's coastal plain of southern Togo (zone V) has a field-fallow mosaic character [30]. Mangroves, grasslands, floodplain savannahs and patches of community/sacred forests are also present [31, 32].

2.2. Description of Species

2.2.1. African Baobab: *Adansonia digitata L.*

The genus *Adansonia* belongs to the Malvaceae family and the Malvales order [33]. It contains eight species, six of which are endemic to Madagascar: *A. grandidieri* Baill., *A. madagascarensis* Baill., *A. perrieri* Capuron, *A. rubrostipa* Jum. & H. Perrier, *A. suarezensis* H. Perrier and *A. za* Baill. The species *A. gregorii* F. Muell is restricted to north-western Australia (Kimberley district and Victoria and Fitzmaurice River region) [33]. *A. digitata* L. is the most widespread species on the African continent and the best described species [1]. It grows in environments where the annual rainfall is between 90 mm and 1400 mm. The rainy season lasts between 3 and 6 months [1]. This tree therefore has a drought tolerance of 9 months [1]. The plant's low requirements in terms of soil quality, and the wide range of climatic conditions it can tolerate, are the main reasons for its wide distribution across the African continent [1].

2.2.2. *Analeptes trifasciata* F.

Analeptes trifasciata is a species of flat-faced longhorn beetle. It belongs in the subfamily Lamiinae of the family Cerambycidae [5]. It is found in West and Central Africa: Angola, Benin, Cameroon, Central African Republic, Democratic Republic of Congo, Ethiopia, Ghana, Ivory Coast, Kenya, Liberia, Niger, Nigeria, Senegal, Sierra Leone and Togo [5, 34]. *Analeptes trifasciata* is a typically savannah inhabitant, but it also occurs in forest margins with plants of the Anacardiaceae family [5, 34]. *Analeptes trifasciata* has several synonyms. One of them is *Diastocera trifasciata* (Fabricius) [5, 34]. Several pests such as aphids, mealybugs, mites and moths attack *Adansonia digitata* plants. *Analeptes trifasciata* has been identified as the most vicious pest of *Adansonia digitata* [5]. The presence of this pest is indicated by the sawdust deposit on the leaves after cutting [35].

2.3. Material and Methods

2.3.1. Current and future spatial distribution of *A. digitata* and *A. trifasciata*

Occurrence data

Occurrence data from the literature and those downloaded from Global Biodiversity Information Facility (GBIF) website (www.gbif.org) were supplemented by occurrence data collected in the field. Field data were collected throughout the five ecological zone of Togo. The literature data were those of Atakpama [12]. These three sources of occurrence data were combined and then carefully formatted. Duplicate occurrences, data without geographic coordinates, data that were too old (the required time of collection ≤ 1800) and data from herbarium specimens were deleted. *A. digitata* and *A. trifasciata* are terrestrial species, their occurrences which were found in seas and oceans were deleted. Altogether, 4253 occurrences of *A. digitata* and 1112 occurrences of *A. trifasciata* were considered (Table 1, Fig. 2).

Improved modelling of ecological niches or spatial distributions can be achieved by including intraspecific

Table 1. Number and source of species occurrence used for modelling
Tabela 1. Liczba i źródło użytych do modelowania informacji o występowaniu gatunków

Occurrences	Database GBIF		Field Data		Atakpama [12]		
	Number	(%)	Number	(%)	Number	(%)	
A. digitata	1655	38.6	538	12.6	2060	48.8	4253
A. trifasciata	707	63.6	405	36.4	–	–	1112

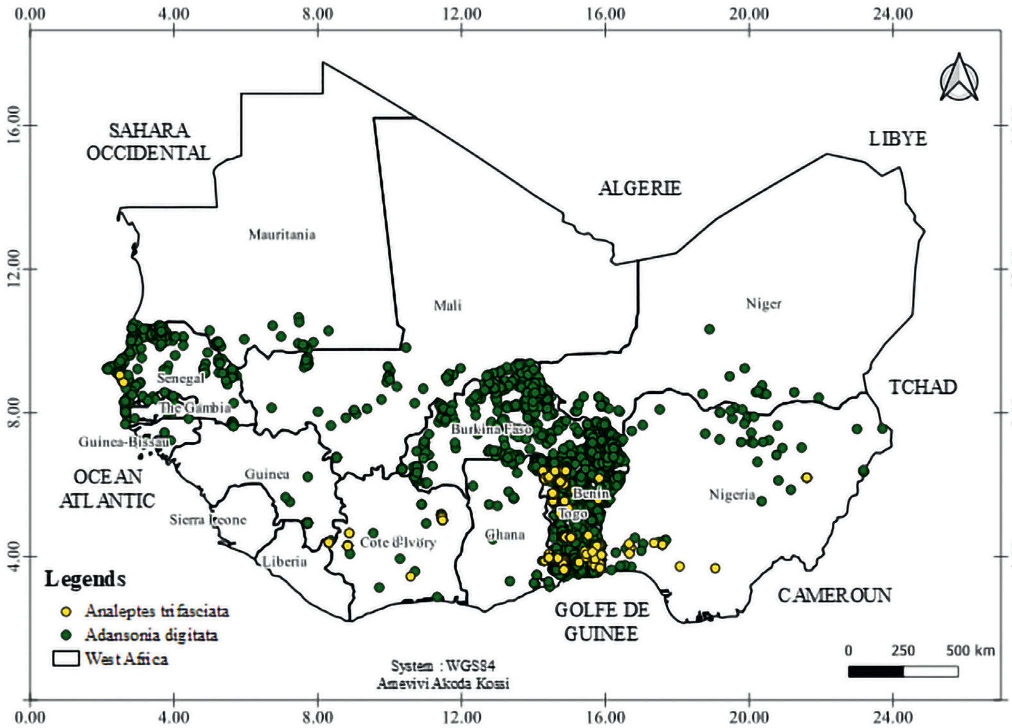

Fig. 2. Spatial distribution of occurrence of *A. digitata* and *A. trifasciata* in West Africa
Source of presence points: *A. trifasciata* : GBIF.org (14 January 2023) GBIF Occurrence Download https//doi.org/10.15468/dl.hzf-pmn; *A. digitata*: GBIF. org (14 January 2023) GBIF Occurrence Download https://doi.org/10.15468/dl.drjnk5; [12] and field data
Ryc. 2. Rozmieszczenie przestrzenne występowania *A. digitata* i *A. trifasciata* w Afryce Zachodniej
Źródło informacji: *A. trifasciata*: GBIF.org (14 January 2023) GBIF Occurrence Download https//doi.org/10.15468/dl.hzfpmn; *A. digitata*: GBIF. org (14 January 2023) GBIF Occurrence Download https://doi.org/10.15468/dl.drjnk5; [12] oraz dane terenowe

variation in distribution models for species with wide spatial distributions [12, 36]. As a result, the impact of climate change can be better assessed to inform conservation decisions. Due to the wide distribution of *A. digitata* [1, 4], intraspecific variation (subpopulations) of *Adansonia digitata* were considered for modeling its spatial distribution.

Environmental data

Soil, altitude and bioclimatic variables were the environmental variables used for modelling. These environmental variables (Table 2) are most directly related to the physiological aspects of growing plants. The ensemble climate models were used at a resolution of 30 seconds. Soil is known to influence on the distribution of *A. digitata* [1]. It was taken from the World Soil Database [37]. The “soil” parameter was not considered for the modelling of the insect. This is because the insect is not directly affected by soil like plants. According to [11] and [34], the presence of the host plant species and the climatic conditions are determinants of the presence, spread and disappearance of *A. trifasciata* in the environment. Altitude is also an environmental factor affecting insects distribution [38]. The altitude and current bioclimatic variables are those of WorldClim [39, 40] and http://www.worldclim.org. Future bioclimatic environmental data for 2055, SSP126 and SSP585 scenarios have been downloaded from WorldClim2.1 website, platform Chelsa V.2.1 (https://www.worldclim.org/data/cmip6/cmip6climate.html). The visualisation of bioclimatic variables on the Atlas platform (www.ala.org.au) shows the discontinuities of the variables Bio8, Bio9, Bio18, and Bio19 in the study area. These discontinuities have been reported in Americas [41] and Sub-Saharan Africa [36, 42]. They have been attributed to sudden changes in the quarterly periods [42]. Therefore, these variables were included in the modeling.

Discrimination of A. digitata *subpopulations based on environmental variables*

QGIS 3.16 software was used to extract and process the environmental data to the same extent, spatial resolution and projection. Environmental variables were aggregated and/or downscaled and adjusted. R software V4.3.1 (R Development Core Team, 2014) was used for data transformations, statistical analyses and graphical representations [36]. Considering local adaptation, the occurrence of *A. digitata* could be classified into different subpopulations according to the climatic zones of West Africa: desert zone, arid zones (arid and dry tropical), humid tropical and the equatorial zone. The raster values of the environmental variables at each site of occurrence were extracted using the R package "Raster". A Principal Component Analysis (PCA) was then performed on the matrix of environmental variables and *A. digitata* occurrence. The R packages "Factoshiny" and "FactoMine R" were used [43]. This analysis allowed the identification of potential subpopulatio ns (SP) of *A. digitata* [12, 44].

Running the model

The maximum entropy approach (MaxEnt 3.4.1) was used to model the species distribution via an independent Java program [45]. This algorithm is one of the best methods for modelling species distribution. It is known to produce reliable models (46). MaxEnt modelling results include the assessment of model performance, each variable's contribution to the model, and species presence probability at each of the study area pixel [45, 46]. This assessment is to measure the com-

Table 2. Environmental variables used for modelling of spatial distribution of species of interest
Tabela 2. Zmienne środowiskowe zastosowane w modelowaniu rozmieszczenia przestrzennego interesującego nas gatunku

	Environmental variables
Hwsd **Elev**	Soil types Altitudem
Bioclimatic variables	
Bio 1	Annual mean temperature °C
Bio 2	Mean diurnal range – Means of monthly (max temp – min temp) °C
Bio 3	Isothermality (Bio 2/Bio7) (100) %
Bio 4	Temperature seasonality (standard deviation × 100) °C
Bio 5	Maximum temperature of the warmest month °C
Bio 6	Minimum temperature of coldest month °C
Bio 7	Temperature annual range (Bio5-Bio6) °C
Bio 10	Mean temperature of warmest quarter °C
Bio 11	Mean temperature of the coldest quarter °C
Bio 12	Annual precipitation mm
Bio 13	Rainfall of wettest month mm
Bio 14	Precipitation in driest month mm
Bio 15	Precipitation seasonality (Coefficient of Variation) mm
Bio 16	Precipitation of the wettest quarter mm
Bio 17	Precipitation of the driest quarter mm

pliance between the model predictions and observations [47, 48]. Cross-validation, which makes it possible to examine the variability in the construction of the model, using part of the data (25 %) for calibration, remains the first test to validate the predictions of Species Distribution Models (SDMs) [48]. Environmental layers were converted to ASCII using QGIS 3.16.1 in order to run MaxEnt.

Model validation

Model validity is characterised by sensitivity and specificity [47]. The Receiving Operator Characteristic (ROC) curve can be constructed from these two parameters [49]. The performance and quality of the model while correctly predicting the occurrence of the species was assessed by calculating the area under the ROC curve (AUC), a threshold that measures the accuracy of the model prediction [50]. The interpretation of the AUC values was done as proposed by [51]. The model is "excellent" if AUC > 0.90; "good" if 0.80 < AUC ≤ 0.90; "acceptable" if 0.70 < AUC ≤ 0.80; "bad" if 0.60 < AUC ≤ 0.70 and "invalid [12, 36] was used to assess the decision thresholds on prediction accuracy and the model performance. The Jackknife test [52] was also carried out on the variables considered in order to determine the predictive power of each variable and to identify those that contribute most to the model [47].

Mapping of habitats

In order to better characterise the distribution of *A. digitata* and *A. trifasciata*, an "S" threshold was used to delineate potential areas. The threshold retained is that relating to the 10 percentile training presence [45], which represents the probability of finding 90 % of occurrence in this potential suitable area [47]. Based on the threshold "S", four intervals presence of probability "P" of the distribution were defined: Unfavourable (P ≤ S/4), Less favourable (S/4 ≤ P ≤ S/2), Moderately favourable (S/2 ≤ P ≤ S) and Highly favorable (P > S) [12, 47].

2.3.2. Impact of climate and global changes on *A. digitata* and *A. trifasciata*

The shapefile layers were superimposed by vectorising the classified rasters of the different subpopulations [36]. For each distribution model two layers were considered: current and future. The impact of climate and global change on the spatial distribution of *A. digitata* and *A. trifasciata* was assessed by analysing the dynamics of current and future distribution. QGIS 3.16 coupled with the Microsoft Excel spreadsheet were used for this analysis. Habitat changes analysis made it possible to identify the changes at each habitat level under the SSP 126 and SSP 585 scenarios by 2055.

2.3.3. Definition of priority habitats

Using Zonation 4.0 software, an initial classification of the conservation priorities for each species was obtained. The map of habitats of *A. digitata* was ranked from the lowest priority, indexed 1 to the highest one, indexed 7. For *A. trifasciata*, the hierarchy goes from 1, the zone with the highest incidence to 7, the zone with the lowest incidence. This classification is based on the hypothesis according to which the presence and development of the baobab are determined not only by pedoclimatic factors, but also by the incidence of parasites. A high incidence of parasitism reduces the capacity of the baobab to develop and spread. The two are then intersected using the ArcGiS Pro Intersect tool in order to highlight the priority areas for *A. digitata* cultivation and conservation in the context of climate change and *A. trifasciata* parasitism.

3. RESULTS

3.1. Spatial Distribution of *A. digitata* Habitat

3.1.1. Distribution of baobab subpopulations

The first two axes of the Principal Component Analysis (PCA) (Dim1 = 51.7 % and Dim 2 = 21.0 %) discriminated of *A. digitata* subpopulations in West Africa with a 95 % confidence interval for clustering. A distinction with overlapping subpopulations (SP) of *A. digitata* is evident from PCA results (Fig. 3).

Three subpopulations can be distinguished on the scale of the climatic gradient in Togo (Fig. 4). These are: the Sudanese zone subpopulation (*Adansonia*_SP 1), the Sudano-Guinean zone subpopulation (*Adansonia*_SP2) and Guinean zone subpopulation (*Adansonia*_SP 3).

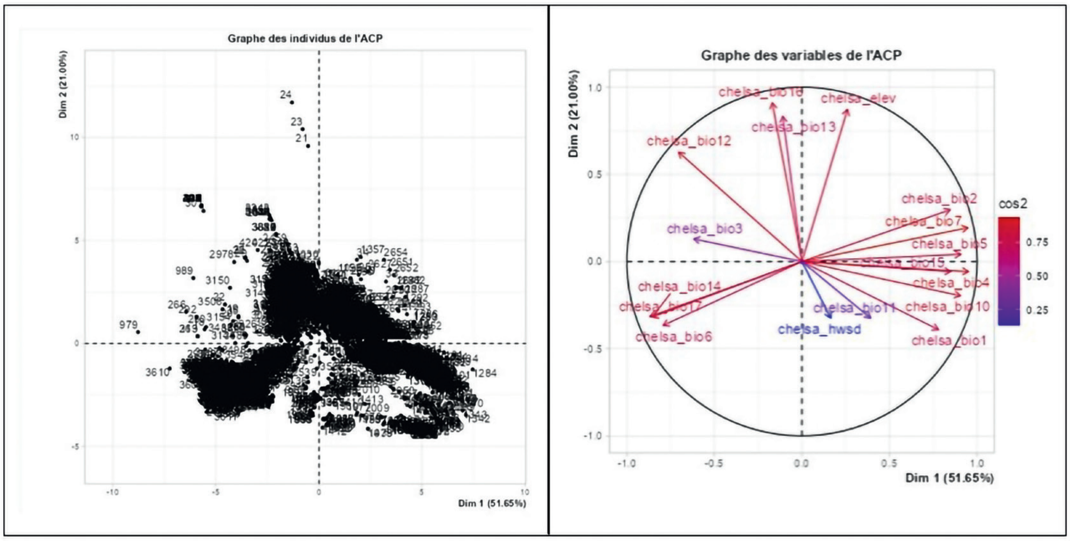

Fig. 3. PCA based on environmental variables to distinguish of *A. digitata*
Ryc. 3. PCA na podstawie zmiennych środowiskowych dla wyróżnienia populacji *A. digitata*

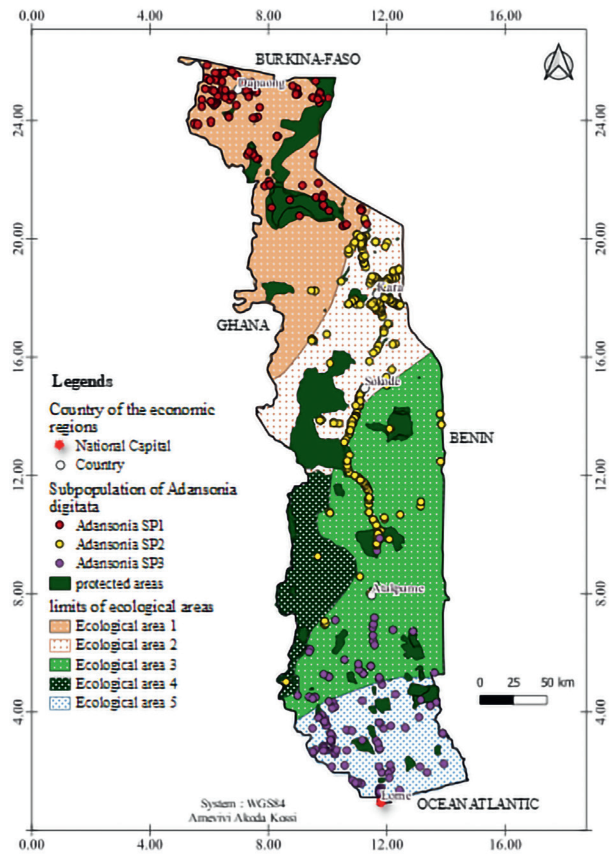

Fig. 4. Spatial distribution of subpopulations of *A. digitata* in Togo
Ryc. 4. Rozmieszczenie przestrzenne subpopulacji *A. digitata* w Togo

3.1.2. Current and future potential habitat of *A. digitata*

The average AUC of distribution models of *A. digitata* subpopulations is ≥ 0.92 for TSS ≥ 0.77 (Table 3). This indicates the robustness of the models. It also demonstrates the excellent performance of the models in predicting the favourable habitats of *A. digitata* subpopulations.

Table 3. Validation index of distribution models of *A. digitata* subpopulations
Tabela 3. Indeks walidacji modeli dystrybucji subpopulacji *A. digitata*

	Adansonia SP1	*Adansonia* SP2	*Adansonia* SP3
AUC	0.92	0.98	0.97
TSS	0.77	0.91	0.84

Precipitation in the wettest quarter (Bio16), soil and seasonality precipitation (Bio15) are, in that order, the main variables contributing more than 10 % for the *Adansonia* SP1 subpopulation. For *Adansonia* SP2 subpopulation, soil, precipitation in the driest quarter (Bio17) and seasonal precipitation (Bio15) are, in that order, the most important variables with a contribution of more than 20 %. Precipitation in the driest month (Bio14), precipitation in the driest quarter (Bio17), soil

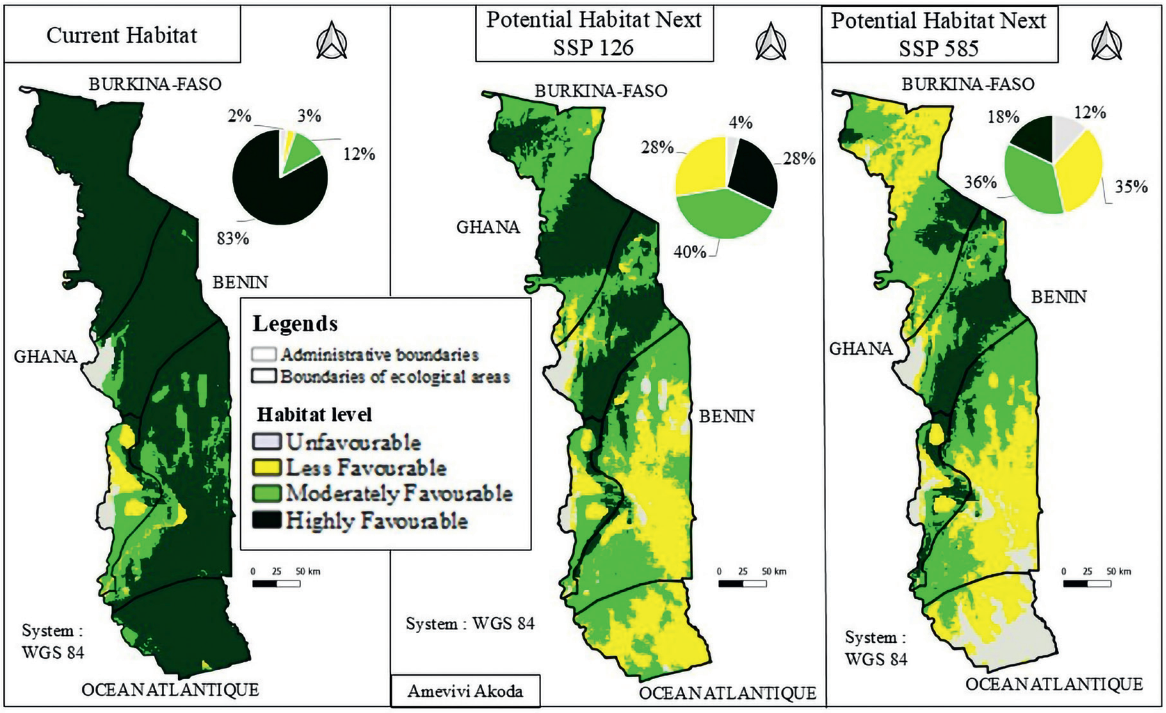

Fig. 5. Current and future spatial distribution of *A. digitata* in Togo
Ryc. 5. Obecne i przyszłe rozmieszczenie przestrzenne *A. digitata* w Togo

and annual precipitation (Bio12) are, in that order, the most important variables with a contribution greater than 10 % to the *Adansonia* SP3 subpopulation. The Jackknife test of the importance the variables shows that the soil (Chelsa_hwsd) is the variable that reduces the gain the most when it is omitted. Soil seems to give the model with information that is not present in the other variables. This shows the importance of this variable for the spatial distribution of *A. digitata* subpopulations and is in line with literature and with the survey data carried out in the field. Current climatic conditions predict that the ecological zones I, II, III and V are mostly highly favourable for *A. digitata* in Togo (Fig. 5). Conversely, part of the Mô plain in ecological zone II and part of the ecological zone IV are unfavourable. The forest zone of Togo (zone IV) is more or less favourable to this species.

The habitats of *A. digitata* in Togo will be affected by climatic and global changes (Fig. 6). Under the SSP 126 (very optimistic) and SSP 585 (very pessimistic) scenarios, highly favourable habitats are predict-

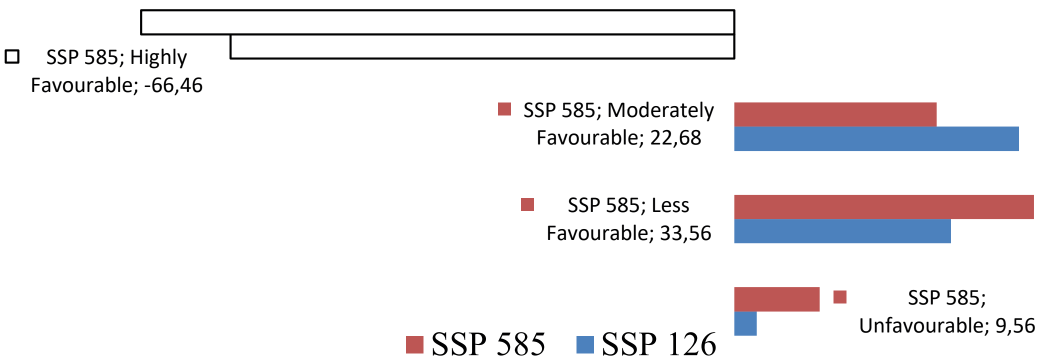

Fig. 6. Trend dynamics of *A. digitata* habitats by 2055 in Togo
Ryc. 6. Dynamika zmienności siedlisk *A. digitata* do roku 2055 w Togo

ed to decrease significantly (more than 50 %) by 2055. In contrast, moderately favourable and less favourable habitats are projected to increase by more than 20 % by 2055 under both scenarios. For unfavourable habitats, at the level of the SSP 585 scenario, the increase in Togo by 2055 is more remarkable (about 9 %).

3.1.3. Habitat change of *A. digitata*

Habitat quality is most likely to be degraded under all scenarios (Fig. 7). Specifically, the SSP 585 scenario would lead to an overall deterioration of habitat quality (72. 55 %) for the southern and coastal plains under the SSP 585 scenario (Table 4). In the southern and northern

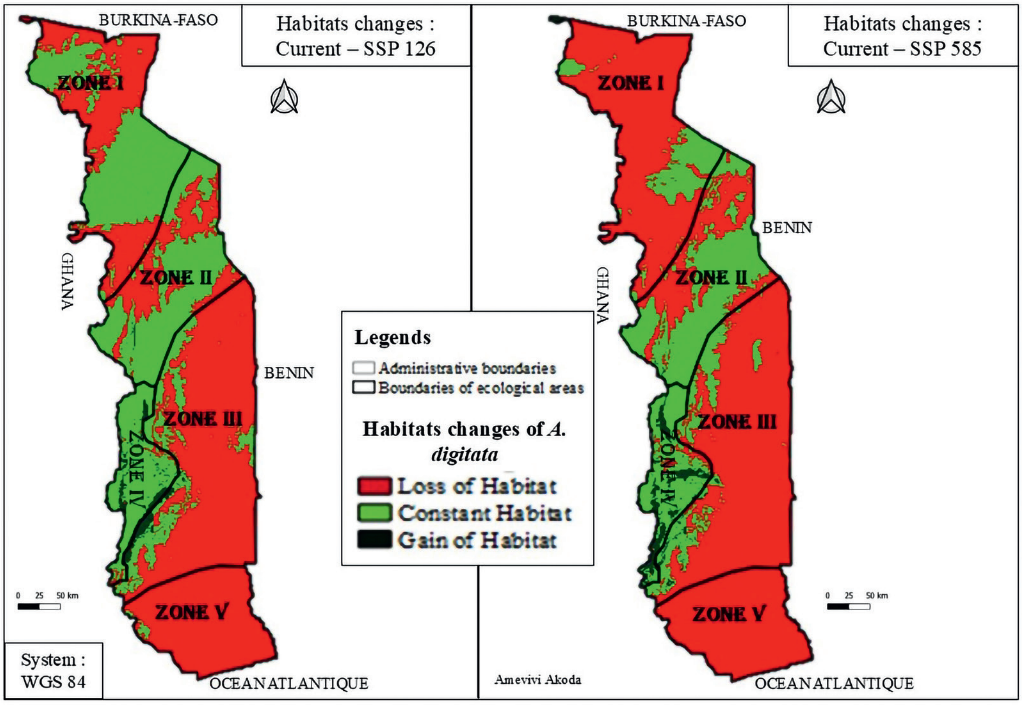

Fig. 7. Habitat changes of *A. digitata* under the impact of climate change
Ryc. 7. Zmiany siedlisk *A. digitata* pod wpływem zmian klimatu

Table 4. Variation in the quality of *A. digitata* habitats according to the SSP 126 and SSP 585 scenarios
Tabela 4. Zróżnicowanie jakości siedlisk *A. digitata* wg scenariuszy SSP 126 i SSP 585

Scenario	Habitats	Loss	Constant	Gain
SSP 126	Unfavourable	0.00 %	2.13 %	0.31 %
	Less Favourable	0.16 %	2.23 %	0.30 %
	Moderately Favourable	4.72 %	6.09 %	1.00 %
	Highly Favorable	56.44 %	26.62 %	0.00 %
	Sous-total	**61.32 %**	**37.08 %**	**1.60 %**
SSP 585	Unfavourable	0.00 %	2.20 %	0.25 %
	Less Favourable	0.61 %	2.04 %	0.31 %
	Moderately Favourable	5.49 %	4.73 %	1.51 %
	Highly Favorable	66.46 %	16.41 %	0.00 %
	Sous-total	**72.55 %**	**25.38 %**	**2.06 %**

mountains, the improvement in habitat quality will be noticeable. These areas also have the highest predicted stability of habitat quality (37.08 %) under the SSP 126 scenario by 2055.

Under the SSP 585 scenario in Ecological zone IV, a gain of unfavourable (0.25 %) and less favourable (0.31 %) habitats is observed in favourable of moderately favourable and highly favourable habitats (Table 3). Zones V, III, II and I also show more habitat loss (72.55 %) than gain. However, in Ecological zone IV, the habitat gain for *A. digitata* under the SSP 585 scenario by 2055 is greater than the habitat loss. It can be concluded that the habitats of the five ecological zones in Togo will be affected in different ways by the effects of climate and global changes under the two scenarios.

3.2. Spatial Distribution of *A. trifasciata* Habitat

3.2.1. Current and future potential habitat of *A. trifasciata*

Average area under the curve (AUC) for 10 replicate was 0.85. This value indicates a good predictive performance of the model. The True Skill Statistic (TSS) value at the threshold of 0.4 was 0.6, showing that the model outperformed than the random model. Jackknife test of variable importance and variable contributions suggests that: annual precipitation (bio12), precipitation of driest month (bio14) and temperature annual range (bio5-bio6) (bio7) are the environmental variables that contribute most to the spatial distribution of *A. trifasciata* with the contribution greater than 10 %. Under current climatic conditions, *Analeptes trifasciata* is predicted to be highly favourable in 91 % of Togo (Fig. 8). Moderately favourable for the presence of *A. trifasciata* are predicted for the prefectures of Cinkassé and Tone in the savannah region belonging to ecological zone I.

The very optimistic model (SSP 126) forecasts a decrease in highly favourable habitats of around 30 %. The very pessimistic model forecasts an increase of 6.2 %. However, moderately favourable, less favourable and unfavourable habitats will increase by 21.5 %, 6.3 % and 0.2 % respectively in the SSP 126 scenario and a regression of 5.8 % and 0.5 % respectively in the SSP 585 scenario by 2055 in Togo (Fig. 9).

3.2.2. Habitat change of *A. trifasciata*

A 31.42 % loss (Table 5) in habitat quality (decrease in the level of incidence) will be observed under the SSP 126 scenario (Fig. 10). The incidence level will remain constant (89.59 %) in the southern, coastal zone and in

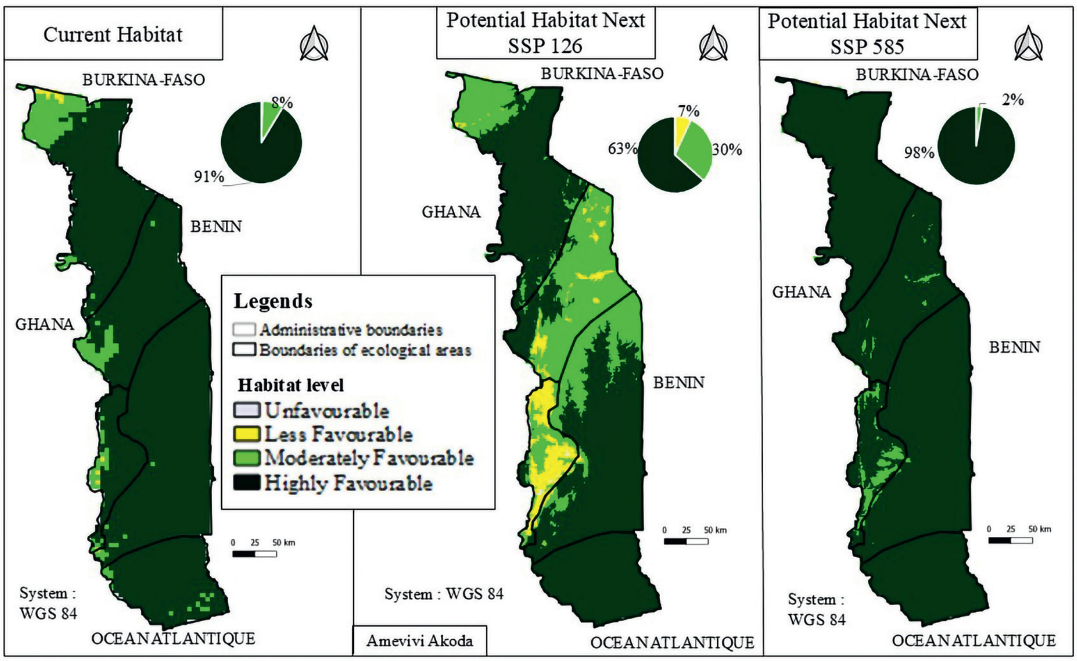

Fig. 8. Current and future spatial distribution of *A. trifasciata* in Togo
Ryc. 8. Obecne i przyszłe rozmieszczenie przestrzenne *A. trifasciata* w Togo

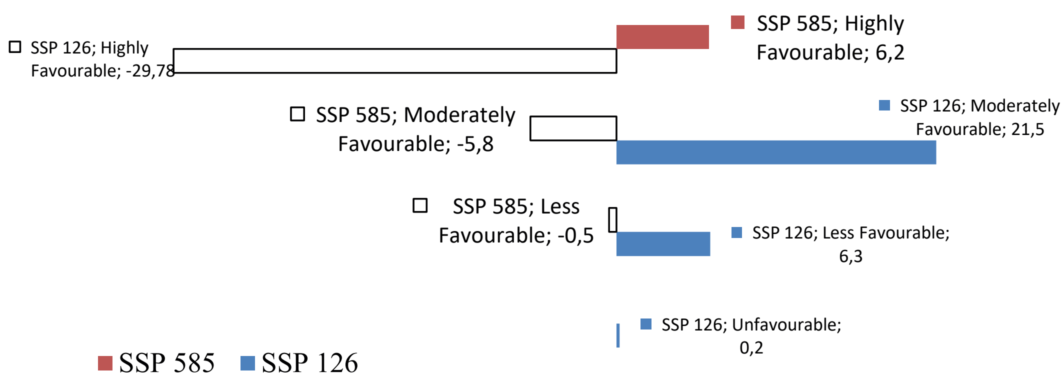

Fig. 9. Trend dynamics of *A. trifasciata* habitats by 2055 in Togo
Ryc. 9. Dynamika zmienności siedlisk *A. trifasciata* do roku 2055 in Togo

Table 5. Variation in the quality of *A. trifasciata* habitats according to the SSP 126 and SSP 585 scenarios
Tabela 5. Zmienność jakości siedlisk *A. trifasciata* wg scenariuszy SSP 126 i SSP 585

Scenario	Habitats	Loss	Constant	Gain
SSP 126	Unfavourable	0.00 %	0.00 %	0.00 %
	Less Favourable	0.00 %	0.02 %	0.40 %
	Moderately Favourable	0.69 %	4.84 %	2.39 %
	Highly Favourable	30.73 %	60.93 %	0.00 %
	Sous-total	**31.42 %**	**65.79 %**	**2.79 %**
SSP 585	Unfavourable	0.00 %	0.00 %	0.00 %
	Less Favourable	0.00 %	0.00 %	0.42 %
	Moderately Favourable	0.00 %	0.12 %	7.79 %
	Highly Favourable	2.20 %	89.46 %	0.00 %
	Sous-total	**2.20 %**	**89.59 %**	**8.21 %**

the north-western part of Ecological Zone I under the SSP 585 scenario. An increase in the quality the habitat (8.21 %) will be observed at the north-west areas of ecological zone 1 under the SSP 585 scenario by 2055.

The loss of very favorable habitats (30.77 %) in favor of favorable, moderately favorable, less favorable and unfavorable habitats according to the SSP 126 scenario is located in the southern mountains and in the northern plains (Table 4). There is more habitat loss (31.42 %) than habitat gain in these zones. However, at the north-west of ecological zone I, there is more gain than loss of habitat for *A. trifasciata* under the SSP 585 scenario by 2055. It was found that by 2055, climate change and global warming would affect the habitats of *A. trifasciata* in different ways under both scenarios.

3.3. Priority Habitats for Conservation and Sustainable Use of *A. digitata*

In Togo, the effects of climate change and parasitism of *A. trifasciata* were used to identify priority habitats (Fig. 11) where climatic and global conditions are suitable for the presence, development and conservation of *A. digitata*. Conservation efforts for *A. digitata* must therefore focus on mountain areas and northern plains (Fig. 11) to achieve a priority level of more than 90 %. These areas are specifically located in prefectures: Kéran in ecological zone I; Assoli, Tchoudjo and Sotouboua in ecological zone II. These zones would remain stable (highly favourable) for *A. digitata* in the future. They would be zones of low incidence for

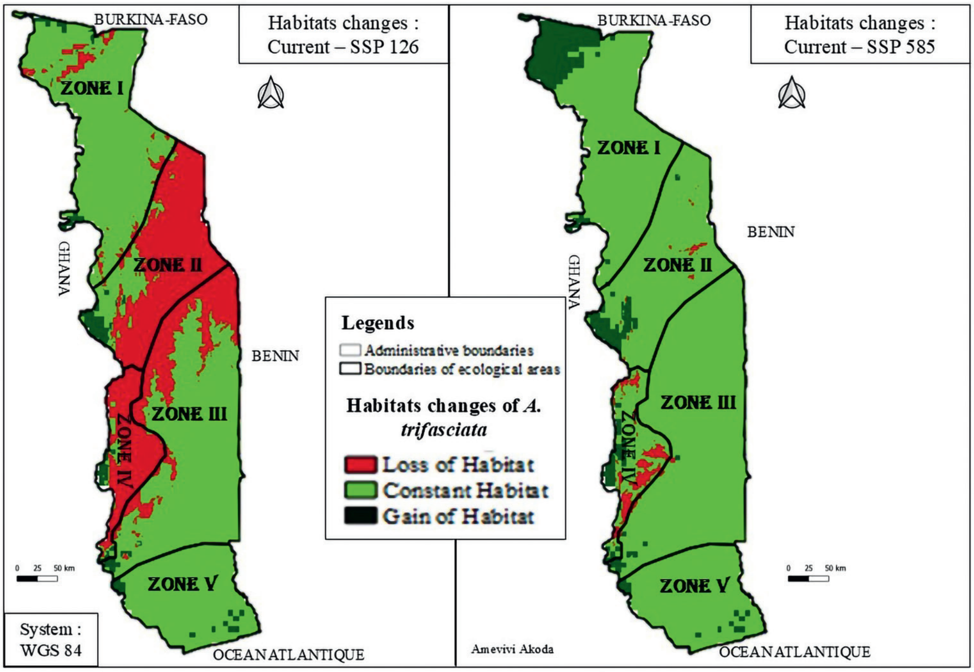

Fig. 10. Changes in the habitats of *A. trifasciata* under the impacts of climate change
Ryc. 10. Zmiany siedlisk *A. trifasciata* pod wpływem zmian klimatu

A. trifasciata by 2055. In contrast, the predicted priority zones of less than 90 % corresponds to either:

- area unsuitable for *A. digitata* currently and in the future and high incidence of the parasite *A. trifasciata*;
- area unsuitable for *A. digitata* currently and in the future and low incidence of the parasite *A. trifasciata*;
- area suitable for *A. digitata* currently, but predicted to be unsuitable in the future under both scenarios and low incidence of the parasite *A. trifasciata*;
- area suitable for *A. digitata* currently, but predicted to be unsuitable in the future under both scenarios and high incidence of the parasite *A. trifasciata*;
- area unsuitable for *A. digitata* currently, but predicted to become suitable in the future in one of the scenarios, and high incidence of the parasite *A. trifasciata*;
- area with high incidence of *A. trifasciata*.

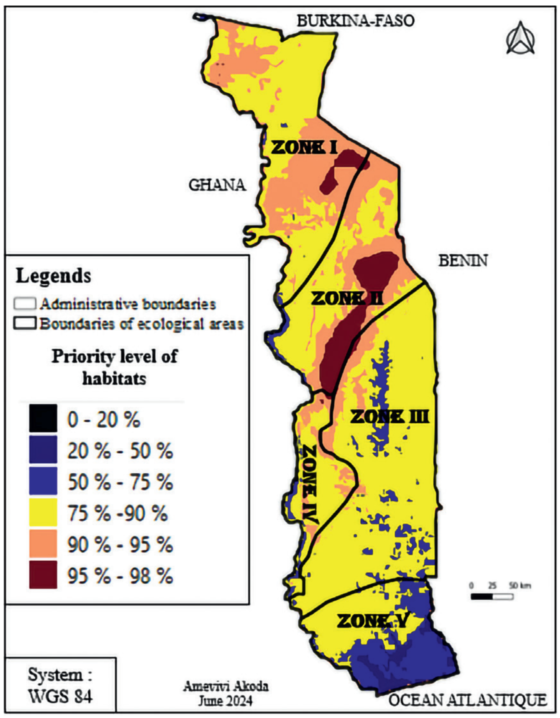

Fig. 11. Priority habitats level for *A. digitata* conservation and cultivation in Togo
Ryc. 11. Poziom siedlisk priorytetowych dla zachowania gatunku i uprawy *A. digitata* w Togo

4. DISCUSSION

4.1. Current Spatial Distribution of *A. digitata* and *A. trifasciata*

Discrimination of *A. digitata* subpopulations shows that their spatial distribution follows a climate gradient. These results are in agreement with those of [12, 36], which previously reported the existence of subpopulations of widely distributed species. The contribution of environmental variables to the construction of models of subpopulations of *A. digitata* confirms the integration of intraspecific variation in the construction of spatial distribution models of this species. These results are in line with those of Biaou, Gouwakinnou [36] on *Pterocarpus erinaceus* in Benin. In the context of sustainable management and prediction of climate impacts on plant distributions, there are several studies at the country or sub-regional scale on the baobab [6, 12, 53–55]. Coupling this knowledge with the occurrence of the main parasite (*Analeptes trifasciata*) remains an innovation that is likely to improve predictive models in order to define more appropriate adaptation and resilience programs to climate change. *Analeptes trifasciata* is typically found in savannahs. However, it can also be found in forest margins with plants of the families of Anacardiaceae and Bombacaceae [35, 56]. Annual precipitation (bio12), precipitation of the driest month (bio14), and annual temperature variation are the variables that contribute most to its distribution. This is consistent with the ecology of the parasite [34, 35, 57] and confirms its affinity to the study area.

4.2. Impact of Climate and Global Changes on the Spatial Distribution of Species of Interest

Habitat dynamics shows that climate and global change will negatively affect the distribution of *A. digitata* in Togo by 2055 under both scenarios. This decline is more significant under the SSP 585 scenario and is located in the north-western part of the ecological zone I, more so in ecological zones V and III. Several socio-cultural groups using *A. digitata* by-products could be affected. The importance of the use and the economic importance of the species in Togo and the West African sub-region are clearly mentioned in recent studies [2, 3, 58]. A decline in the range would lead to a collapse and an increase in the price of the species' by-products in the markets. For *A. trifasciata*, climatic and global changes are expected to have a negative impact on its spatial distribution in Togo by 2055, according to the SSP 126 scenario and positive impact according to the SSP 585 scenario. The regression is predicted in the areas of the northern mountains and the northern plains. On the other hand, progression is predicted to be higher in the north-western part of zones I, IV and V. The overall temperature increase is favourable for insect proliferation [59]. Increasing temperature improves the survival, speed of insect development and number of annual generations [60, 61]. Analysis of *A. digitata* habitat changes shows that under the most optimistic scenario (SSP 126), 32.71 % of favourable habitat will remain constant. This bodes well for the management and the cultivation of this species. On the other hand, under the same scenario, *A. trifasciata* has the highest loss of habitat quality, estimated at 31.42 %. This loss is predicted to occur in mountain areas and in the northern plains. These areas coincide with those that are predicted to be favourable for *A. digitata* under the same (very optimistic) scenario. More than 90 % of *A. trifasciata* habitats will remain favourable under the very pessimistic scenario (SSP 585). It shows that so-called favourable and stable areas are severely affected by parasitic species. Thus, under climate change impacts, some habitats currently suitable for *A. digitata* cultivation would become unsuitable or remain stable. Others currently unsuitable will become suitable or remain unsuitable under the SSP 126 and SSP 585 scenarios by 2055. These results corroborate those of [62–64] on the impact of climate change and changes occurring in habitats.

4.3. Priority Habitats for Conserving and Cultivating *A. digitata*

A. digitata priority habitats with priority thresholds above 90 % result from the combined effects of climate change and parasitism by *A. trifasciata*. These habitats can be considered, in the context of climate and global change and parasitic attacks in Togo, as priority habitats for the conservation and sustainable use of *A. digitata* by-products. These are the areas of the northern plains and mountains. They are located in ecological zones I and II. Ecological zones III and IV are of lower priority. Zone V is not recommended for conservation and cultivation of *A. digitata*. An in-situ conservation strategy [62–64] is proposed for the recovery of *A. digitata*. This strategy should take into account suitable areas for its growth, development and reproduction [12, 44]. For the sustainable use of *A. digitata* co-products in Togo, in situ conservation in agroforestry systems and home gardens need to be promoted. There are several steps in the process of developing a conservation strategy, but the chosen approach is crucial. The participative and multi-stakeholder approach, the chosen method, allows for the identification of a vision over a given horizon that considers the reality and represents a compromise for all participants and stakeholders in the strategy of the development process. This vision is operationalised into conservation targets. These realistic goals will make it possible to identify objectives that take into account the threats to the *A. digitata.* These objectives must be: sensitive, measurable, achievable, feasible and time-bound. The monitoring indicators and the evaluation of the activities carried out can be linked to these well-developed objectives.

5. CONCLUSION

Modelling shows that the spatial distribution of the African baobab (*Adansonia digitata*) is governed by six variables: annual precipitation, precipitation in the driest month, precipitation in the wettest quarter, precipitation in the driest quarter, precipitation and seasonality and soil. Beyond climatic factors, parasites including *A. trifasciata* cause enormous damage to the survival of the species. The spatial distribution of *A. trifasciata* is linked to three main environmental variables: annual precipitation, precipitation in the driest month and the difference between annual temperatures. Climate change will lead to a regression of *A. digitata* habitats whatever the scenario. On the other hand, in the very optimistic scenario (SSP 126), the regression is maximum compared to *A. trifasciata*. The priority areas for cultivation and conservation of *A. digitata* in Togo by 2055 are located in the areas of the northern plains and mountains. Given the parasitic threats to the sustainability of *A. digitata*'s, it will be useful to develop pest management approaches with a view to adjusting the baobab to climate and global changes.

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