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First digital characterization of the transhumance corridors through Benin used by cattle herds from Burkina Faso and associated risk scoring regarding the invasion of *Rhipicephalus* (*Boophilus*) *microplus*

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Short running title: Associated risks of transboundary transhumance

ABSTRACT

Background: Livestock plays a key role in the macro economy of West Africa and provides livelihoods for millions of people. The main cattle rearing strategy in West Africa is pastoralism, including transhumance: i.e. a seasonal migration of cattle with their herders. This adaptive strategy aims to optimize livestock access to water and pastures. However, it can favour pathogens and vectors transboundary spread. This study aim is to highlight, firstly the corridors and grazing areas used by Burkina Faso transhumant cattle herds going to Benin, secondly the characteristics of departure and arrival areas of transhumance and thirdly, the risk score related to introduction and spread of the invasive tick species, *Rhipicephalus* (*Boophilus) microplus,* in free areas. **Methods and principal findings:** Therefore, GPS devices were given to 27 herders to monitor a full transhumance season between East Burkina Faso and North Benin. The analysis of 14,966 spots generated by the GPS devices revealed four main corridors and five main grazing areas used by cattle herds during transhumance. Statistical analysis of normalized difference vegetation index (NDVI), rainfall and temperature data, highlighted significant differences between departure and arrival areas. NDVI and rainfall are significantly higher in Benin than Burkina Faso whereas temperature is significantly lower. Additionally, using biotic and abiotic parameters, a risk scoring was developed to predict the presence of *Rhipicephalus* (*Boophilus) microplus* at municipality level. **Conclusions and significance:** The better vegetation, temperature and rainfall conditions during the dry seasons in Benin attract cattle herds from Burkina Faso. The invasiveness and adaptability of *Rhipicephalus* (*Boophilus) microplus* added to the frequent stays of transhumant herds in infested areas suggest its potential introduction and establishment in free areas soon. Moreover, frequent intrusions of the transhumant cattle in the wildlife reserves is another risk of vectors and pathogen exchange between domestic and wild animals.

Keywords: Transhumance; Cattle; Ticks; *Rhipicephalus* (*Boophilus) microplus;* Burkina Faso; Benin

INTRODUCTION

Livestock plays a key role in the macro economy of the Economic Community of West African States (ECOWAS) and contributes to 44% of the regional agricultural Gross Domestic Products (GDP). This sub-sector provides livelihood opportunities for millions of people who are involved in various production, processing, marketing and livestock service activities (ECOWAS Commission, 2010). The main strategy in cattle rearing in West African countries is pastoralism. Grazing seems to be the main method of its sustainable development in fragile and irregular natural vegetation in Sub-Saharan Countries (SSC). This form of stockbreeding adapts both flexibly and rapidly to the wide seasonal and inter-annual variations in plant biomass and water resources (FAO, 2012). Transhumance is a cyclical migration of pastoralists with their herds. In SSC, the transhumance is an adaptive strategy that aims to improve livestock access to water and quality grazing land to sustain annual production. Transhumance accounts for 70 to 90 % of cattle 30 to 40 % of small ruminants breeding in West Africa. It contributes to the production of 65% of beef, 40% of small ruminant meat and 70% of milk production. This form of livestock farming provides employment for about 80 million people and represents a source of income for local governments (SWAC/OECD, 2007; World Bank, 2013). Practically, at the end of the rainy season, livestock farmers leave their homeland for areas better suited to cover the nutritional needs of their livestock. The same family may split up into several transhumance routes depending on (e.g.) its assets, composition of the family, the use or not of paid workers and the herd size (FAO, 2012).

During the transhumance, pastoralists choose itineraries that allow them to reach the target area as soon as possible under good feeding and watering conditions for their cattle. Therefore, transhumance is constituted by a range of steps based on information (grazing land, water, crop residues, livestock markets, and security) gathered from informants and depending on the farmer's personal experiences. Information and communication technologies (mobile phones, radio) have fundamentally changed the practices of today's pastoralists, empowering them to evaluate at a distance the resources available in the hosting areas, the terms of trade and the cross-border gateways. This itinerary choice depends also on the information provided by livestock networks on livestock safety and health status. Itineraries may change during the trip depending on the updated information.

Pastoralists move their livestock to avoid drought, disease or conflict. Some climate models predict that precipitation will be increasingly erratic and unpredictable during the next few decades (Ingram et al., 2002). In this context, herd mobility will be essential to help farmers adapt to changes in the climate.

South-north movements are most frequent during the rainy season, with livestock leaving their home areas in the most southern regions and extending to non-cropped pasturelands in the north to take advantage of the higher quality forage available there. Another advantage of these south-north migrations during the rainy season is that livestock are removed from the agricultural areas of the south and conflicts between herders and crop farmers are avoided. Livestock return in south with the senescence of pastures and the drying up of surface water points. The timing, direction and extent of these movements are influenced by the biogeography of vegetation phenology, particularly latitudinal gradients during the greening period and the onset of senescence at the onset and end of the monsoon rainy season (Butt et al., 2011).

Herds on transhumance may face many animal health risks when they arrive in new areas with various disease vectors and when they encounter other herds with a different or unknown health status. Grazing areas, vaccination parks, transhumance corridors, livestock watering points, livestock markets are the principal places where animals of different health's status meet and where pathogens and vectors are exchanged. However, very few studies addressed the transhumance routes and its determinants.

The objectives of this study were first to precisely identify the corridors used by Burkina Faso transhumant cattle herds going into Benin, the timing of this transhumance and finally the characteristics of the arrival areas of these transhumant herds. Given that *Rhipicephalus* (*Boophilus) microplus*, an invasive tick is not yet recorded in the eastern part of Burkina Faso but well in the North of Benin, this study will also help to determine the parts of the study area, which are suitable for this tick species development and invasion. The choice of this tick species as a model in our analyses is not only based on its invasive characteristic. It is also resistant to local usual acaricide products and involved in the transmission of various tick-borne diseases. The most known animal diseases transmitted by *Rhipicephalus* (*Boophilus) microplus* are anaplasmosis and babesiosis, thus emphasizing its veterinary and economic importance.

MATERIALS AND METHODS

Study area

The study area comprises the eastern region of Burkina Faso and the North of Benin. It is located between 8° - 13° N latitude and 1°E - 4°W longitude. The climate in these two regions are almost similar with few particularities. The eastern region of Burkina Faso is characterised by south Soudan climate with five months of rainy season (May to September) and seven months of dry season (October to April) (AQUASTAT/FAO, 2015). The North of Benin is characterised by a Sudan-Sahel type climate located between 10° N and 12° 30' N with a rainy season of 5 months (May to September) and a dry season of 7-8 months (October to April).

It is noteworthy to underline that the localities considered within each country do not have the same administrative level. In Burkina Faso, transhumant herds were sampled from three provinces (i.e. Gourma, Kompienga, Tapoa) whereas in Benin four departments (i.e. Alibori, Atacora, Borgou, Donga) were studied as arrival points. For the analyses in this study, these seven localities were regarded as "provinces".

Characterisation of the vegetation

In order to determine the state of the vegetation during the transhumance period we calculated its stress using the normalized difference vegetation index (NDVI) based on the raster images downloaded on the web site of Landsat (https://landsat.gsfc.nasa.gov/landsat-8/) and according to the formula below (Rouse Jr et al., 1973; Tucker, 1979). These data were used to map the vegetation stress with QGIS software (Quantum GIS Development Team, 2016) in the study area. This index varies from -1 for less vegetative areas to 1 for more vegetative areas (Pettorelli et al., 2005). The NDVI is one of the most successful of many attempts to simply and quickly identify vegetated areas and their "condition". It remains the most well-known and used index to detect live green plant canopies in multispectral remote sensing data (Alonso-Carné et al., 2016; Butt et al., 2011; Hogrefe et al., 2017).

$$NDVI = \frac{NIR - R}{NIR + R} \qquad \text{(Equation 1)}$$

With, NDVI= Normalized Difference Vegetation Index; NIR= Near Infrared; R= Red.

Vegetation Index (NDVI) data for the various locations in our study area were downloaded from the NASA moderate resolution imaging spectro-radiometer (MODIS) website (https://modis.gsfc.nasa.gov/data/dataprod/) for a 10-year retrospective period (2009 to 2018) including thus our field work period (2016-2017). The data used here are precisely that of the MODIS vegetation index MOD13Q1 v006. This MODIS vegetation index product makes spatio-temporal time series comparisons of global vegetation conditions. These data can be used to monitor the photosynthetic activity of vegetation through the detection and interpretation of phenologic changes. Maps describing spatial and temporal variations in vegetation activity are generated at 16-day and monthly intervals for accurate periodic monitoring of terrestrial vegetation (Didan, 2015). The 10-year NDVI mean data were compared according to the departure and arrival locations of the transhumant herds and according to whether or not they were infested by *Rhipicephalus* (*Boophilus) microplus*.

Characterisation of the climate

To analyse the climate patterns with accurate data (rainfall, temperature and moisture) we retrospectively collected data for the last 20 years from the local climate stations of the study area. Ten years (2009 to 2018) land surface temperature and emissivity (LST&E) data were also downloaded from the NASA moderate resolution imaging spectro-radiometer (MODIS) website (https://modis.gsfc.nasa.gov/data/dataprod/). The product used here is the MOD11A2 v006, which provides an average of 8 days LST&E pixel with a spatial resolution of 1 kilometer. The 8-day composition period was chosen because twice this period is the exact repetition period of the ground track of the terra and aqua platforms. The day and night surface temperature bands are supplemented by quality control assessments, observation times, zenith angles and clear sky cover, as well as emissivity bands for the associated land cover types (Wan et al., 2015). These data were compared to detect the suitability of these areas to tick species development and establishment.

Herds tracking with Global Positioning System tags

To precisely determine the different spaces covered by herds during transhumance, twenty-seven herdsmen conducting cattle herds from Burkina Faso to Benin were given global positioning system (GPS) tags SPOT Gen3 (SPOT LLC, San Francisco, CA, USA). These GPS tags send signals every hour and those signals were visualised as spots through an account created on the website of Findmespot (https://africa.findmespot.com/en/). This allowed us to follow the selected herds in real time and to know their position when the GPS tags worked normally. When there is dysfunction with the GPS tags we noticed it on the website and instructions were given to the herdsmen responsible to solve the problem. This tracking helped to determine: i) the real itinerary of every surveyed cattle herd and the transhumance corridors used; ii) the entry point to the arrival country; iii) the duration of the transhumance season; iv) the stay areas in the arrival country; v) and the grazing areas during their stay in the arrival country. These transhumance parameters (i.e. corridors, main entry point in Benin and grazing areas during the dry season) were highlighted on heat maps of all spots generated by the SPOT gen GPS devices. using QGIS software (Quantum GIS Development Team, 2016).

Evaluation of the risk of the presence of *Rhipicephalus* (*Boophilus) microplus* in the different municipalities of the study area

The main farming system practiced in West African countries is free ranging. This farming system is based on quest of pasture to feed livestock and water points for watering animals. Livestock vaccination campaigns are organised every year against the main diseases (i.e. contagious bovine pleuropneumonia and bovine pasteurellosis) for which vaccines are available. Livestock markets are set in every locality to facilitate trade of animals and animal products. These various meeting points are risk areas for many vectors and diseases transmission between animals (Kao, 2006, 2002; Kao et al., 2007; Ortiz-Pelaez et al., 2006; Shirley and Rushton, 2005).

A census of these different areas has been done through the geolocation with GPS devices and information given by offices in charge of animal health in the two countries. The statistics of these risk areas crossed with the biotic and abiotic factors of the tick *Rhipicephalus* (*Boophilus) microplus* (e.g. NDVI, cattle density and climate data) allowed generating an infestation risk score for this tick species. A model was developed based on eight variables (**Table 1**) which can influence the presence or absence of *Rhipicephalus* (*Boophilus) microplus* in the area. A score was attributed to each variable by the authors according to its importance in the introduction and development of the tick in an area (maximum score of 100). The biotic and abiotic factors (rainfall, temperature, vegetation index and cattle density) had the highest score because of their importance in the life cycle of ticks. These four variables that have a key role in the life of the ticks received 80% of the global score of the risk. The other variables (livestock market, water point, transhumance corridor and transhumance grazing area), which are involved in the introduction and the spread of ticks, had lower scores (**Table 1** and **Table 2**). The importance of each variable has been documented by some publications that have highlighted their role in the biology or spreading of the tick. These different publications are referenced in **Table 2**. The scoring grid (**Table 2**) attributed to each variable is the result of the authors' proposals according to the importance and optimal value of this variable for the tick. These applied scores have been subject to a validation and amendment process by a panel of four experts (two acarologists, one parasitologist and one epidemiologist) consulted for this purpose. In each municipality, every variable receive a score according to its value in this locality. The score is the highest when the value of the variable is optimum and lowest when the value is worst. The risk score of each municipality was calculated by summing all the scores of the different variables of that specific area. The results were mapped with QGIS.

Table 1. List of variables used for the presence risk model of *Rhipicephalus* (*Boophilus) microplus.* (NASA: National Aeronautics and Space Administration ; MODIS: Moderate Resolution Imaging Spectroradiometer ; DGSV: Direction Générale des Services Vétérinaires; DE: Direction de l'Elevage)

Variable names	**Variable categories**	**Data sources**	**Weight justification**	**Justification references**
Rainfall	Abiotic	Météo Bénin & https://www.infoclimat.fr/climato	Abiotic factors, essential for the presence and the development of the tick. They heavily influence the distribution of the tick.	(Estrada-Peña et al., 2006)
Temperature	Abiotic	NASA/MODIS https://modis.gsfc.nasa.gov/data/dataprod/		(Estrada-Peña et al., 2006; Estrada-Peña and Venzal, 2006)
Vegetation Index	Abiotic	NASA/MODIS https://modis.gsfc.nasa.gov/data/dataprod/		(Estrada-Peña et al., 2006; Estrada-Peña and Venzal, 2006)

Variable names	Variable categories	Data sources	Weight justification	Justification references
Cattle density	Biotic	DGSV (Burkina Faso) & DE (Benin)	Biotic factor, also needed in the development of the life cycle of the tick.	(Baneth, 2014; McCoy et al., 2013)
Livestock market	Biotic	DGSV (Burkina Faso) & DE (Benin)	Cattle is the favourite host for *Rhipicephalus* (*Boophilus) microplus*. These variables represent areas of meeting of hosts and spread of the parasites and pathogens.	(Ma et al., 2016)
Water point	Biotic	DGSV (Burkina Faso) & DE (Benin)		
Transhumance corridor	Biotic	Transhumance monitoring (this study)		
Transhumance grazing area	Biotic	Transhumance monitoring (this study)		

Acarological survey used for validation of the model

An acarological survey was carried out simultaneously with the present study (Ouedraogo A.S., 2020, personal communication). The results of this survey is ongoing of publication with parasitologists of the consortium as lead. The *Rhipicephalus (Boophilus) microplus* occurrence data used to validate the risk model resulted from morphological and molecular identifications of ticks sampled in the same study area.

Sensitivity analysis of the predictors used in the risk model

A sensitivity analysis was added to check whether all the predictors (eight variables) used to evaluate the risk of presence of *Rhipicephalus* (*Boophilus) microplus* in the municipalities of the study area are useful. The first step consists in ranking all the 44 municipalities considering their global risk score with all the eight variables. At the second step, one by one predictors were suppressed and the risk score was ranked each time considering all the municipalities. The third (and last) step was counting how many changes occurred in the municipalities ranking, using a diagram. We only count changes in rank that represent at least 10% of the total number of municipalities (10% of 44=4). For each variable, we look at how many municipalities were affected by a change of superior or equal to 4 ranks (Petit et al., 2020; Saegerman et al., 2020). This allow to evidence the variables that have the most influence on the ranking of the municipalities and consequently in the evaluation of the risk of the presence of *Rhipicephalus* (*Boophilus) microplus*.

A sensitivity analysis was also carried out by comparing the rankings of municipalities in the model with weighted criteria and the model without weighting.

Statistical analysis

Analysis of variance (ANOVA) was used to determine whether the means of NDVI, rainfall and temperature (10 years retrospective data) are the same in the departure and arrival areas or in the areas where *Rhipicephalus* (*Boophilus) microplus* was found or not. A negative binomial regression analysis was performed with Stata/SE 14.2 (StataCorp, College Station, TX, USA) to understand the variation of the risk between the two countries and also between areas where *Rhipicephalus* (*Boophilus) microplus* was found or not. The aim was to check the variation of the risk score (dependent variable) according to the various countries and areas where the tick was found (independent variables).

To test the predictive performance of our model in terms of the presence of *Rhipicephalus (Boophilus) microplus,* we used the Area Under the Curve of the Receiver Operating Characteristic (AUC-ROC) plot and the scale established by John .A. Swets (Swets, 1988). The risk score prediction of the presence of the invasive tick by municipalities was compared to data of tick sampling which occurred during the studied transhumance campaign within the concerned herds.

Table 2. Variables and corresponding scores used in the risk model for *Rhipicephalus (Boophilus) microplus*

Variables (unit)	**Variable (value range)**	**Score attributed**	**Justification references**
Vegetation Index (index)	Null [0]	0	(Estrada-Peña et al., 2006; Estrada-Peña and Venzal, 2006)
	Low [0.10-0.40]	6	
	Medium [0.41-0.50]	12	
	High [0.51-1]: 20	20	
Temperature mean (°C)	Low [20-29.4]	20	(Estrada-Peña et al., 2006; Estrada-Peña and Venzal, 2006)
	Medium [29.5-30.4]	12	
	High [30.5-45]	6	
	Other	0	
Rainfall mean (mm)	Null [0]	0	(Estrada-Peña et al., 2006)
	Low [0-1000[	6	
	Medium [1000-1100[	12	
	High [1100-∞[	20	
Cattle density (cattle/km^2)	Low [0-20]	6	(Baneth, 2014; McCoy et al., 2013)
	Medium [21-40]	12	
	High [41-60]	20	
Water point (number)	Null (0)	0	(Perry et al., 2013)
	Low [1-6]	2	
	Medium [7-12]	4	
	High [13-21]	6	
Transhumant grazing area (number)	Absent	0	(Perry et al., 2013)
	Small	2	
	Medium	4	
	Large	6	
Transhumance corridor (number)	Absent	0	(Perry et al., 2013)
	Present	4	
Livestock market	Absent [0]	0	(Perry et al., 2013)

Variables (unit)	Variable (value range)	Score attributed	Justification references
(number)	Very low [1]	1	
	Low [2]	2	
	Medium [3]	3	
	High [4]	4	

RESULTS

Characterisation of the vegetation

The satellites images downloaded on NASA website help to map the vegetation of the study area. The vegetation in the arrival area in Benin is greener and healthier than the departure area (**Figure 1**) during the transhumance period. A ten-year mean value of NDVI also showed that during all the years the vegetation is always better in Northern Benin than in Eastern Burkina Faso (**Figure 2**). An analysis of variance (ANOVA) showed that the vegetation index (NDVI) of the North of Benin was higher than that of the Eastern region of Burkina Faso ($P<0.001$). An analysis of variance (ANOVA) indicated that there was also an important difference between the NDVI of some of the departments located in the study area (**Figure 3**). This statistical analysis revealed that Atacora, the main arrival area of the transhumant in Benin, has a better NDVI than the three other departments of Burkina Faso ($P<0.001$). The NDVI map also indicated that wildlife reserves areas are greener than other parts of the study area (**Figure 1**). During the period of transhumance, cattle herds spent their stay in Benin in the greenest places of the moment. Those that do not transhumant, graze near the wildlife reserve areas. The vegetation is still green and better around the parks even in the dry season. Some of the transhumant cattle herds, passed over the ban, and visited the wildlife reserve area and spent some days in the park of Pendjari in Benin (**Figure 1**).
An ANOVA of the vegetation index revealed that, there was a statistically significant difference ($P<0.001$) between areas where *Rhipicephalus (Boophilus) microplus* is found and where it is not yet found.

Characterisation of the climate

ANOVA test revealed that there is a sizeable difference ($P<0.001$) between the rainfall of Eastern region of Burkina Faso (ten years annual rainfall average: 713 ±115 mm) and the North of Benin (ten years annual rainfall average: 1130 ±101 mm) (**Figure 2**). The two areas have almost the same rainy season duration (From May to September). However, the north part of Benin is more watered than the eastern part of the Burkina Faso (difference of +417 mm between the two regions). The areas where *Rhipicephalus (Boophilus) microplus* has been found (Northern Benin) appear to be more watered than those (eastern region of Burkina Faso) where it is not yet found based on the current study.

Regarding temperature, statistical analysis (ANOVA test), results revealed that Eastern region of Burkina Faso (annual mean: 29.8 ±2.7 °C) is ($P<0.001$) hotter (+2.03°C) than the North of Benin (annual mean: 27.8 ±2.6 °C). The ANOVA test also indicated that the areas where *Rhipicephalus (Boophilus) microplus* has been sampled are colder (-2.03°C) than the areas where it has not been encountered ($P<0.001$). Additionally, there is a strong positive correlation between NDVI and rainfall (Pearson correlation coefficient, $r=0.8$), a strong negative correlation between the NDVI and the temperature ($r=-0.77$) and a negative correlation between rainfall and temperature ($r=-0.65$).

Herds tracking with global positioning system tags

The 27 global positioning system (GPS) tags SPOT Gen 3 have emitted 14,966 spots during the transhumance season. Around 70% of these spots have been emitted between 06:00 am and 07:00 pm (**Figure 4**). This time slot of the day matched with the period when the cattle herds were on pasture for grazing. At night, the GPS tags are kept in houses or under shelters where the transmission with satellites is very bad so few spots were recorded during this period.

The monitoring of transhumance for one season with GPS tags helped to know the real corridors used by the selected herds. Four corridors and three entry points were identified (**Figure 5**). The herds coming from Gourma used only one corridor, which passed through Kompienga to join Atacora in Benin. The entry point used by these herds is Porga, the main one also used by some herds from Kompienga. The transhumant herds coming from Tapoa used two corridors. The first and main one joins the corridor of Gourma and the second one joins Alibori in Benin *via* Banikoara, the second entry point (**Figure 5**). Some herds from Kompienga also used the first corridor of Tapoa. The fourth and last corridor is the one through which, some herds illegally enter the Pendjari park where there are wild animals. The Pendjari biosphere reserve (PBR) is situated in the Atacora department, in the north-western part of Benin (10°30’ to 11°30 N; 0°50’ to 2°00’ E).

Prediction of the risk of the presence of *Rhipicephalus (Boophilus) microplus* in the different municipalities of the study area

The kernel density estimate of the risk score indicated a discriminatory power due to the bimodal distribution (**Figure 6**). The result of the risk score evaluation is mapped and represented in **Figure 7**. These results showed that the North of Benin is more suitable to the ticks than the eastern region of Burkina Faso. Furthermore, a negative binomial regression analysis revealed that the scores associated with the presence of *Rhipicephalus (Boophilus) microplus* ($P<0.001$) were higher in the northern part of Benin (mean score of Benin is 62.70%) compared to the eastern part of Burkina Faso (mean score of Burkina Faso is 33.76%). Results also indicated that the scores in areas where the tick was found were ($P<0.001$) higher (mean score difference is +23.33%) than those it was not yet found.

The heatmap shows the grazing areas (i.e. places with high value of spots density corresponding to more red coloured areas) of the cattle herds during transhumance. There were five main grazing areas (three in Benin and two in Burkina Faso) (**Figure 5**). This heatmap also confirms that some herds had a stay in the park of Pendjari where we have wild animals.

The statistical analysis of the risk scores across the provinces showed wide variations and important differences between some of them. The province with the lowest risk score is the province of Gourma in Burkina Faso and the highest risk was noticed in the province of Atacora in Benin.

The evaluation of the performance of our model in predicting the presence of *Rhipicephalus (Boophilus) microplus* using the area under the ROC curve revealed that the AUC was 0.81 with a standard error of 0.07 (**Figure 8**). According to the classification established by Swets J.A. (1988), such model is qualified as a “useful” model.

Sensitivity analysis about the impact of predictors on the municipalities risk score ranking and the associated weighting

The sensitivity analysis results showed that all our predictors are important in the *Rhipicephalus (Boophilus) microplus* presence risk scoring of the municipalities. The removal of each predictor (variable) induced important changes in the ranking. The threshold has been set at least on four units difference in ranking of the municipalities. Three predictors which have a strong effect on the sensitivity (**Figure 9a**) generate at least twelve municipalities ranking changes. These predictors are: “Cattle density” (n=14), “Rainfall mean” (n=13), “Temperature mean” (n=12). “Cattle density” was the predictor that induced the most changes in the ranking of the risk score of the municipalities: i.e. 14 municipalities ranking changed. Meanwhile, “Livestock markets” generate the least changes: 01 municipality ranking changed. The other predictors changes in municipalities ranking are in decreasing order: “Transhumance corridor” (05 municipalities ranking changes); “Water point” (04 municipalities ranking changes); “Transhumant grazing area” (04 municipalities ranking changes); “Vegetation Index” (03 municipalities ranking changes) and “Livestock market” (01 municipality ranking changes).

The sensitivity analysis according to weight of the predictors show a great variation the ranks of many municipalities between the weighted and unweighted models. The comparison of the weighted and the unweighted models revealed that 25 municipalities ranking change with at least four units (**Figure 9b**).

DISCUSSION

Vegetation and climate divergences between Eastern Burkina Faso and North of Benin: main drivers of the transhumance

Globally the North of Benin has significantly a better NDVI, a greater rainfall and is less warm than the Eastern region of Burkina Faso. Additionally, there is a positive correlation between the NDVI and the rainfall and a negative correlation between temperature and NDVI and also between temperature and rainfall. Higher rainfall generate a better vegetation index (NDVI) and low temperature. Indeed, ticks biology needs good vegetation, humidity, and appropriate temperature. It is well known that, abiotic factors, including climatic factors, ecological factors and vegetation cover, govern the presence and development of ticks in an environment (Dantas-Torres, 2015). Variations in these abiotic factors can lead to modifications in the distribution of ticks species (Léger et al., 2013).

Vegetation plays a key role in the development of ticks because they can spend 80-90% of their life out of the host as questing larvae in nature (Leal et al., 2018). They need during these periods an adequate vegetation coverage that will generate at the same time a good humidity and temperature essential for their development (Pfäffle et al., 2013). Vegetation is also important to the tick for host questing. Ticks use vegetation to stay alert waiting for the host to pass by. Depending on the size of the hosts available in their living environment, ticks need vegetation of high or small size accordingly to increase the probability of catching these hosts (Ginsberg et al., 2014). The availability of vegetation is also an opportunity for ticks to have host that need vegetation (e.g. ruminants). Therefore, area with better NDVI represents better areas for both ticks and their host and their relationship.

The risk of presence of tick species in green and wet places is higher than in the dry and hot ones. During the dry season, the density of cattle increases on the few places where there is grass and water. Many herds with various health status come from different places. This situation increases the risk of infection/infestation and raising of epidemic diseases (e.g. foot-and-mouth disease).

Burkina Faso is globally hotter and drier than Benin. The downloaded climate data have shown it clearly (**Figure 2**). These climate pattern seems to be more suitable for *Rhipicephalus (Boophilus) microplus* in Benin than Burkina Faso. Climatic risk factors (rainfall and temperature) are more favourable to cattle of Burkina Faso than those of Benin for the infestation by ticks. *Rhipicephalus (Boophilus) microplus* seems to have a preference to areas that are not too hot like the Sahel region in Burkina Faso. In fact, statistical analyses of its presence and temperature data showed that its presence areas are not as hot as those of absent areas.

Period and location of grazing during transhumance: are protected areas at risk?

Most of the spots of the global positioning system (GPS) tag were emitted in the daytime from 06:00 am to 07:00 pm. This time slot corresponds to the time spent by the herds on pasture and this correlates with the statements of the majority of herders in the survey that followed this work. However, some herders asserted that sometime they could go on pasture at night whereas it is forbidden. The 30% of spots we had at night time may be a result on these forbidden practises.

The Pendjari biosphere reserve (PBR) is located in North-western Benin (10°30' to 11°30' N; 0°50' to 2°00' E) in the department of Atacora. It was designated as a hunting reserve in 1954 and transformed into a national park in 1961. Today, it is divided into a protected core area (Pendjari

National Park, PNP: 2,660 km²) and a buffer and hunting zone to the west and south (1,870 km²). This biosphere is one of the best managed protected areas in Benin. It is also one of the richest and most diversed wildlife reserves in West Africa (Nago et al., 2006; Oumorou et al., 2011). Whereas the PNP has a special status (protected area) and its access is forbidden to domestic animals, we noticed that this ban is not respected by some local and transhumant herds. Such protected areas are very attractive to transhumant herds because there, they can find water and pasture during the dry seasons (Séidou et al., 2017). The droughts of 1973 and 1984 and the pressure of the tsetse fly obliged the transhumants of the Sahel (Niger and Burkina-Faso) to descend into the protected areas of northern Benin. This was the beginning of incursions into these protected areas (Boutrais et al., 2008; Escadafal et al., 2012; Kagone et al., 2006). Interestingly, a census conducted in 2000 reveals twenty species of wild animals, comprising most of the larger mammals of West Africa, in particular bovids (Sinsin et al., 2002), like (e.g.) buffaloes. These wild animals can easily share vectors and pathogens with transhumant cattle, which spent time in the park during the dry season questing water and pasture. This represents a real health risk for wildlife. If we consider the importance of the protected species for this park and the wildlife, it is important to control the sanitary situation of these wild animals by avoiding frequent contact with domestic ones. Wild animals also are often reservoirs for zoonotic pathogens which can transmitted to humans *via* domestic animals Whereas *Rhipicephalus (Boophilus) microplus* is described as a specific tick for cattle (cattle fever tick), it can use other mammals (e.g. deer, wild carnivores and oryx) as alternate host (Busch et al., 2014; De Meeûs et al., 2010; Labruna et al., 2005; Tonetti et al., 2009). An introduction of *Rhipicephalus (Boophilus) microplus* in the park will cause a real threat to the protected species that can host this vector and its transmitted diseases (George, 1990). Its introduction in wildlife will also complicate its control. Buffaloes are reservoirs for the foot-and-mouth disease virus. The frequent relationship of cattle and wild bovids could undermine ongoing efforts to control and/or eradicate this disease (in domestic animals) in West Africa.

Prediction of the risk of the presence of *Rhipicephalus (Boophilus)* microplus in the different municipalities of the study area

A scoring system was developed using biotic and abiotic variables to predict the presence of *Rhipicephalus (Boophilus) microplus* at municipality level. The choice of variables was motivated either by their importance in the biology of the tick (temperature, rainfall, vegetation index, cattle density) or by their role in the introduction and spread of the tick in an environment (livestock market, transhumance corridor, grazing area and water points). The score of 20% was dedicated to each of the four variables (rainfall, temperature, vegetation index and cattle density) because they are vital factors for the tick life. The tick cannot live without one of these factors (Baneth, 2014; Estrada-Peña et al., 2006; Estrada-Peña and Venzal, 2006; McCoy et al., 2013). The introduction and the spreading of the tick will be possible through the four other factors (livestock market, water point, transhumance corridor and transhumance grazing area). They are highly implicated in changes of spatial dynamics of animal diseases (Perry et al., 2013). These variables that are not crucial for the tick life are rated lower than the first four ones. The importance of these variables lies in their involvement in the infestation of new animals and environments. Using this scoring system, the predictability of the model for the presence of *Rhipicephalus (Boophilus) microplus* was estimated as useful according to John A. Swets (Swets, 1988) scale. These value means that our model can predict the presence of *Rhipicephalus (Boophilus) microplus* with an accuracy of 81%.

Benin presents more suitable conditions to *Rhipicephalus (Boophilus) microplus* than Burkina Faso. This tick prefers wet and cold places than dry and hot ones (Estrada-Peña and Venzal, 2006). The risk of its presence in the Eastern region of Burkina Faso as shown by current results is not null (**Figure 7)**. The periodic movements of cattle through the eastern part of Burkina Faso and the North of Benin enhances the risk of introduction of *Rhipicephalus (Boophilus) microplus* in this part of Burkina Faso. Such situation has yet been observed in Western-south Burkina Faso where transhumant herds to Côte d'Ivoire lead on the introduction and establishment of the invasive tick species (Adakal et al., 2013; Biguezoton et al., 2016).

The risk is higher in some municipalities of Benin, bordering Burkina Faso, in contrast to some municipalities in central Northern Benin. This difference is due to some abiotic factors such as vegetation index, rainfall and temperature, which are better in the first areas and make there the environment more suitable for ticks. The same thing has been noticed with the municipalities of Burkina located near the border with Benin. These municipalities appear to be more suitable to the tick than others. The municipalities of Benin and Burkina Faso around the borderline belong to complex WAP (W-Arly-Pendjari). It is a transnational property shared by the Republic of Niger, Burkina Faso and the Republic of Benin in West Africa. Furthermore, this complex is at the heart of the largest protected area block in the West African Savannah/Woodland Biogeographic Province. It comprises the largest and most important continuum of terrestrial, semi-aquatic and aquatic ecosystems in the West African savannah belt (Schmidt et al., 2016). The controlled management of this area prevents anthropic action and allows the conservation of several animal and plant species. Moreover, there is a permanent river (Pendjari) along the borderline between Burkina Faso and Benin and a mountain range (Atacora mountain range) in the eastern north of Benin that makes its climate different from the rest of northern Benin.

Furthermore, the frequent introduction of transhumant cattle in the park of Pendjari, as it was revealed by the GPS trackers, will create damages later. The park showed a suitable habitat for *Rhipicephalus (Boophilus) microplus* through our risk map (**Figure 7)** and many wild animal species, which could be alternative host to this tick, are present. An introduction of *Rhipicephalus (Boophilus) microplus* even if it is known to be cattle tick (specific to cattle) in wildlife seems to be possible and will complicate its control or/and eradication.

Among the wild mammals listed in the Pendjari National Park, there is the African Buffalo (*Syncerus caffer*). This animal is known to be a reservoir host to many pathogens responsible of economically important livestock disease. Several livestock tick-borne diseases (theileriosis, heartwater, babesiosis and anaplasmosis) have been cited among these diseases (Eygelaar et al., 2015). Therefore, contact with domestic animals can severely affect their health and thus their production.

The model used here for risk analysis could be improved later by incorporating additional variables such as tick species interaction and the vaccination parks. These data were not available for all the parts of our study area when this paper was written. Since the presence and abundance of native tick species can increase the presence and the abundance of the invasive tick (Biguezoton et al., 2016), such parameter should be considered too. Regarding parks, they represent as grazing areas and markets, some meeting points for many herds and can favour sharing of pathogens and parasites. Even if animals do not meet on these areas, they can infest the areas during their short stay and other animals could be contaminated later when they visit.

The model should be implemented in larger areas than our study area and be further externally validated by *Rhipicephalus (Boophilus) microplus* presence/absence data of these areas.

The sensitivity analysis of the importance of each predictor in the model highlight the prominent role of “Cattle density”, “Rainfall mean” and “Temperature mean”. These three variables generate the ranking changes of at least twelve municipalities when they are remove from the model. This prominence would be attributed to the weight of these predictors in the model but NDVI, which had the same weight, did not have such impact on the sensitivity. Furthermore all the predictors

used in the model are relevant because their removal induced the ranking change of at least one municipality.
The sensitivity analysis according to the weight of predictors reveal great variation between weighted and unweighted models. The weighting of the criteria has a major effect on the ranking of municipalities. It is very important to make a reasoned case for this weighting.

CONCLUSION

Globally Benin has better vegetation index, temperature and rainfall compared to Burkina Faso even during the dry season. These are certainly the main reasons driving the movement of cattle from Burkina Faso to Benin in the dry season. Burkina Faso transhumant cattle herds use four transhumance corridors during their displacement into Benin. These corridors pass through various areas with different pathogens and vector risks. The eastern region of Burkina Faso is not yet known to be infested by *Rhipicephalus (Boophilus) microplus*. However, the probability of infestation of animals in this part of Burkina Faso by the invasive tick is not null. Considering its progression in the North of Benin, various cattle movements between the two countries and the suitability of some localities in Burkina Faso bordering Benin, such an event will certainly occur.
Besides, the frequent intrusion of domestic cattle in the wildlife reserves also presents a high risk of introduction of the invasive tick species in wildlife, ensuring pathogen sharing. In fact, sharing grazing areas with wild animals means the sharing of pathogens and vectors with these animals. This represents a risky behaviour that will complicate plans to control certain infectious, parasitic and vector-borne diseases. Some of the wild animals that live in this reserve such as African Buffaloes are known to be reservoir hosts to many pathogens. Thus, herdsmen should avoid contact of their cattle or environment sharing with these animals. A screening of the ticks infesting the potential *Rhipicephalus (Boophilus) microplus* host in this reserve is needed.

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Health and Production engineer with a Master's degree in epidemiology. He is an agent of the veterinary services of Benin. He is currently doing a PhD at the University of Liège. His research focuses on epidemiological aspects of ticks and tick-borne diseases on transhumant cattle between Burkina Faso and Benin.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The activities of the research project "Support to epidemio-surveillance networks for animal diseases and associated sociological aspects in West Africa (Acronym: TransTicks)" have received the favourable opinion of the Ethics Committee of the International Centre for Research and Development on Livestock in Subhumid Zones (CIRDES) (Ref. 001-02/2017/CE-CIRDES) under the strict respect of the protocol submitted to the members of the Committee and their unannounced control.

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Figure caption

Figure 1. Normalized Differentiated Vegetation Index of the study area

Figure 1. Comparative monthly evolution of rainfall, temperature and normalized differentiated vegetation index (NDVI) between the departure and arrival areas

Figure 2. Distribution of comparative normalized differentiated vegetation index (NDVI) across the provinces of the study area (Alibori, Atacora, Borgou and Donga are Benin provinces and Gourma, Kompienga and Tapoa are Burkina provinces)
Legend: The dashed line represents the median of the score distribution between the different experts; the solid lines below and above each rectangle represent, respectively, the first and the third quartiles; adjacent lines to the whiskers represent the limits of the 95% confidence interval.

Figure 4. Spots distribution according to the time of transmission, expressed in hours
Legend: Grazing period in daytime, between 06 and 19 (hours); Rest period in the park at night, between 20 and 05 (hours).

Figure 5. Transhumance corridors, grazing areas and entry points of Burkina Faso transhumant herds through Benin

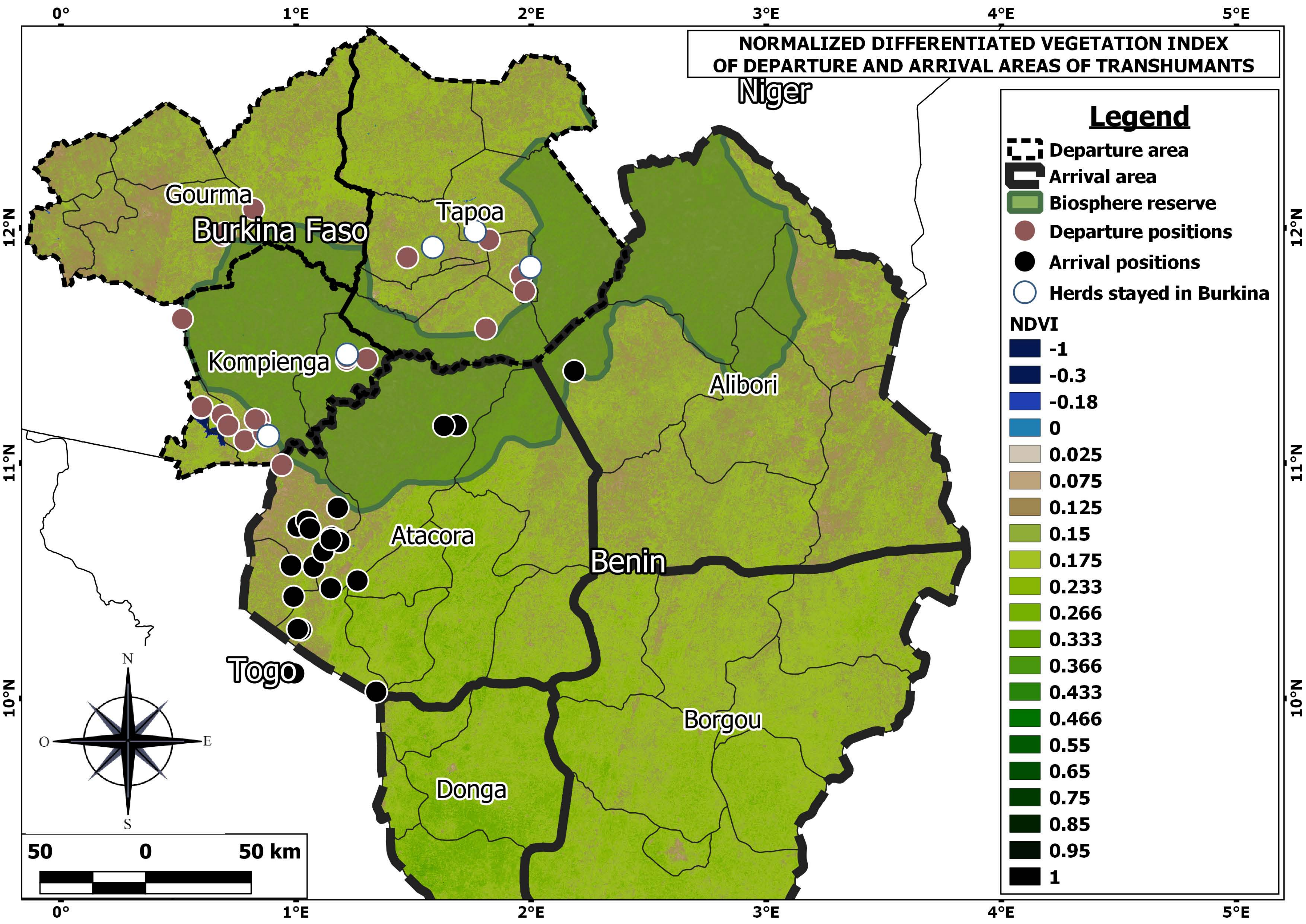
Figure 6. Kernel density estimate of the risk score produced to predict the presence of *Rhipicephalus (Boophilus) microplus*
Legend: Vertical line corresponds to the best cut-off to divide the distribution in two different sub-populations according to the ROC curve presented in the Fig 8.

Figure 7. Distribution of risk scores for the occurrence and establishment of *Rhipicephalus (Boophilus) microplus* in the various of the study region

Figure 8. Area under the curve (AUC) of a receiver operating characteristic (ROC) plot with 95% confidence interval (broken line) for the risk scoring system of prediction of the presence of *Rhipicephalus (Boophilus) microplus*

Figure 9. Sensitivity analysis according to the predictors of the risk of presence of *Rhipicephalus* (*Boophilus*) *microplus*. [A] The diagram shows the modifications of the rank induced by the removal of a given predictor of the presence risk score. [B] The diagram shows the modifications of the rank induced by the weighting of the predictors or not.

Legend: Rank All, all the eight predictors included; Rank-Tc, Rank All minus Transhumance corridor; NDVI, Normalized differentiated vegetation index; Tm, Temperature mean; Rm, Rainfall mean; Wp, Water point; Lm, Livestock markets; Cd, Cattle density; Tga, Transhumant grazing area; Red circles represent the cut-off of more than three rank between different step. Removal of the predictor Cd (Cattle density) highlights the importance of this predictor leading to the highest cut-off number.


NORMALIZED DIFFERENTIATED VEGETATION INDEX
OF DEPARTURE AND ARRIVAL AREAS OF TRANSHUMANTS
Legend
Departure area
Arrival area
Biosphere reserve
Departure positions
Arrival positions
Herds stayed in Burkina
NDVI
-1
-0.3
-0.18
0
0.025
0.075
0.125
0.15
0.175
0.233
0.266
0.333
0.366
0.433
0.466
0.55
0.65
0.75
0.85
0.95
1
Niger
Gourma
Burkina Faso
Tapoa
Kompienga
Alibori
Atacora
Benin
Togo
Borgou
Donga
N
S
O
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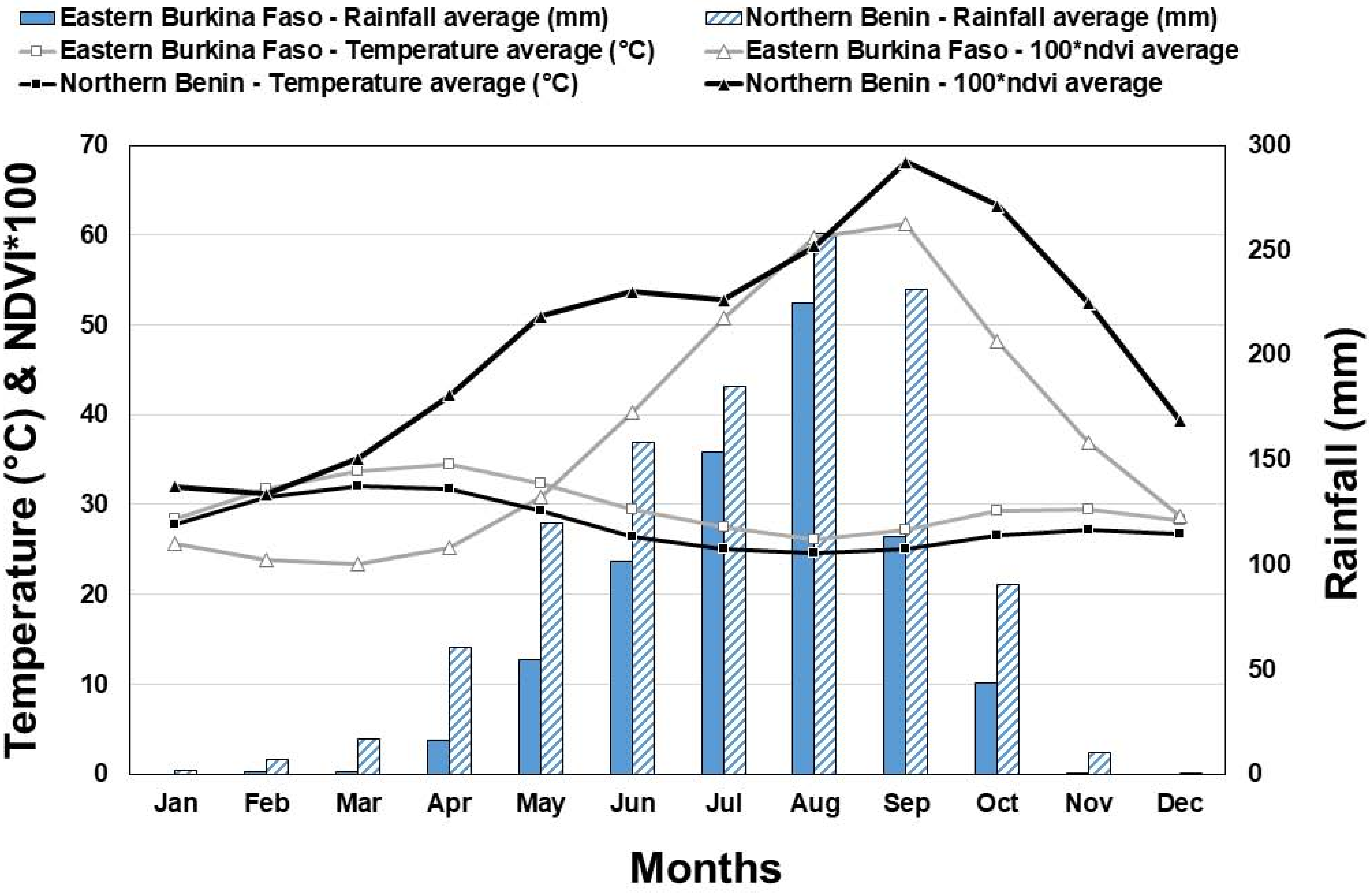
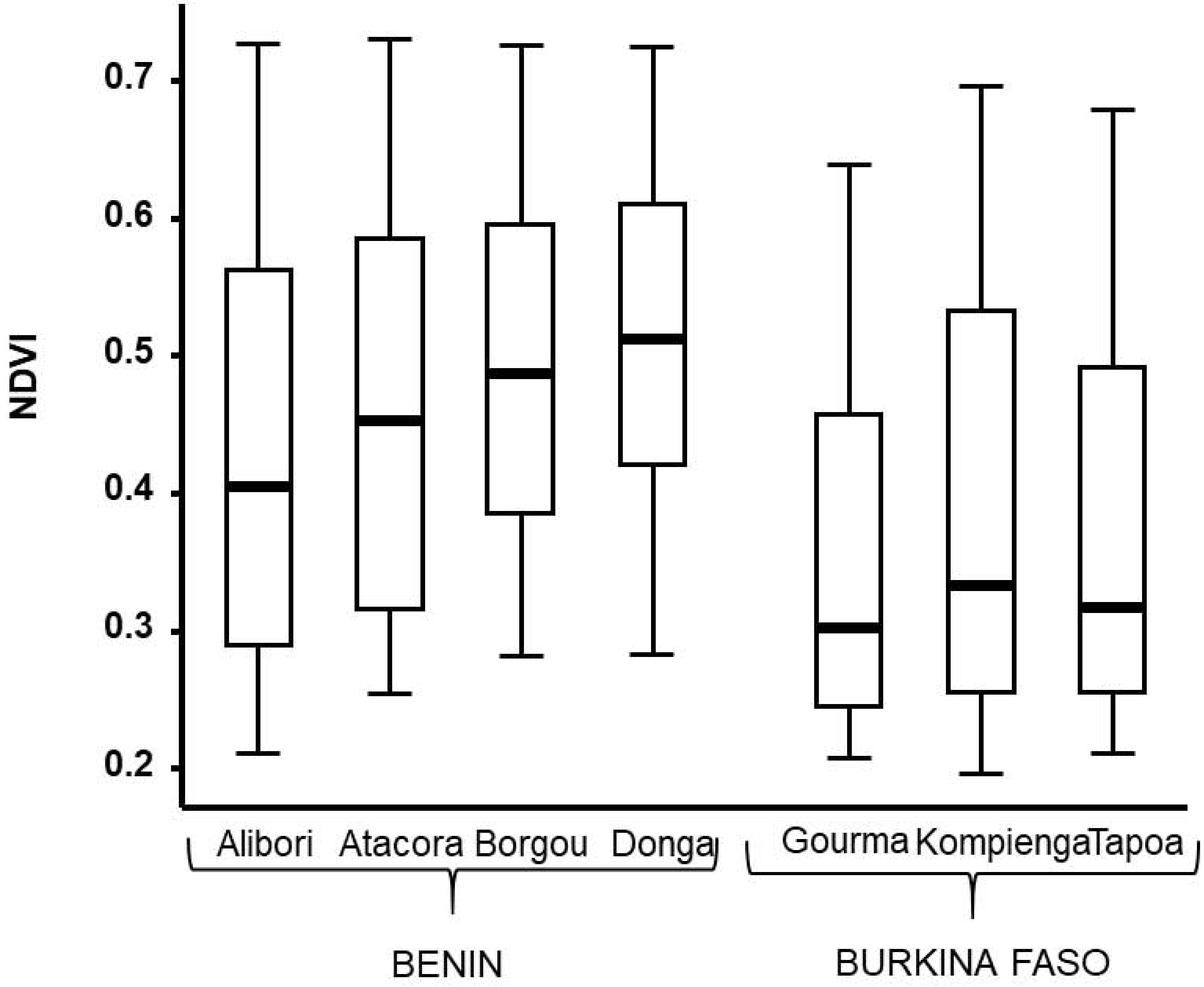
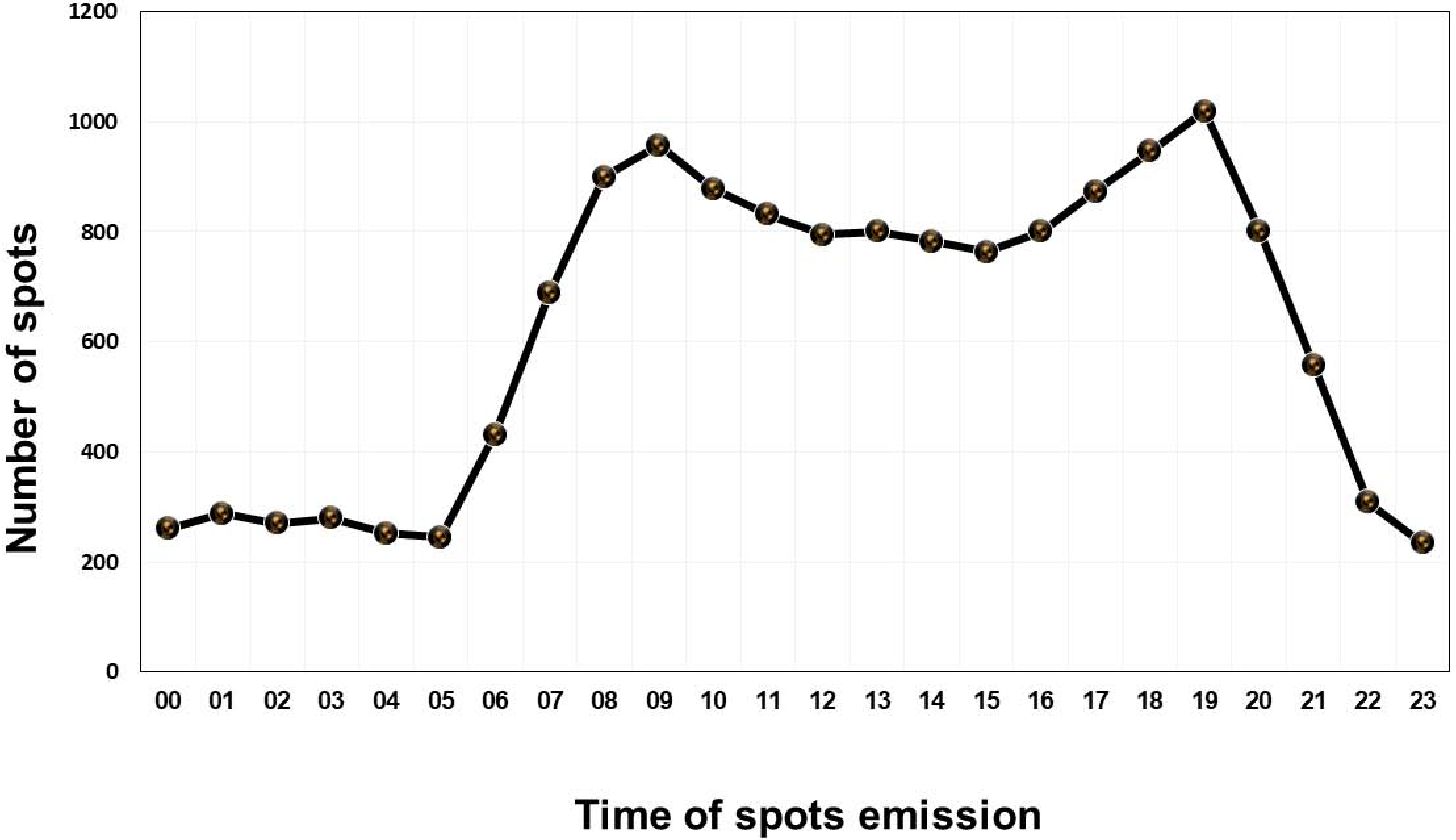
50
0
50 km
0°
1°E
2°E
3°E
4°E
5°E
12°N
11°N
10°N



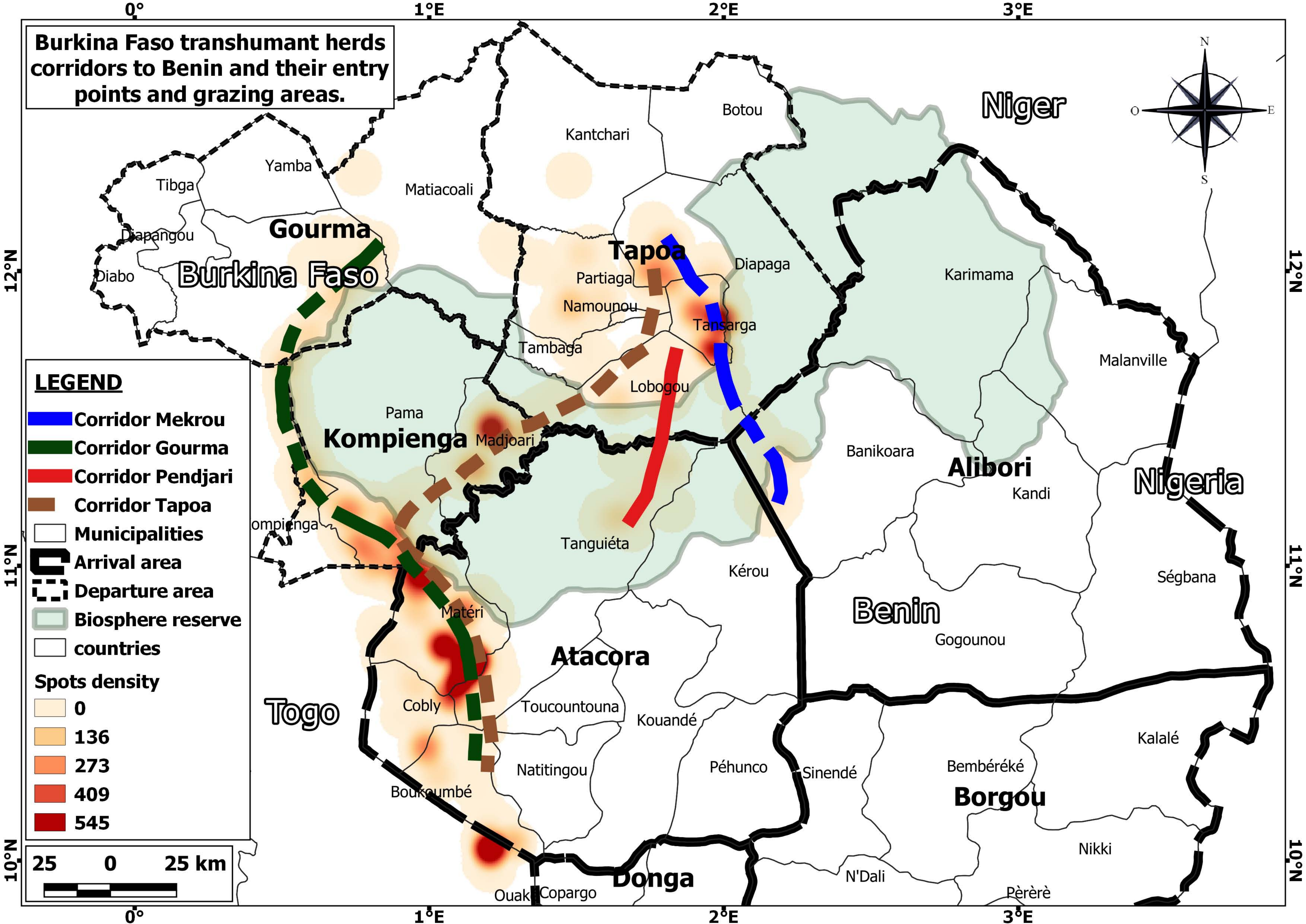
Eastern Burkina Faso - Rainfall average (mm)
Northern Benin - Rainfall average (mm)
Eastern Burkina Faso - Temperature average (°C)
Eastern Burkina Faso - 100*ndvi average
Northern Benin - Temperature average (°C)
Northern Benin - 100*ndvi average
Temperature (°C) & NDVI*100
Rainfall (mm)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months



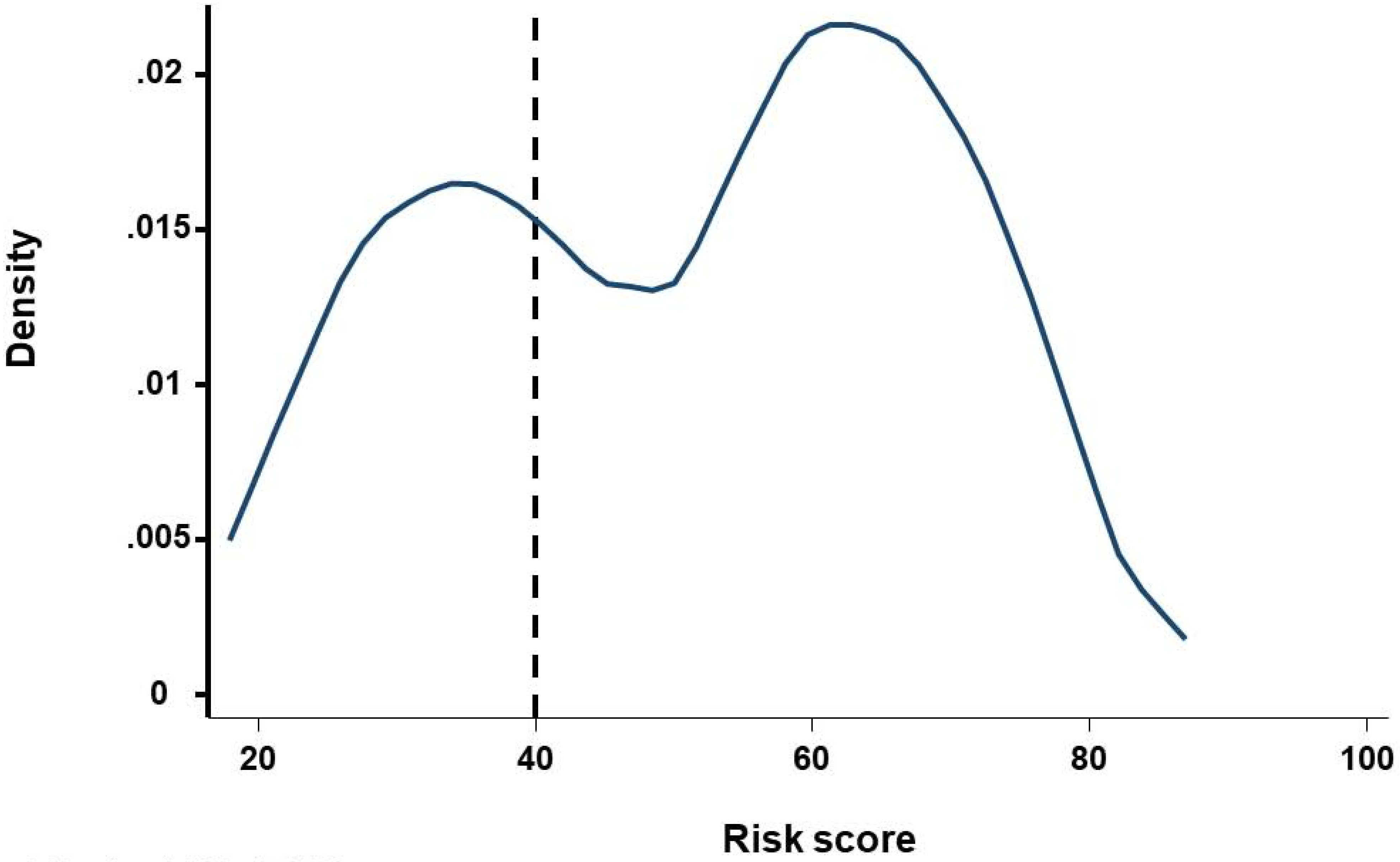
NDVI
0.7
0.6
0.5
0.4
0.3
0.2
Alibori
Atacora
Borgou
Donga
Gourma
Kompienga
Tapoa
BENIN
BURKINA FASO



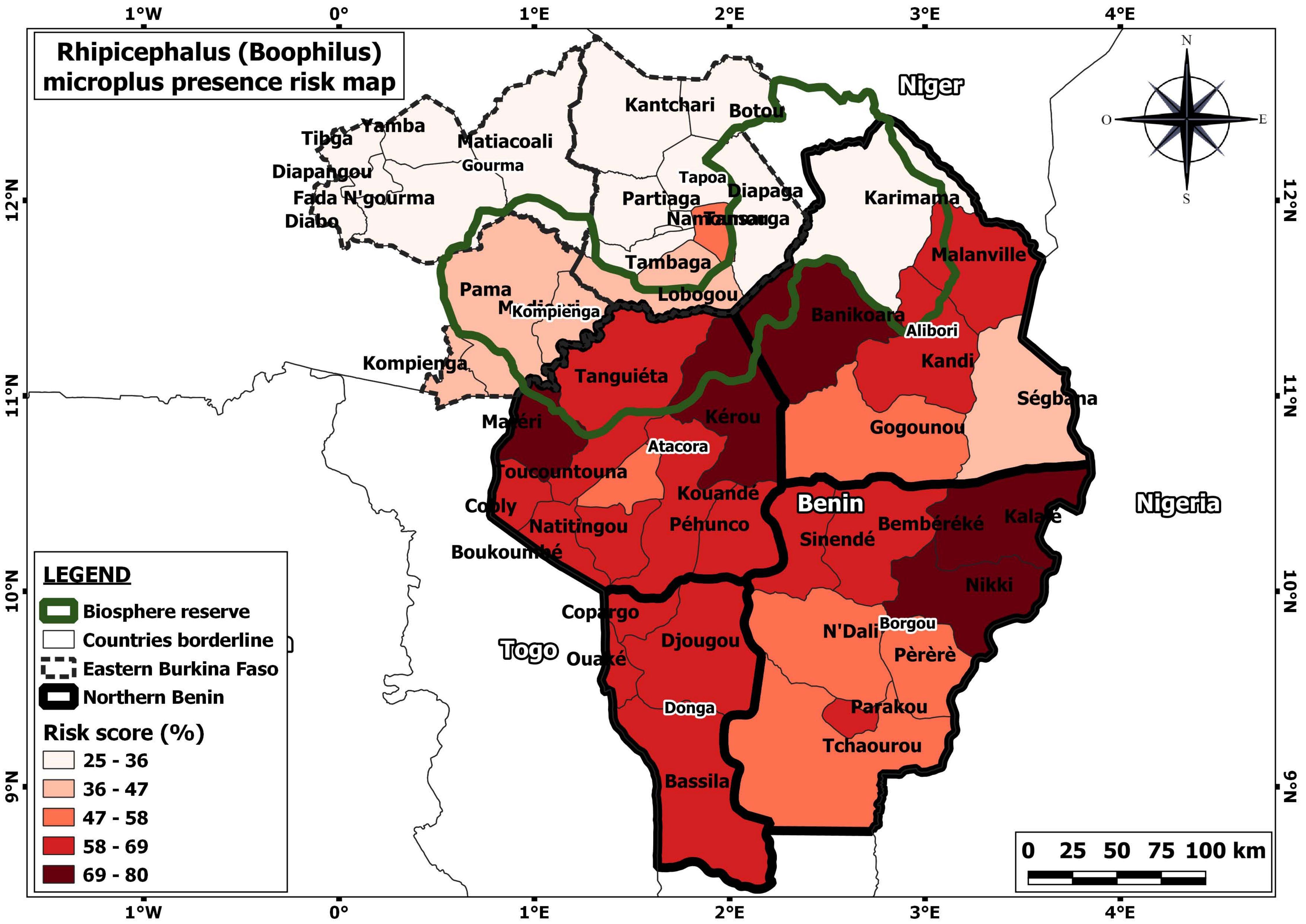
Number of spots
0
200
400
600
800
1000
1200
00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Time of spots emission



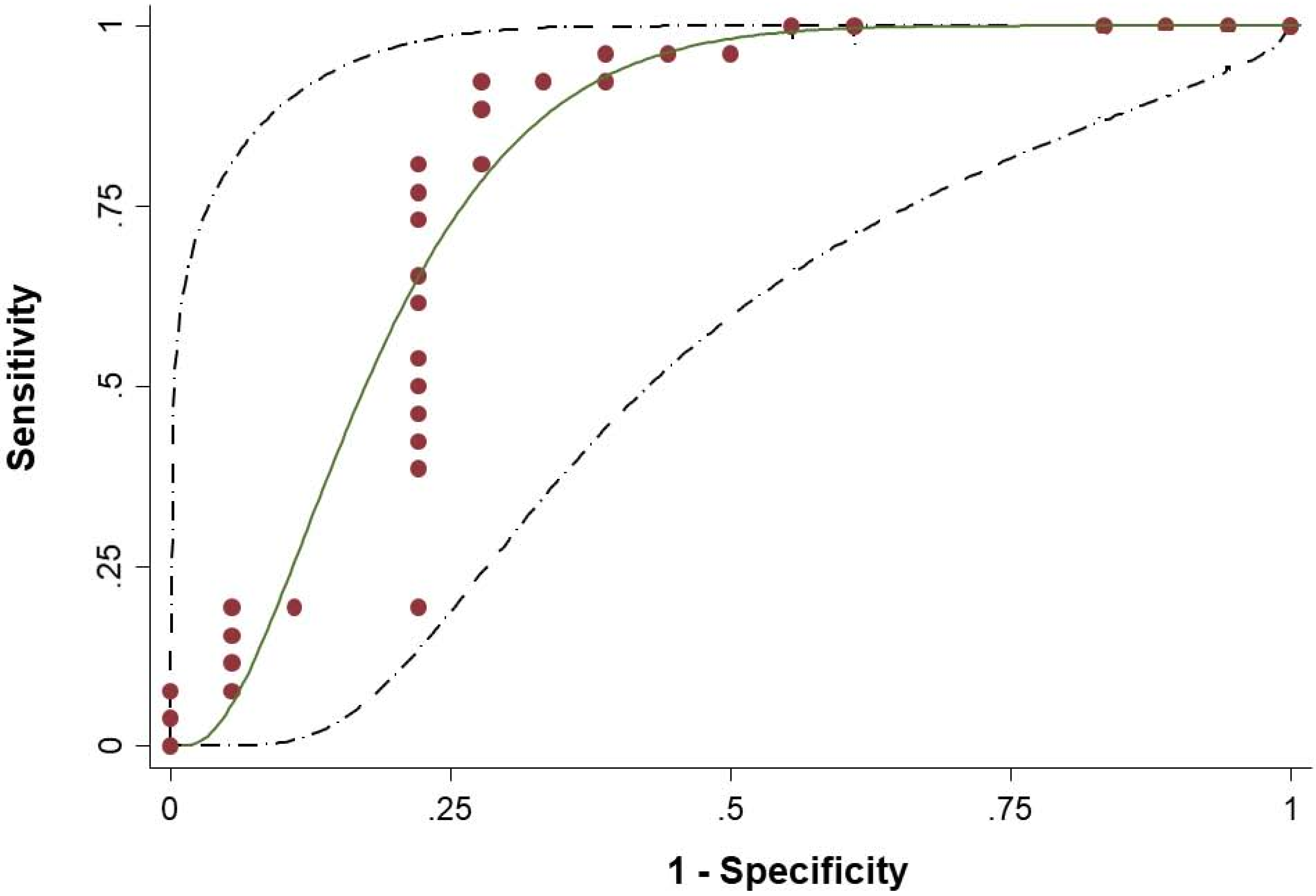
Burkina Faso transhumant herds corridors to Benin and their entry points and grazing areas.
LEGEND
Corridor Mekrou
Corridor Gourma
Corridor Pendjari
Corridor Tapoa
Municipalities
Arrival area
Departure area
Biosphere reserve
countries
Spots density
0
136
273
409
545
25 0 25 km
0°
1°E
2°E
3°E
12°N
11°N
10°N
N
S
O
E
Niger
Nigeria
Burkina Faso
Benin
Togo
Gourma
Tapoa
Kompienga
Alibori
Atacora
Borgou
Donga
Botou
Kantchari
Yamba
Tibga
Matiacoali
Diapangou
Diabo
Partiaga
Namounou
Diapaga
Tansarga
Tambaga
Lobogou
Karimama
Malanville
Pama
Madjoari
Banikoara
Kandi
Kompienga
Tanguiéta
Kérou
Ségbana
Matéri
Gogounou
Cobly
Toucountouna
Kouandé
Natitingou
Péhunco
Sinendé
Bembéréké
Kalalé
Boukoumbé
Nikki
N'Dali
Ouaké
Copargo
Pèrèrè



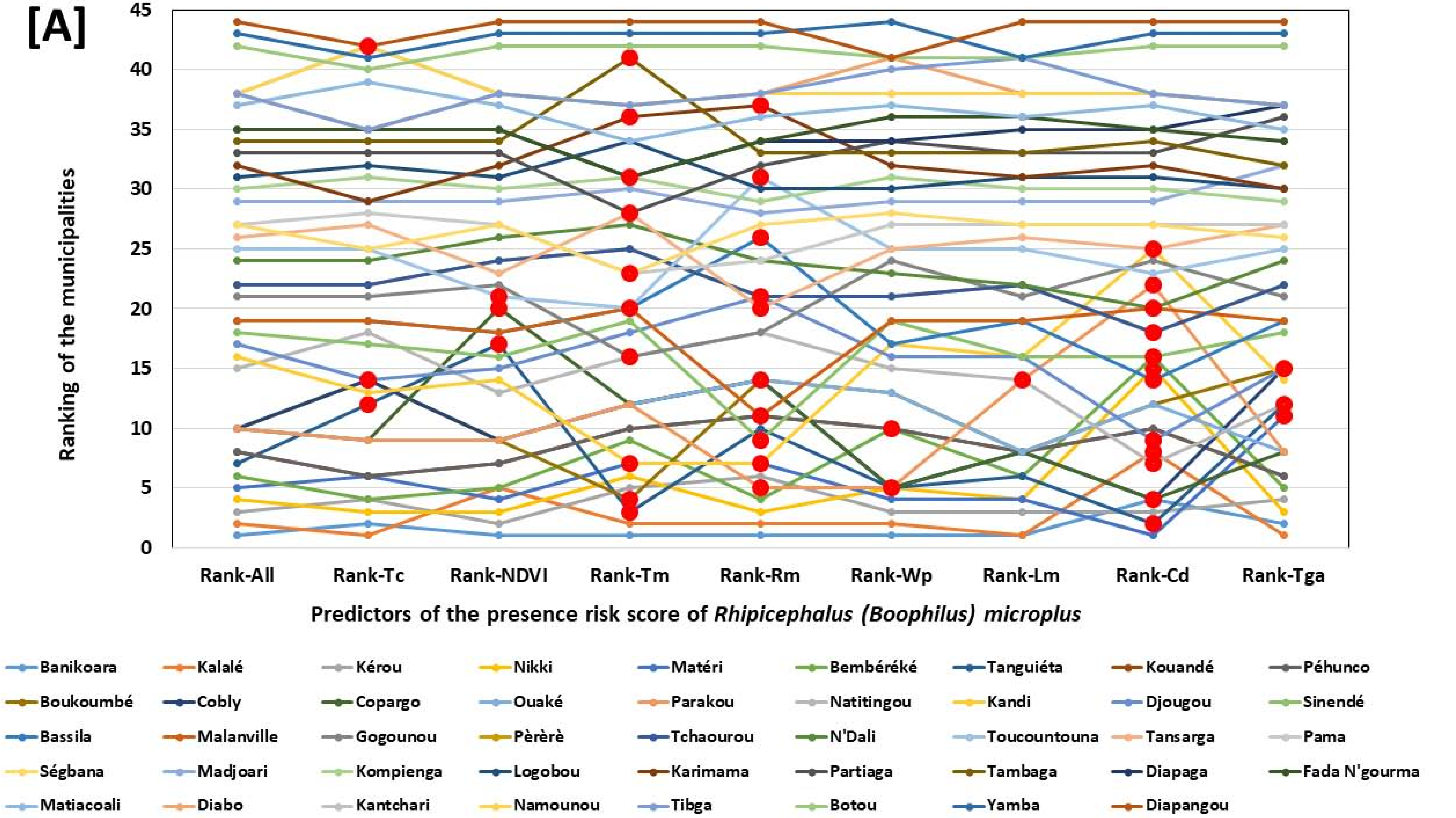
kernel = epanechnikov, bandwidth = 7.0096



Rhipicephalus (Boophilus) microplus presence risk map
1°W
0°
1°E
2°E
3°E
4°E
12°N
11°N
10°N
9°N
Niger
Nigeria
Togo
Benin
Kantchari
Botou
Yamba
Tibga
Matiacoali
Gourma
Diapangou
Fada N'gourma
Diabo
Tapoa
Diapaga
Partiaga
Namounou
Tansarga
Tambaga
Lobogou
Pama
Madjoari
Kompienga
Karimama
Malanville
Banikoara
Alibori
Kandi
Ségbana
Gogounou
Tanguiéta
Kérou
Matéri
Atacora
Toucountouna
Kouandé
Cobly
Natitingou
Péhunco
Boukoumbé
Sinendé
Bembèrèkè
Kalalé
Nikki
Copargo
Djougou
Ouaké
Donga
Bassila
N'Dali
Borgou
Pèrèrè
Parakou
Tchaourou
LEGEND
Biosphere reserve
Countries borderline
Eastern Burkina Faso
Northern Benin
Risk score (%)
25 - 36
36 - 47
47 - 58
58 - 69
69 - 80
0 25 50 75 100 km
N
S
E
O

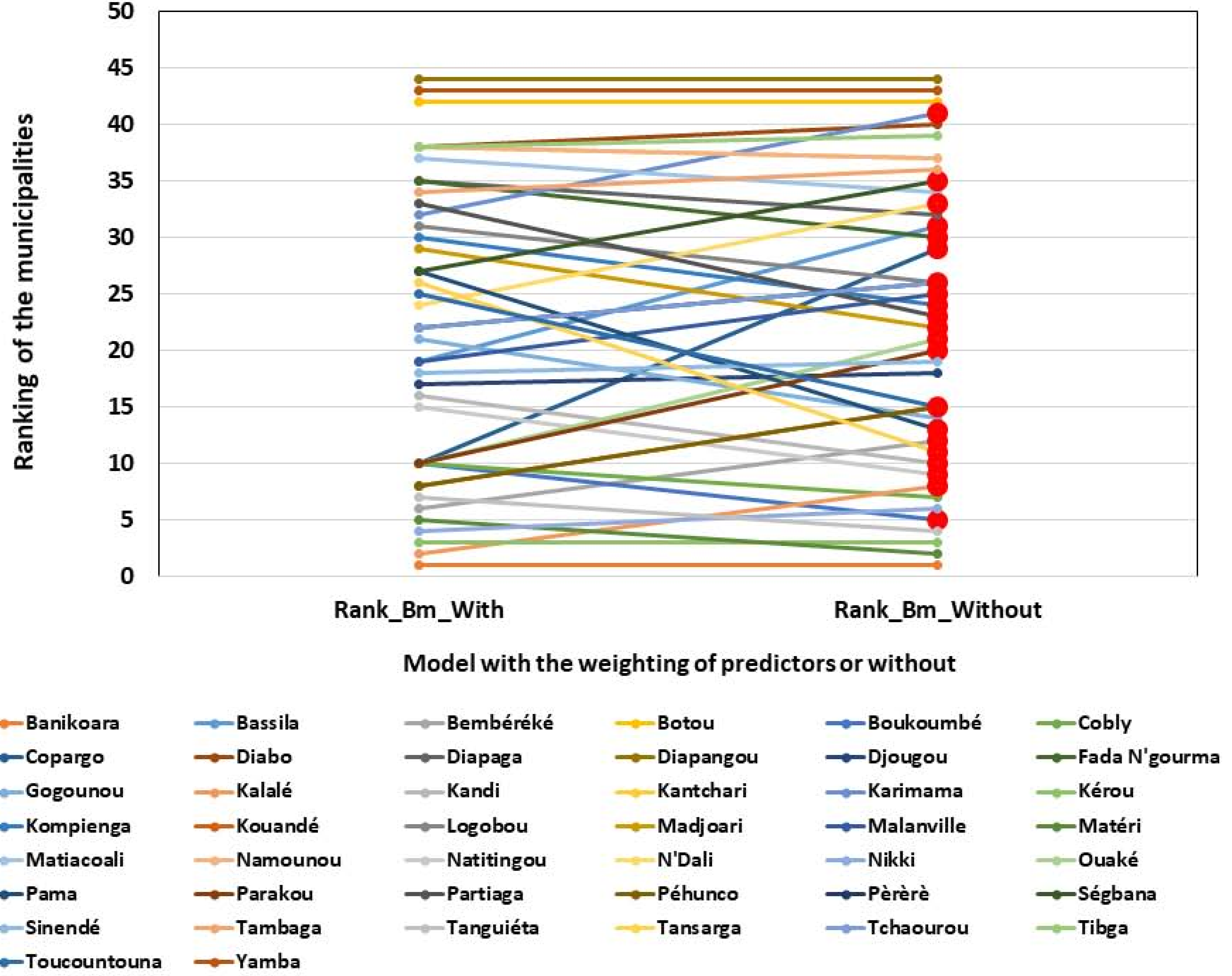


Area under curve = 0.8130 se(area) = 0.0718



[A]
Ranking of the municipalities
0
5
10
15
20
25
30
35
40
45
Rank-All
Rank-Tc
Rank-NDVI
Rank-Tm
Rank-Rm
Rank-Wp
Rank-Lm
Rank-Cd
Rank-Tga
Predictors of the presence risk score of Rhipicephalus (Boophilus) microplus
Banikoara
Kalalé
Kérou
Nikki
Matéri
Bembéréké
Tanguiéta
Kouandé
Péhunco
Boukoumbé
Cobly
Copargo
Ouaké
Parakou
Natitingou
Kandi
Djougou
Sinendé
Bassila
Malanville
Gogounou
Pèrèrè
Tchaourou
N'Dali
Toucountouna
Tansarga
Pama
Ségbana
Madjoari
Kompienga
Logobou
Karimama
Partiaga
Tambaga
Diapaga
Fada N'gourma
Matiacoali
Diabo
Kantchari
Namounou
Tibga
Botou
Yamba
Diapangou

[B]



Ranking of the municipalities
50
45
40
35
30
25
20
15
10
5
0
Rank_Bm_With
Rank_Bm_Without
Model with the weighting of predictors or without
Banikoara
Bassila
Bembéréké
Botou
Boukoumbé
Cobly
Copargo
Diabo
Diapaga
Diapangou
Djougou
Fada N'gourma
Gogounou
Kalalé
Kandi
Kantchari
Karimama
Kérou
Kompienga
Kouandé
Logobou
Madjoari
Malanville
Matéri
Matiacoali
Namounou
Natitingou
N'Dali
Nikki
Ouaké
Pama
Parakou
Partiaga
Péhunco
Pèrèrè
Ségbana
Sinendé
Tambaga
Tanguiéta
Tansarga
Tchaourou
Tibga
Toucountouna
Yamba