Lantana camara (verbenaceae) : a potential threat to the effectiveness of protected areas to conserve flora and fauna in Benin

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ABSTRACT

Invasive plant species are today among the biggest threats to integrity of many ecosystems including that of the protected areas. Climate change may exacerbate the negative effects of invasive plant species. Here, we used the Maximum Entropy model to project habitat suitability for *Lantana camara L.*, an invasive plant species under current and future climates in the national protected areas network of Benin. The models were run using bioclimatic data and data on soil type. Nineteen percent of the total land in the protected areas network was highly suitable for L. camara under current climate. Highly suitable areas under current and future climates cover about 65 % of the Pendjari Biosphere Reserve, the major wildlife sanctuary in Benin. Other bio-reserves such as W National Park, Lama, Agoua, Dogo-Kétou, Atchérigbé, Mékrou and Kouandé Forest Reserves were also suitable for the species. Presence of L. camara in the protected areas represents a great potential threat to the global food webs being conserved. Based on these results, areas with highly suitable habitats are at high risk of invasion by L. camara, and should be accorded high priority when formulating appropriate management strategies.

Key words : Invasive species ; Climate change ; Habitat suitability ; Protected areas ; West Africa

RESUME

LANTANA CAMARA *ET LES AIRES PROTEGEES AU BENIN*

Les espèces invasives font de nos jours partie des plus importantes menaces aux quelles font face les écosystèmes y compris les aires protégées. Les changements climatiques peuvent amplifier leurs effets négatifs. Dans la présente étude, nous avons utilisé un algorithme de modélisation de niche écologique, le Maximum Entropy pour analyser la susceptibilité des habitats à être colonisés par *Lantana camara L.*, une plante invasive, sous les conditions climatiques actuelles et futures dans les aires protégées du Bénin. Les modèles ont été établis en utilisant des données bioclimatiques et des données relatives aux types de sol. Dans les conditions climatiques actuelles, 19 % de la superficie totale du réseau des aires protégées est significativement favorable à *L. camara.* Sous les conditions climatiques actuelles et futures, 65 % de la réserve de biosphère de Pendjari, le plus important sanctuaire de faune sauvage du Bénin, est hautement favorable à l'espèce. D'autres bio-réserves telles que le Parc National W et les réserves forestières de Lama, Agoua, Dogo-Kétou, Atchérigbé, Mékrou et Kouandé ont aussi des habitats favorables à l'espèce. En nous fondant sur ces résultats, les zones favorables sont à haut risque d'invasion par *L. camara* et devraient être priorisées lors de la formulation de stratégies préventives appropriées.

Mots clés : Espèces envahissantes ; Changements Climatiques ; Habitats favorables ; Aires protégées, Afrique de l'Ouest.

INTRODUCTION

Lantana camara belongs to the genus *Lantana* that comprises up to 150 species (Gujral and Vasudevan 1983). Many of those species including *L. camara* are native to South America, Central America or southern North America, while some few species occur naturally in Africa and Asia (Munir 1996). In this taxonomic group, *L. camara* is the most known for its economic and environmental impacts as an invasive taxa in natural and agricultural ecosystems (Taylor *et al.* 2012). Its environmental impacts are said to be very harmful in native disturbed forests where it can form a dense understory thereby disrupting succession, and decreasing biodiversity (IUCN AsESG 2010). Invasion by *L. camara* has been invoked as a possible cause of extinction of a native plant species *Linum cratericola* Linaceae on the Galapagos Islands (Mauchamp *et al.* 1998). In Australia, *L. camara* covers 5.1 % of the total land area where it threatens diversity of more than 80 native plant species (Coutts-Smit hand Downey 2006). To our knowledge, there is no report tracing back the period of its introduction in West Africa.

The introduction of invasive alien plant species to new geographic areas has been attributed to human activities mainly through trade and travels spanning millennia (Hulme 2009). With a recent intensification of such human activities, it is expected that more invasive plant species will be newly introduced to other regions (Hulme 2009).

Protected areas are important zonesfor biodiversity conservation as well as for provisioning of various ecosystem services (Millennium Ecosystem Assessment 2005). However, integrity of ecosystems within the protected areas in many parts of the world is currently threatened by a variety of factors including climate change and invasive plant species (Millennium Ecosystem Assessment 2005 ; Foxcroft *et al.* 2007).

In the light of limited availability of resources for management of protected areas, prudent management of invasive plant species requires information that can enable risk assessment and formulation of strategies that include : periodic monitoring for new invasions, early detection and eradication of the invasive plants, and resource allocation (Foxcroft *et al.* 2011 ; Taylor *et al.* 2012 ; Taylor and Kumar 2013).

Potential distribution of *L. camara* has been modeled previously (Taylor *et al.* 2012). However, this model was at much larger spatial scales global/intercontinental, and that makes it unsuitable for management decision making at local scale.

There is little information about the distribution of *L.camara* in West Africa. Invasion risk assessment of *L. camara* in Benin, proper research planning and design and implementation of management strategies are limited by lack of information on its spatial distribution and little awareness.

Species distribution or potential invasive habitat suitability mapping has been modeled using a diverse list of statistical methods to analyze environmental and presence/ absence data to estimate the probability of occurrence of a given species at given geographic coordinates (Guisan and Zimmermann 2000). Among these modeling tools, Max Ent (maximum entropy) modeling is one of the most powerful tools as it provides highly informative biogeographical information and a better discrimination of suitable versus unsuitable areas for a species, compared to other methods (Phillips *et al.* 2006).

Since climate is one of the major determinants of plant distributions, changes in climate may influence range shifts i.e. range expansion or contraction by invasive plant species with significant consequences to the invaded ecosystems (Diez *et al.* 2012).

In Benin, likewise other West African countries, potential effect of climate change on the spread of invasive species has been poorly addressed. Scarcity of information on distribution of *L. camara* and how it could be influenced by climate change critically limits integration of both ecological stressors in protected areas management in West Africa.

Such information can be generated from ENMs that estimate future potential spread of invasive plants, and the specific sites at risk of invasion under current and future climates (Taylor *et al.* 2012 ; Foxcroft *et al.* 2011). Here, MaxEnt was used to model the vulnerability of the National protected Areas Network of Benin to a probable invasion by *L. camara*, under current and future climates.

METHODS

STUDY AREA

The Republic of Benin (6-12° N ; 0.40-3°E) is a West African country located with in the Dahomey Gap. The Dahomey gap is a savanna mosaic corridors which fragments the zonal west African rain forest, likely induced by climate change during the Holocene (Salzmann & Hoelzmann 2005).Climatically, Benin is subdivided in three main regions : the sub-humid humid, sub-humid dry and the semi-arid regions. Table 1 summarizes location and characteristic of each of the three climatic regions. Benin covers 112622 km² of which 22.7 % are legally protected (FAO 2001).

DATA SET

Geographic coordinates longitude and latitude of location records of *L. camara* were gathered from the Global Biodiversity Information Facility (2013) and field survey in northern Benin (Table 2). For field data collection, firstly, an exploration phase was conducted along roadsides surrounding the Pendjari Biosphere Reserve. On the basis of preliminary records of the species, sixteen 10 km transects were defined within the Reserve. Along each transect latitude and longitude information of every contact point with the species was recorded using a GPS receiver GARMIN 60, Precision 3 m.

For both current and future climates, 19 bioclimatic variables were obtained from Worldclim website (https:/www.worldclim.org and downscaled for the area of interest. For projection under future climate, the CSIRO-MK3.0 which is one of the top models performing well relative to other Global Circulation Models in terms of representing basic aspects of the observed climate at a regional scale (Kriticos *et al.* 2012) was used. To account edaphic conditions, one soil variable soil type was generated from the Harmonized World Soil Database FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and used along with Bioclimatic variables in the model. Including data on soil type helped control biologically unrealistic projections (Pearson & Dawson 2003).

The projection was made for 2050 under the A2 emission scenario. This scenario was preferably used since it predicts a situation reported to be more likely for Africa (Williams *et al.* 2007) : very heterogeneous world with high population growth, slow economic development and slow technological change (IPCC 2007). All variables were used at a resolution of 2.5 minutes grid approximately 4.62 km x 4.62 km resolution.

MODELING AND VALIDATION

Duplicate records in each grid were removed to reduce the sampling bias in favor of sites where sampling may be concentrated (Elith *et al.* 2006). Bioclimatic variables were screened to

Table 1 : Characteristics of the three climatic regions (Assogbadjo *et al.* 2005 ; ECOWAS-SWAC/OECD/CILSS 2008).

Caractéristiques des trois régions climatiques (Assogbadjo et al. 2005 ; ECOWAS-SWAC/OECD/CILSS 2008).

	Semi-arid	Subhumide dry	Sub-humid humid
Location	9°45'-12°25' N	7°30'-9°45' N	6°25'-7°30' N
Rainfall regime	Unimodal	Unimodal	Bimodal
Rainfall (mm/year)	600-900	900-1110	1200
Mean temperature (°C)	24-31	25-29	25-29
Relative humidity (%)	18-99	31-98	69-97
Soil	Hydromorphic soils Well-drained soils andlithosoils	Ferruginous with variable fertility	Either deep ferrallitic or rich in clay, humus and minerals
Climate type		Tropical	

Table 2 : *Lantana camara* presence records used in the study

Points de présence de Lantana camara *utilisés dans cette étude*

Source	Records	Location
Field records	32	Benin, Burkina Faso
Global Biodiversity Information Facility (GBIF) 2013	25*	Benin, Burkina Faso, Cote d'Ivoire, Ghana, Togo

identify least correlated variables to account for correlation which may bias the future projection. A Jackknife procedure was performed on the bioclimatic least correlated variables to determine variables which best contribute to the model prediction. For model evaluation, 25 % of location records were used to test the model. Then all records were used for model calibration. To validate findings from the modeling, the area under curve (AUC) was used following Phillips *et al.* (2006). A model with an AUC value close to one (AUC > 0.90) was deemed as good (Swets 1988). A one tailed binomial test was executed to test the statistical significance of the model (Anderson *et al.* 2002).

MAPPING CURRENT AND FUTURE POTENTIAL SUITABLE AREAS AND PROTECTED AREAS' VULNERABILITY ANALYSIS

Using ArcGIS 9.3, current and future suitable habitats for *L. camara* modeled with MaxEnt were mapped. The logistic probability distributions generated by the model were used as a measure of the habitat suitability for the species. The maximum training sensitivity plus specificity threshold was taken as the threshold and all areas with an occurrence probability below this threshold were deemed not to be suitable for the species. Two suitability levels were defined using the equal training sensitivity and specificity as threshold (Liu *et al.* 2005) : low and high.

To assess current and future vulnerability of national protected areas network to invasion by *L. camara*, the overlays of present and future habitat suitability maps with the national protected areas network (PAN) map of Benin was done. The latter map was extracted from the global protected areas network obtained from the world database of protected areas (IUCN & UNEP 2009). Area and percentage of highly

suitable areas within the PAN was estimated using spatial analysis tools in ArcGIS. On the basis of the potential habitat suitability maps obtained for the current and future climates, percentage of present unsuitable areas projected to become suitable and vice versa by the year 2050 was estimated.

RESULTS

LEAST CORRELATED ENVIRONMENTAL VARIABLES AND MODEL VALIDATION

A layer containing soil type and six least correlated bioclimatic variables were selected as predictors in the models (Table 3). Soil type and precipitation of the driest quarter were the best predictors. Soil type was the environmental variable with the highest gain when fitted in the model in isolation, and also the variable that contains the most information that is not present in the rest of the variables considered Jackknife test. The models showed statistical significance ($p < 0.001$) and good predictive ability with an AUC of 0.91. The maximum training sensitivity plus specificity and the equal training sensitivity and specificity thresholds were, respectively, 0.104 and 0.107.

VULNERABILITY OF THE NATIONAL PROTECTED AREAS NETWORK TO *L. CAMARA*

Under current climate, 19 % of the land cover of the national protected areas network were found to be highly suitable for *L. camara*, mainly between 10°30'N and 11°5'N latitudes (Figure 1 Figure 2 ; Figure 3A). Some small pieces of land were also projected to be highly suitable for the species between 6°N and 7°30'N latitudes.

Under current conditions, 65 % of the Pendjari Biosphere Reserve was projected to be highly suitable for the species while about 6 % of the W National.

Park was found suitable for the species. About half the Lama, Mékrou and Kouandé Forest Reserves, total area of Djigbé, and a piece of Agoua Forest Reserve were also projected to be highly suitable for *L. camara.* The overall highly suitable area was projected to increase slightly by one percent under future climate by the year 2050 (Figure 2 ; Figure 3A). By 2050 while all currently vulnerable protected areas will remain so, the species was projected to find new suitable areas in the Agoua, Kétou-Dogo and Atchérigbé Forest Reserves between 6°N and 7°30'N.

**Table 3 :** Contribution of predictor variables to the model

Contribution des variables prédictrices au modèle

| Variables	(%)
Annual precipitation	1.8
Mean temperature of coldest quarter	0.1
Precipitation of driest month	0.6
Precipitation of driest quarter	73.2
Precipitation of warmest quarter	0.8
Soil layer	20.8
Temperature seasonality	2.8
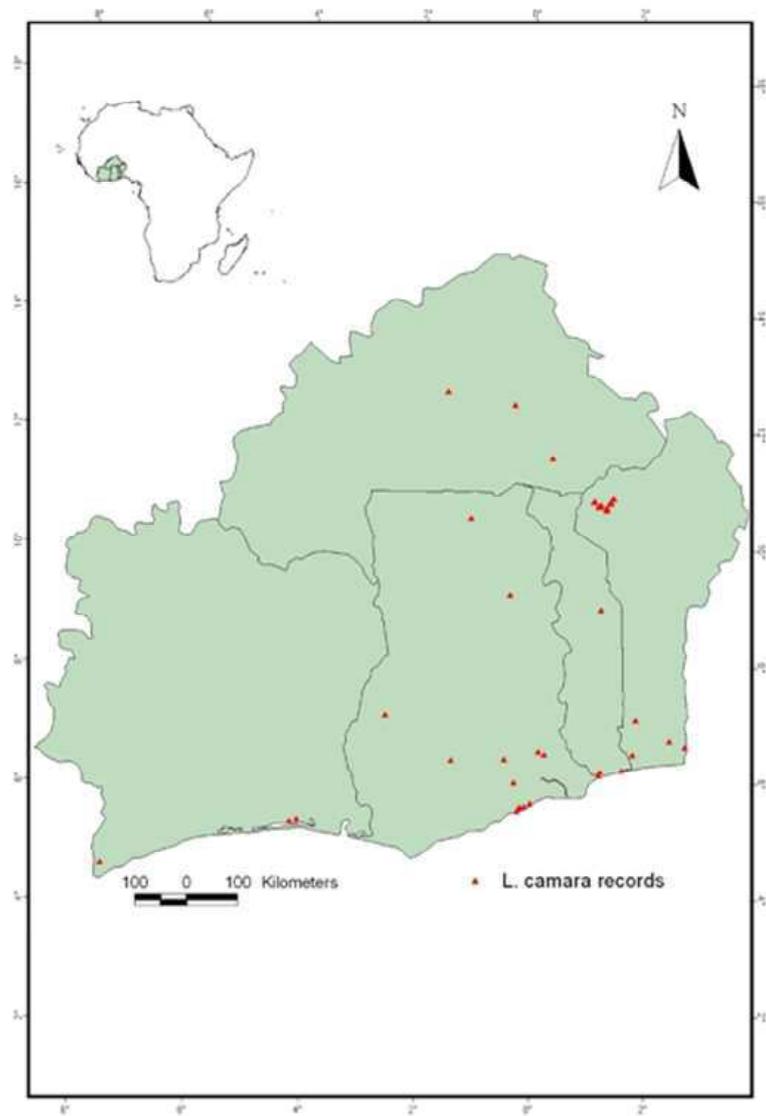
FIGURE 1 : *Study area and geographical distribution of presence records used in the model.*

Milieu d'étude et distribution géographique des points de présence utilisés dans les modèles.
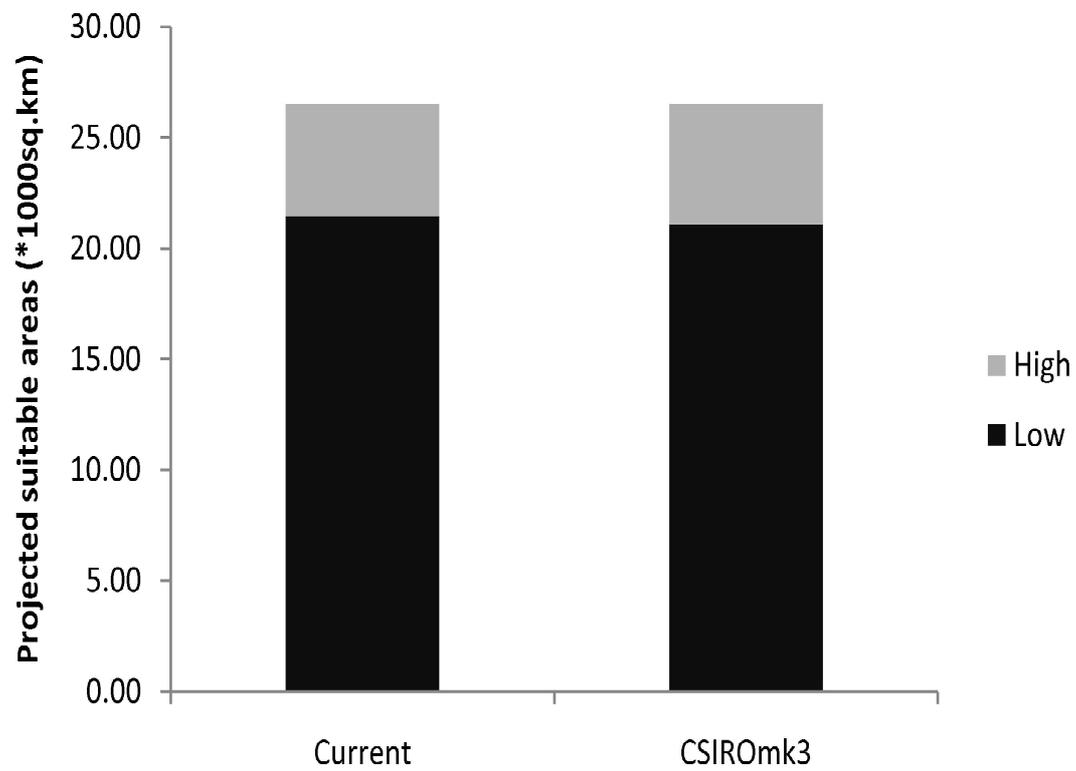
FIGURE 2 : Projected habitat suitability (low, high) for *Lantana camara* in protected areas of Benin under current (current) and future (CSIROmk[3]) climates.

Susceptibilité projetée des habitats (faible, élevée) à être colonisés par Lantana camara dans les Aires Protégées du Bénin sous les conditions climatiques actuelles et futures(CSIROmk[3]).
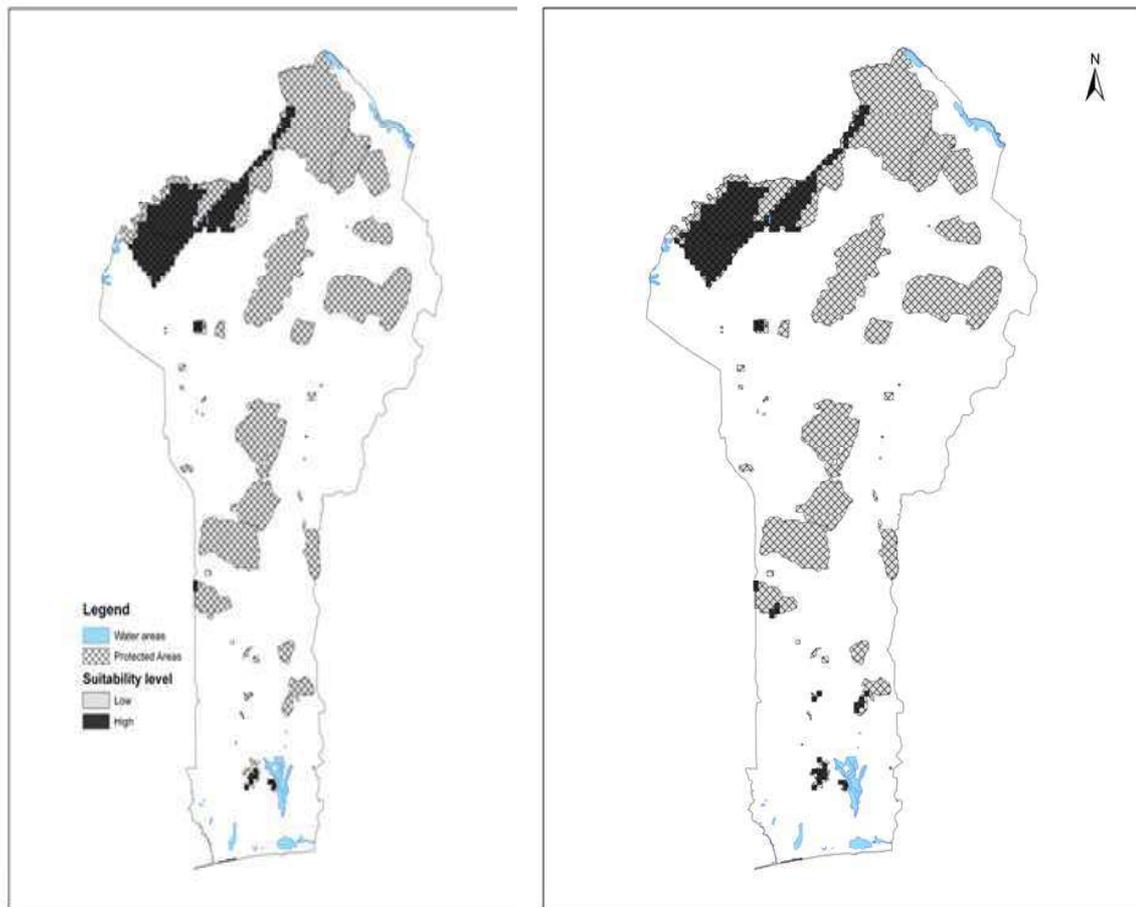
FIGURE 3 : *Map of projected habitat suitability for Lantana camara under current (A ; left) and future (SCIRO mk3 scenario A2) (B ; right) climates. Some key vulnerableprotected areas are highlighted : a, W ; b, Pendjari ; c, Mékrou and Kouandé ; d, Agoua ; e, Atchérigbé f, Dogo-Kétou ; g, Lama ; h, Djibgé.*

Carte montrant la susceptibilité projetée des habitats (faible, élevée) à être colonisés par Lantana camara sous les conditions climatiques actuelles (A ; gauche) et futures (SCIRO mk3 scenario A2) (B ; droite). Quelques Aires Protégées importantes vulnérables sont mises en exergues : a, W ; b, Pendjari ; c, Mékrou et Kouandé ; d, Agoua ; e, Atchérigbé ; f, Dogo-Kétou ; g, Lama ; h, Djibgé.

DISCUSSION

REACTION OF INVASIVE PLANTS TO CLIMATE CHANGE

This study has modeled the potential suitable environmental area for *L. camara* in Benin under current climate and CSIRO MK3_0 future climate at horizon 2050 using MaxEnt. The model was statistically significant (p < 0.01) ; one-tailed binomial test along with an AUC > 0.90.

Invasive plants may have opportunity to spread if the projected changes in the climate are in agreement with their ecological preferendum. In face of unfavorable climate change, species may either withstand without substantial biological change 'resistance' or recover after being damaged 'resilience' (Hannah 2008). They can also show rapid evolutionary response to environmental changes (Görgens and van Wilgen 2004). Climate change will thus provide the species ample opportunity to express their climatic tolerances. In these cases, the actual effect of climate change on the species range will even be worse than the here projected future range. This is because outputs of projections in the future not only assume that relations between species and environmental variables are fiixed, but also consider that the currently known climatic range is the best for the species. Such assumption overlooks the capacity of the species to adapt to changing environments due to phenotypic plasticity or even to show evolutionary response to environment changes.

In absence of resilience, resistance or evolutionary adaptation response, the species will have to migrate through dispersion to fit in its climate tolerance zone. On the one hand bioclimatic models are increasingly been reported to be relevant to forecast suitable habitats that are potentially under the threat of invasion (Kriticos *et al.* 2005 ; 2012 ; Taylor *et al.* 2012 ; 2013). On the other hand, their capacity to provide relevant information on range narrowing, range shifting or unsuitable habitats is questionable (Scharwtz 2012). Indeed, invasive species are well known for their plasticity and increase competitive ability traits in adverse conditions Matesanz *et al.* 2010.

With some new location records for *L. camara*, our results illustrate that some areas previously reported to be unsuitable or marginal for the species Taylor *et al.* 2012 are suitable and will

remain so by 2050. This illustrates the sensitivity of climate models to availability and quality of species record data *e.g.*, known realized niche.

VULNERABILITY OF THE NATIONAL PROTECTED AREAS NETWORK TO INVASION BY *L. CAMARA*

In the present study the core part of the most important wildlife sanctuary in Benin (Pendjari Biosphere Reserve) was found to be currently vulnerable to *L. camara* invasion and was projected to remain so by 2050. During the field survey, many records of Lantana camara were made in farmlands and the hunting zone surrounding the integrally protected part of the PBR. While *Lantana* is said to be unpalatable to large mammal (Plumptre *et al.* 2010), recent reports evidenced elephants browsing on it either in the diet observation in Asia (IUCN AsESG 2010) or in the dung survey in Ethiopia (Biru & Bekele 2011). Incursions in farmlands surrounding the protected areas are daily habits of elephants not only because these areas were in their historical home range but also because they feed on many crops cultivated (Fandohan, field observation). It is thus likely that elephants once in contact with *Lantana* in farmlands will browse the plant and then disseminate its seeds across the Pendjari Biosphere Reserve (PBR). With the high suitability of the core protected areas to *L. camara*, it may rapidly spread out into the PBR. This scheme is likely across the whole study area. The effect of *L. camara* on the national protected areas network may be dramatic. Invasive species used to exert huge detrimental effect on biodiversity, increase fire frequency and intensity, displace native species, destroy pasture lands, reduce quality and quantity of forage and thus threaten food webs and wildlife (Plumptre *et al.* 2010). Since in this study the field data collection was mainly conducted around only one reserve, it is urgent to run a thorough risk assessment study and build a control protocol to protect protected areas from being invaded by *L. camara.*

PERSPECTIVES FOR CONTROLLING INVASIVE PLANTS SPECIES

Control of invasive species in forested lands and/ or protected areas has received little attention in Western Africa as compared to Southern and Eastern Africa. This may partly be because the local scientists and practitioner are primarily trained to control invasive species in infested

agricultural lands and not in protected areas. Besides, the used methods often include introduction of biological control agents and are not applicable to protected areas. In addition, protected areas managers mostly forest officers in West African French speaking countries are rarely trained to manage invasive species. As previously advocated, early warning, awareness raising capacity building, effective implementation of existing laws on movement and transport of *L. camara* together with a public education campaign in this region are possible measure for effective management (Welch 2005 ; Taylor *et al.* 2012).

Control protocols development requires several steps including : thorough risk assessment at national level, identification of environmental assets at risk of invasion by *L. camara*, prioritizing site for control, control protocol development implementation and evaluation. Protocols developed elsewhere include ex-poachers employment to manually harvest the invasive plants till their eradication (Plumptre *et al.* 2010), stick raking or slashing in large infested areas, bobcat grubbing of individual plants, stump cutting, control fire (the National *Lantana* Management Group. 2009). Because almost all removal strategies of these invasive plants have proved unsuccessful so far elsewhere, their management by utilization has been suggested (Patel 2011). Recent studies have reported that *L. camara* has bioactive ingredients exhibiting anticancer, anti-ulcerogenic, hypolipidemic, larvicidal and anti-inflammatory activity (Patel 2011 ; Kouamé *et al.* 2012). However it is still not clear how such protocol will be designed, mainly because encouraging people to use such species may result in people conserving the species and favoring its spread.

Perspectives for further research

Restoration of invaded places has failed in several instances : native plant species failed to reestablish in ecosystems cleared of invasive plants. This is because invasive plants leave behind toxic chemicals in the soil that inhibit reestablishment of native plants. However, in some cases, native plants show positive evolutionary response and withstand competition with invasive plants (Sebade *et al.* 2012). This leads to the hypothesis that invasive plants species could be used as a proxy to select native genotypes with superior resistance for restoration of invaded areas (Ferrero-Serrano *et al.* 2011). These provide opportunity for local

research teams on protected areas to undertake experimental research to identify candidate superior species and genotypes for restoration of invaded areas. If conclusive it could result in more sustainable, coast effective and environmentally friendly biocontrol protocols.

Assuming the CSIRO mk3 model is one of the best in terms of representing basic aspects of the observed climate at a regional scale (Kriticos *et al.* 2012), aridification of the West African climate is likely. The resulting higher evaporation rates, low leaching because of low rainfall may result in higher concentration of allelochemicals in the soil (Nakafeero *et al.* 2007). Such scheme is likely to worsen the environmental impact of invasive species. It will require higher and faster adaptive capacities from native plants to withstand the competition or otherwise go extinct. In this regard it will be interesting to assess the effect of aridification on the evolutionary response of native plants to invasive species.

CONCLUSION

Control of invasive species in forested lands and/ or protected areas has so far received little attention in Western Africa. This study provides information on habitat suitability for *L. camara* and how its spread into protected areas could be favored by climate change. However, with the plethora of papers being published using climate only models it may be now more insightful to move forward and integrate evolutionary biology perspectives to make projections more robust. This will further result in more effective suggestions for management.

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