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***RESEARCH ARTICLE***

# CURRENT STATUS AND FUTURE INVASION POTENTIAL OF *LANTANA CAMARA* L. UNDER THE CHANGING CLIMATE AND LAND COVER IN THE CENTRAL RIFT VALLEY, ETHIOPIA

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**ABSTRACT:** In Ethiopia, *Lantana camara* is listed among the top ten worst invasive weeds. *Lantana* has become a chronic environmental, social, economical and health problem in different parts of the country, mainly in the eastern escarpments of Hararghe, Somali and Wollo. Understanding the potential distribution of this invasive species will give useful information in planning effective strategies to control its invasion. This study aimed to examine the current (2020) and future invasion potential of *L. camara* in the Central Rift Valley (CRV), Ethiopia, under climate and land cover change using an ensemble ecological niche modeling approach. Under the current climate scenario, 90.5% of the study area was unsuitable for the establishment and invasion of *L. camara*, while 1.4% was highly suitable. The model predicted that the rate of *L. camara* invasion will increase across the CRV as increasing temperature undermining the competitive power of indigenous species. In 2050, a highly suitable area for *L. camara* establishment is expected to increase by 22.2%, while the moderately suitable area is projected to increase by 11.4% under RCP4.5 climate scenarios. Compared to the current climatic condition, in 2070, a highly suitable area for the species is projected to increase by 41.7%. With the current cover, this invasive species had already caused a significant impact in many parts of the country. Further invasion of the species would lead to serious environmental and socio-economic damage, thereby threatening the livelihood of the community. Thus, a well-coordinated management strategy should primarily target areas that are suitable for *L. camara*.

**Key words/phrases**: Biodiversity, Climate change, Ecological niche modelling, Invasion, *Lantana camara*, Suitability.

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## INTRODUCTION

Ethiopia is a country vulnerable to climate change and has been experiencing a 0.37°C annual temperature increase per decade since the 1990s. Current predictions suggest that there would be further rise of temperature by 0.9 to 1.1°C, 1.7 to 2.1°C and 2.7 to 3.4°C by 2030, 2050 and 2080, respectively compared to the 1961–1990 status (Conway and Schipper, 2011). Annual precipitation is also predicted to be high in several parts of eastern Africa including Ethiopia (Conway and Schipper, 2011; Sintayehu Workeneh, 2018). Since the potential invasion of invasive species is governed by both climate-related factors, the nature of the species and other abiotic interactions such as land cover change (Araújo and New, 2007; Qin *et al*., 2016; Hulme, 2017; Sintayehu Workeneh *et al*., 2020), changes in climatic conditions and land cover change are likely to cause major shifts in their geographic ranges (Walther *et al*., 2009; Hulme, 2017; Sintayehu Workeneh, 2018). Therefore, it is essential to better understand the risk of invasion under climate change scenarios for effective management of invasive plants in the 21st century.

Global Invasive Species Information Network report showed that *Lantana camara* is among the top ten invasive species in the world and it is included in the International Union for Conservation of Nature's (IUCN's) list of world's 100 worst alien invasive species (Lowe *et al*., 2000; Bhagwat *et al*., 2012). It has posed many negative impacts on environment and socio-economy around the world (Sharma *et al*., 2005). In Ethiopia, *L. camara* was introduced as an ornamental plant because of its attractive aromatic flowers (Binggeli and Desalegn Desissa, 2002). However, because of prolific seed production and easy dispersal, it has quickly spread throughout the country (Binggeli and Desalegn Desissa, 2002). Nationally, *L. camara* is one of the top five worst invasive plant species, causing major threats to biodiversity and livelihood of communities dependent on natural resources. The species usually form a dominant understory shrub, competing out native species and reducing their species richness and abundance thereby altering species assemblages (Wakshum Shiferaw *et al*., 2018). As reported by Ahmed *et al*. (2007), the different parts of *L. camara* contain allelo-chemicals mainly aromatic alkaloids and phenolic compounds which can interfere with seed germination and early growth of many plant species. It can also interfere with the growth of nearby plants by aggressively competing for soil nutrients and altering microenvironment (light, temperature) by forming dense thickets (Sharma and Raghubanshi, 2006). Furthermore, *L. camara* is a threat to agriculture due to its capacity to invade large areas in a short space of time. For instance, the invasion of *L. camara* in Uganda caused about a 50% decrease in the amount of grazing land available for the domestic animals and a 25% decrease in crop productivity (Shackleton *et al*., 2017). *L. camara* was also reported to have significantly inhibited seed germination and also reduced shoot and root length, stem thickness and biomass of crops (Desalegn Tadele, 2014). Despite its recognition as among the worst invasive alien species in the world (Sharma *et al*., 2005), its potential distribution in Ethiopia has yet to be investigated. It is, therefore, vital to understand its spatial distribution across landscapes, to predict its potential shifts and effects on various ecosystems as well as design appropriate monitoring schemes.

Mechanical and chemical management are currently used for the eradication and control of *L. camara*. These options, however, are often costly because invaded areas tend to be vast with limited access (Firew Bekele, 2018). On the other hand, biological control agents seem less effective for reducing the abundance of *L. camara* to manageable levels (Wakshum Shiferaw *et al*., 2018). Management of *L. camara* by utilization is used in several part of the world. Thus, as with many invasive plant species, prevention is the first recommendation to limit expansion of *L. camara*. The efficient implementation of preventive actions to stop the arrival and establishment of invasive species relies on the correct identification of potentially suitable areas. It is, therefore, vital to understand its spatial distribution across landscapes, to predict its potential shifts and effects on various ecosystems as well as to design appropriate monitoring schemes. However, the environmental suitability for *L. camara* under the predicted climate and other environmental change scenarios remains underexplored. Thus, this study aimed to examine the current and future potential invasion of *L. camara* in the Central Rift Valley, Ethiopia, under climate and land cover change and describes its possible range shift using an ensemble ecological niche modeling approach. Several algorithms are currently used for modeling the distribution of species and the performance of each algorithm varies significantly (Elith *et al*., 2006), the ensemble modeling methods account for uncertainties of the results of a single algorithm by combining the predictions of individual algorithms (Marmion *et al*., 2009), thus increasing the accuracy of species distribution forecasts (Araújo and New, 2007). Therefore, ensemble modelling approach was used in the present study. The work will provide valuable distribution information to assist land managers to effectively plan and implement early detection and rapid response (EDRR) programs to control lantana widespread.

## MATERIALS AND METHODS

### Study area

The study was conducted in fifteen selected districts in the Central Rift Valley (CRV) of Ethiopia located between longitudes 38°12′–39°60′E and latitudes 6°58′–8°47′N. The districts are Arsi Negele, Degeluna Tijo, Diksis, Dodota, Hitosa, Inkolo Wabe, Limu Bilbilo, Lude Hitosa, Munessa, Shalla, Shashemene Zuria, Siraro, Tena, Tiyo and Ziway Dugda. The altitude of the study area ranges from 1,396 to 4,216 m above sea level. The area is predominantly characterized by semi-arid and sub-humid climate. The elevation of the valley ranges from approximately 1,600 m above sea level in the valley to over 3,000 m on the east and west. Annual rainfall ranges from about 650 mm near Lake Abijata in the valley up to 1,250 mm in the higher elevations near the borders of the basin. Average annual temperature varies from 19°C in the valley to about 14°C in the higher elevations (NMA, 2019).

### About the study species

*L. camara* is a woody thicket forming shrub native to South America, and considered one of the world’s worst alien species. The species is found frequently in East and South Africa where it occurs at altitudes below 2,000 m sea level and often invades previously disturbed areas such as logged forests, rangeland, and areas cleared for agriculture (Sharma *et al*., 2005). In Ethiopia, the species was introduced as an ornamental plant due to its beautiful aromatic flowers (Binggeli and Desalegn Desissa, 2002). This weed is locally known as Yewof kolo (Amharic), Bekerketia (Oromiffa), and qarfa-weyn (Somali). Presently, it has been loctaed almost all over the country (Binggeli and Desalegn Desissa, 2002). *L. camara* is a medium-sized perennial aromatic woody shrub, 2–5 m tall, forms dense mono-specific thickets, 1–4 m high and approximately 1–4 m in diameter, although some of the thickets smother nearby trees and reach up to the height of 8–15 m (Sharma *et al*., 2005). It has arching quadrangular stems in cross-section with pithy centres and sometimes has prickles or spines. As lantana stems mature, they become rounded and turn grey or brown. The leaves are simple and oppositely arranged along the stem. Flowers are small, multicoloured; in stalked, dense, flat-topped inflorescences. Flowering and fruiting throughout the year with a peak during the first two months of the rainy season. The plant has a shallow root system made up of short taproot with lateral roots branching out to form a mat (Sharma *et al*., 2005).

## Species occurrence data

*L. camara* occurrence was retrieved primarily from the Global Biodiversity Information Facility database (GBIF, www.gbif.org, accessed 15 January 2020), using the “gbif” function through R statistical software (https://CRAN.R-project.org) and was supplemented with other relevant databases: direct field sampling conducted in Central Rift Valley of Ethiopia and desk review of published literature (Dereje Abera *et al*., 2014; Mohammed Musa *et al*., 2018). Thus, a total of 224 (168 from the Global Biodiversity Information Facility database, 21 from published articles and 35 from field survey) documented presence records were obtained for constructing the models. Additional 1000 pseudo-absence data points were generated using random sampling (Barbet-Massin *et al*., 2012) as a background data.

## Selection of variables

Different predictor environmental variables including climate, topography and land cover were collected and evaluated for their usefulness to predict *L. camara* invasions. A total of 19 bioclimatic variables with a spatial resolution of 30 arc-sec (~1 km x 1 km) were downloaded from the WorldClim 1.4 database (version 1.4, http://www.worldclim.org, accessed on 15 January 2020) using the raster package in R (https://cran.r-project.org/; R Core Team 2018). Elevation data was collected from the WorldClim database. Land cover data for the current and future were derived from GeoSOS global database (http://geosimulation.cn/GlobalLUCCProduct.html). Multi-collinearity among predictor variables was tested using Pearson’s correlation and variance inflation factors (VIFs). Only environmental predictors with a Pearson correlation >0.80 and VIF >5 were removed to reduce the high collinearity among variables and minimize model overfitting. Finally, six environmental variables were retained for modelling the distribution of *L. camara* (Table 1). Currently, it is not clear which future climate change scenario provides the best predictions for invasive species (Hayes and Piaggio, 2018), thus we used one Representative Concentration Pathways RCP4.5 for the greenhouse gas concentration trajectories of 2050 and 2070, because RCP4.5 represents a stabilization scenario. Thus, we used RCP4.5 climate change scenario in our analysis. Thus, for future climatic projections, we used the bioclimatic variables representing simulations for Representative Concentration Pathway of 4.5 (RCP4.5), for the two time periods (2050 and 2070), from Hadley Global Environment Model 2-

Atmosphere Ocean (HADGEM2-AO) as presented by the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change.

Table 1. Environmental variables used for modeling the potential distribution of *L. camara* in CRV, Ethiopia.

| **Label** | **Predictor variables** | **Units** |
|---|---|---|
| bio1 | Annual mean temperature | Degree Celsius |
| bio3 | Isothermality | Degree Celsius |
| bio12 | Annual precipitation | Millimetre |
| bio18 | Precipitation of warmest quarter | Millimetre |
| LC | Land cover | |
| EL | Elevation | Metre |

## Modelling approach

Ensemble modelling approach was used in the present study using the six statistical and machine learning algorithms implemented in the Biomod2 package (https://CRAN.R-project.org/package=biomod2) within R statistical software v3.6.3 (https://cran.r-project.org/; R Core Team 2018). The employed algorithms were generalized linear models (GLM), generalized boosted regression models (GBM), Maxent, random forest for classification and regression (RF) and classification tree analysis (CTA) (Sintayehu Workeneh *et al*., 2020). The models were run using the default settings and calibrated by using a random set of 70% of the data (presence and pseudo-absence) as training data and evaluated against the remaining 30% as testing data (Araújo and New, 2007).

Two types of evaluation tools were used to assess model performance namely the area under the curve (AUC) of receiver operating characteristics (ROC) and true skills statistics (TSS) (Allouche *et al*., 2006). AUC values range from 0–1. An AUC value ranges between 0.5 and 0.7 shows weak model performance, 0.7 to 0.9 shows good performance, and >0.9 indicated high performance (Allouche *et al*., 2006). TSS metric ranges from –1 to +1. In general, values of TSS below 0.40 indicate weak model performance, while values between 0.40 and 0.75 shows good model and above 0.75 are indictors of excellent model performance (Allouche *et al*., 2006). From the 81 model outputs per time period, we built the final ensemble model using a weighted-mean method in which weights are given for every model proportionally to their evaluation metrics score, hence the discrimination is fair in this approach (Araújo and New, 2007). During our model performance evaluation, predictive power (AUC>0.8 and TSS>0.6) were used to build the final ensemble model (Bellard *et al*., 2013). Finally, one ensemble projection of the current suitable habitat and four ensemble projections of future suitable habitat corresponding under RCP4.5 for the two periods (2050 and 2070) were obtained and then used for further analysis.

## Area change analysis

Two indicators were used to examine the effect of climate and land cover change on the suitability for *L. camara* habitat: (1) the change in the percentage of suitable habitat area (AC); (2) the percentage of currently suitable habitat area lost or gain by the 2050 and 2070 (CH) following the methods of Duan *et al*. (2016). Indicators were quantified as:

$$AC = \frac{Af - Ac}{Ac} x100\% \qquad \text{(equation 1)}$$

$$CH = \frac{Af - Ac}{Af} x100\% \qquad \text{(equation 2)}$$

where Af is the predicted area of suitable habitat for *L. camara* in the future; and Ac is the predicted area of suitable habitat under current conditions.

The final map was categorized into four suitability categories according to Hamid *et al*. (2018): not suitable (0.0–0.25), low suitable (0.25–0.50), moderately suitable (0.50–0.75) and highly suitable (0.75–1.00). Using ArcGIS 10.8, the percentage of area change was calculated by simple differencing.

## RESULTS

In the present study, the final ensemble model had an AUC and TSS value of 0.95 and 0.81, respectively, indicating the performance of the model was excellent in predicting the potential distribution of *L. camara* in the CRV of Ethiopia. Among models, RF and GBM algorithms performed very well, followed by SRE and Maxent whereas the algorithms like GLM and CTA achieved the lowest accuracy among all the algorithms implemented in the biomod2 (Table 2).

Table 2. AUC and TSS (by algorithms) of models for predicting current and future habitat suitability for *L. camara* in CRV, Ethiopia.

| | **Models** | | | | | | |
|---|---|---|---|---|---|---|---|
| | GLM | SRE | RF | CTA | Maxent | GBM | mean |
| AUC | 0.9 | 0.96 | 0.99 | 0.94 | 0.96 | 0.96 | 0.96 |
| TSS | 0.75 | 0.82 | 0.88 | 0.81 | 0.82 | 0.79 | 0.82 |

GLM=generalized linear models, SRE=surface range envelop, RF=random forest for classification and regression, CTA=classification tree analysis and GBM=generalized boosted regression models.

The analysis revealed that 1.4% of the study area is highly suitable for *L. camara* under current climate while 3.9% and 4.2% have moderate and low suitability, respectively (Table 3, Fig. 1). On the other hand, the predictions suggested that 90.5% of the study area in the CRV is unsuitable for the establishment of the invasive species (Table 3).

Table 3. Percentage of current and future (2050 and 2070) climatic suitability class for *L. camara* in Central Rift Valley (CRV) of Ethiopia under RCP4.5 climate change scenarios.

| **Decades** | **Scenarios** | **Total suitability (%)** | | | |
|---|---|---|---|---|---|
| | | **Not suitable** | **Low** | **Moderate** | **High** |
| Current | - | 90.5 | 4.2 | 3.9 | 1.4 |
| 2050 | RCP4.5 | 88.8 | 4.9 | 4.4 | 1.8 |
| 2070 | RCP4.5 | 85.3 | 7.8 | 4.6 | 2.4 |

Fig. 1 shows the habitat suitability for *L. camara* in CRV of Ethiopia under the current and future climatic scenarios. The model showed habitat suitability of the species (*L. camara*) will increase by the years 2050 and 2070 compared to the current period. The results of the study found four potential invasion hotspots districts for the invasion of *L. camara* under the current climatic conditions and land cover; 1) Ziway Dugda hotspot, 2) Arsi Negele hotspot, 3) Dodota hotspot, and 4) Siraro hotspot of Oromia Region (Fig. 1). Future scenario model projections revealed a possible increase in the potential distribution of *L. camara*. By the year 2050, the total highly suitable area for *L. camara* under RCP4.5 scenarios will be 1.8%, while the total non-suitable area will be 88.8% (Table 3, Fig. 1). Under RCP4.5, in the 2050s, the highly suitable area for *L. camara* is predicted to increase by 22.2%, while the moderately suitable area is expected to increase by 11.4%.

Compared to the current climatic condition, in 2070, the highly suitable climate for the species is projected to increase by 41.7% under RCP4.5 scenarios, while the moderately suitable area is projected to increase by 15.2% under RCP4.5 climate scenario. In the same period, the total non-suitable area for *L. camara* under RCP4.5 scenarios will decrease by 5.8%. Overall, areas considered with low suitability in the study area will increase by 46.2% compared to the current climatic condition under RCP4.5 in 2070 (Table 4). Under RCP4.5 emission scenarios in both 2050s and 2070s, the ensemble model projection revealed that Shalla and Hitosa hotspot would be the fifth and sixth new hotspot for the invasion of the species, respectively by 2050s and 2070s.

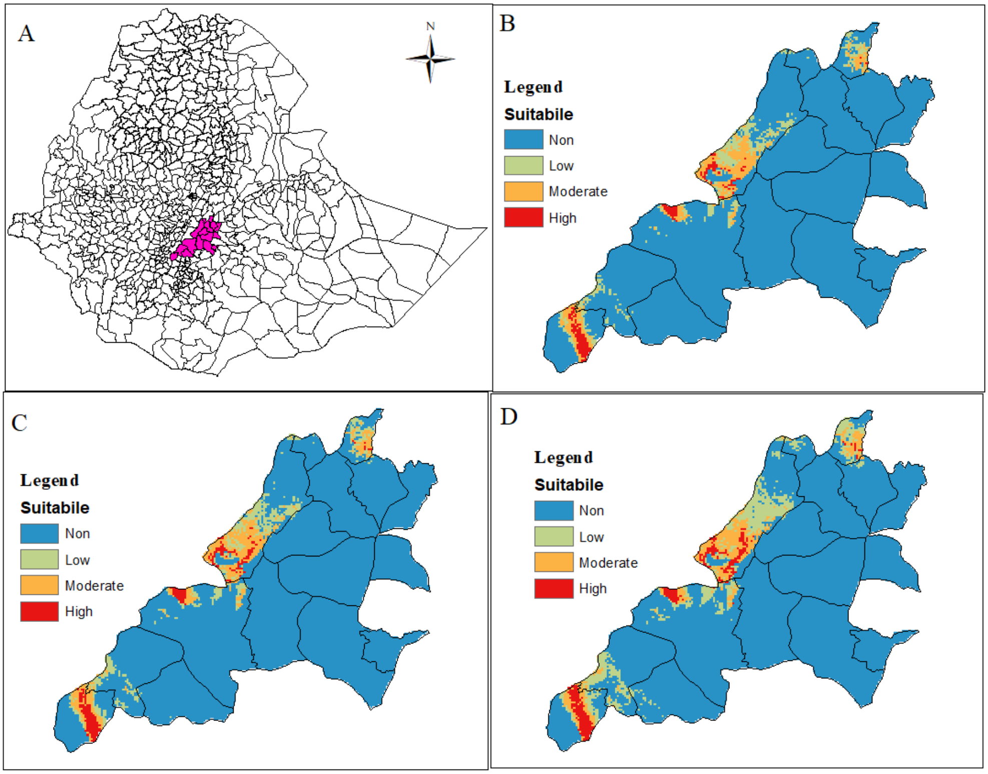

Fig. 1. Current (B) and future (2050 (C) and 2070 (D) potential distribution map of *L. camara* in CRV, Ethiopia under RCP4.5.

Table 4. Change in habitat suitability for *L. camara* under current and future (2050 and 2070) climate and land cover change in CRV under RCP4.5 climate change scenario in CRV, Ethiopia.

| **Decades** | **Scenarios** | **Change (%) compared to the current suitability** | | | |
|---|---|---|---|---|---|
| | | **Not suitable** | **Low** | **Moderate** | **High** |
| Current | - | | | | |
| 2050 | RCP4.5 | -2.1 | 14.3 | 11.4 | 22.2 |
| 2070 | RCP4.5 | -5.8 | 46.2 | 15.2 | 41.7 |

## DISCUSSION

*Lantana camara* is a weed of global significance and one of the worst invasive plant species in Ethiopia with deleterious ecological and socio-economic impacts (Binggeli and Desalegn Desissa, 2002; Shackleton *et al.*, 2017; Wakshum Shiferaw *et al.*, 2018). The present study represents a pioneering attempt to empirically investigate the current and future invasion potential of *L. camara* in the Central Rift Valley of Ethiopia both under current and future climate and land cover change. With respect to environmental variables, our results revealed that temperature related variables [i.e. annual mean temperature (Bio1) and isothermality (Bio3)], precipitation related variables [(i.e. annual mean precipitation (Bio12) and precipitation of warmest quarter (Bio18)] and land cover made a significant contribution in governing the distribution of invasive *L. camara*. This is in agreement with some recent studies which posit both temperature, precipitation and land cover derived variables as the main determinants of invasive species distributions (Day *et al*., 2003; Goncalves *et al*., 2014; Zhang *et al*., 2014; Qin *et al*., 2016). This can be attributed to the fact that climate variables like temperature and precipitation and human interference variables such as land cover influence key physiological processes with the former being responsible for altering the metabolism especially the enzymatic activity and reproductive potential of species and the latter determining the temporal variations of droughts and floods (Goncalves *et al*., 2014), which in turn synchronize several important biological processes of a species, especially a dispersal ability (Sharma and Raghubanshi, 2006), ability to survive under adverse conditions (Diez *et al*., 2012) and home range size (Becerra López *et al*., 2017).

The results of our study is also associated with a study conducted by Gujral and Vasudevan (1983) which indicates that *L. camara* can flower year round if there is adequate moisture and conducive temperatures (between 28°C and 33°C). Furthermore, since the focal species is characterized by short roots that barely reach groundwater level, it depends on soil moisture for successful invasion (Day *et al*., 2003). This is similar with other recent studies (Goncalves *et al*., 2014; Subhashni and Lalit, 2014; Zhang *et al*., 2014; Qin *et al*., 2016; Shrestha *et al*., 2018; Eckert *et al*., 2020) which posit both temperature derived variables as the main determinants of *L. camara* distributions. This can be attributed to the fact that climatic variables like temperature and precipitation influence key physiological processes with the former being responsible for altering metabolism especially enzymatic activity and reproductive ability of species while the latter influences the temporal dissimilarities of droughts and foods (Becerra López *et al*., 2017), which, in turn, synchronize several important biological processes of a species, especially the dispersal ability (Sharma and Raghubanshi, 2006) and ability to survive under adverse conditions (Bradley *et al*., 2010).

*L. camara* is listed among the top ten worst invasive alien species in Ethiopia (EBI, 2015). According to various studies (Ahmed *et al*., 2007; Shackleton *et al*., 2017; Firew Bekele, 2018; Wakshum Shiferaw *et al*., 2018), the species tends to inhibit the regeneration of native species as it suppresses undergrowth. The leaves of *L. camara* contain various chemicals such as tannins, flavonoids, steroids, hydrocarbons, waxes and alkaloids which are known to have negative impacts on the germination and growth of other plant species (Ahmed *et al*., 2007). The species forms intermingled and interwoven branches at its early stage of growth and prevents sunlight from reaching to the under canopy vegetation, thereby negatively affects local biodiversity (Firew Bekele, 2018; Wakshum Shiferaw *et al*., 2018). Furthermore, with its deep root system, it survives well in moisture stressed ecosystems over competing other species especially herbaceous species. Invasive species like *L. camara* have the inherent ability to tolerate wider environmental ranges or adapt to new environmental conditions (Vilà *et al*., 2011; Qin *et al*., 2016; Kariyawasam *et al*., 2019). This means that in the long run, the inherent characteristic attributed to the species and lack of their native competitors may lead to a process of niche shift in new regions. Our prediction model has revealed that the area of high and moderate suitability for *L. camara* in future climate scenarios will increase relative to the current area. Within this context, further expansion of *L. camara* might cause loss of biodiversity and reduce the cover of native herbaceous vegetation, which can further frustrate and affect pastoralist and agro-pastoralist livelihoods and societal well-being in CRV in particular and in Ethiopia in general. This is because climate change often favours invasive species as environmental conditions worsen for native species undermining their competitive power against invaders in ecosystem resources (Hellmann *et al*., 2008).

## Conservation implications

Species distribution modelling is a cost-effective and easy to implement predictive tool that delineates the high priority conservation areas at a finer-scale over a long period. In this study, based on the ensemble modelling, the distribution pattern and niche dynamics of *L. camara* is predicted to respond variedly under the changing climate and land cover. Based on the results, we suggest that the predicted impacts of climate and land cover change need to be integrated for the management of *L. camara* expansion in Ethiopia. Our ensemble model showed that climate and land cover change would influence the distribution of *L. camara* in CRV. The model suggested that there would be an increase in both the highly and moderately suitable ranges, especially, and the ranges adjacent to the current distribution of the species are those that are under high risk of invasion. Thus, it calls for refrain from the usual piecemeal approach and concerted efforts to develop efficient management strategies to prevent the expansion and also to manage the invasion of *L. camara* in the study area for the betterment of the environment and societal livelihood on a sustainable basis. Moreover, modeling, as presented in our study, provides an easy and less costly tool in predicting *L. camara* invasion hotspots, allowing for early detection and rapid response (EDRR) system and in developing efficient scientific strategies to proactively manage future invasions. Thus, well-coordinated prevention measures should primarily target areas that are suitable for *L. camara*.

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