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Modelling the potential risk zone of *Lantana camara* invasion and response to climate change in eastern India

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Abstract

Background: The aim of this study is to elucidate the potential risk zones prone to the invasion of perennial ornamental plant *Lantana camara,* which is native to South America and has invasive tendency in Jharkhand, eastern India, for present (2020) and the future (2050) climatic conditions under four different Representative Concentration Pathways scenarios (RCPs). We analysed the current distribution pattern of *L. camara* in the plateau region of eastern India and identified potentially suitable habitats prone to its further infestation in the future under the climate change scenario.

Results: Results showed the presence of *L. camara* invasion in ~ 13% of the geographical area of Jharkhand, Chotanagpur plateau which may expand up to 20–26% by 2050 depending upon emission scenarios as characterised by the four RCPs. Analysis for the current scenario suggests the dominance of *L. camara* in sub-zone V (12.77% under high risk zones (HRZ) and 9.5% under critical risk zones (CRZ)) followed by sub-zones IV (6.7%: HRZ; 4.19%: CRZ) and VI (2.49%: HRZ; 2.14%: CRZ). Future projection (2050) indicates a possible expansion of its distribution range across all agro-climatic sub-zones with dominance in sub-zones V and IV. Variable Bio_4 (temperature seasonality) was observed as the most contributing factor for the distribution of *L. camara* for current and future scenarios across all RCPs. Suitable habitat for *L. camara* mostly occurred under natural vegetation (66.05% of CRZ and 60.71% of HRZ) and agriculture landscape (29.51% of CRZ and 34.48% of HRZ).

Conclusions: The study provides an insight of invasion of *L. camara* in the plateau region of eastern India, and reveals wide distribution across all the agro-climatic sub-zones of Jharkhand, mostly in open and disturbed areas under natural vegetation and agriculture landscapes. Future projections for the year 2050 suggest a continuous increase in the expansion range of invasion across Jharkhand and call for urgent initiatives to combat its further invasion.

Keywords: Climate change, Forest, Invasion, *Lantana camara*, Maxent, RCPs

Background

Lantana camara of the Verbenaceae family has more than 600 varieties and is a native terrestrial weed of South and Central American origin, which is considered among the top 10 worst invasive species by IUCN. It severely affects the native composition of terrestrial ecosystems (Swarbrick 1986; IUCN 2001). *L. camara*, a short height shrub, attains heights to 1.2–2.4 m, ovate-oblong, opposite, rugged, and a bit hairy leaf structure. The species was introduced in India in 1809 (Kohli et al. 2006) and later invaded most of disturbed forest, pasture and fallow landscapes, with an estimated cost of US$ 70 per hectare for its control (Negi et al. 2019). The *L. camara* distribution has adversely impacted the population stratification, regeneration, and anticipated

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future composition of tree communities in tropical dry deciduous forests of India (Sharma and Raghubanshi 2006). The species due to its wide eco-tolerance (Negi et al. 2019) has dominated varied landscapes including disturbed areas (Richardson et al. 2004), along streams (Ramaswami and Sukumar 2014) open and disturbed forests (Raghubanshi and Tripathi 2009) and riparian vegetation (Meek et al. 2010; Dobhalet al. 2011). *L. camara* spread contributed to a 50% decrease in livestock forage, diminished natural resources, and obstructed human and livestock movements (Shackleton et al. 2017). *Lantana* occupies a wide category of habitats and varied soil types (Sharmaet al. 2005), and disperses mostly through frugivorous birds (Hariharan 2017), anthropogenic factors (Lin 2007), and forest fire (Hiremath and Sundaram 2005). The spread of *L. camara* stimulates forest fires (Raghubanshi et al. 2005). Improved soil nutrients were observed in western Himalayan forests due to the invasion of *L. camara* (Singh and Singh 1992). Due to its high regeneration potential and perennial reproduction, *L. camara* rapidly invades habitats (Daizy et al. 2004). Allelochemical ingredients of *L. camara* adversely affect plant richness (Day et al. 2003).

Habitat suitability models (viz., Maxent, GARP and Biomapper) have been widely used to predict the potential distributions of invasive plant species (Hoffman et al. 2008) and IUCN red-listed species (Rajput et al. 2020; Kumar et al. 2020). For example, about 65% of the geographical area in the southern province of Zimbabwe may comprise suitable habitat for *L. camara* by 2070 (Ncube et al. 2020). Investigators have used Maxent to determine the potential distribution of various invasive species viz., *Sapium sebiferum* in western Himalaya (Jaryanet al. 2013); *Chromolaena odorata*, *L. camara*, and *Parthenium hysterophorus* in the Western Ghats (Patil and Janarthanam 2013). Distance from river and elevation contribute significantly to the prediction of potential distribution zone (Hoffman et al. 2008). In a comparative study to evaluate the model performances of Maxent, GARP and Biomapper for the prediction of the *L. camara* distribution in Jim Corbett and Rajaji National Park, Maxent performed best and was the most reliable for determining the spatial distribution of *L. camara* (Priyanka and Joshi 2013a).

This literature review suggests that substantial work on *L. camara* has focused on understanding its impact on native species, distribution, niche conservation, use, and allelopathic effects, etc. (Witt et al. 2018; Goncalves et al. 2014). Evidence from a number of studies suggests that once *L. camara* is established, little can be done to eradicate it (Bhagwat et al. 2012), and hence early detection is the key to addressing invasion issues. In most cases, steps are taken without the proper identification and prioritization of the target site.

The present work aims to understand the existing distribution patterns of *L. camara* under different agro-climatic conditions in the Chotanagpur plateau and to understand its response to climate change by 2050 under different climatic Representative Concentration Pathway (RCP) scenarios, i.e., 2.6, 4.5, 6.0 and 8.5. This study aims to provide an in-depth analysis on existing distribution pattern and identification of identification of potential distribution sites prone to invasion risk of *L. camara*, and prioritization of areas for treatment in Jharkhand, a major part of Chotanagpur plateau in eastern India. This would lead to early detection of infestation status and management strategies to curtail the spread of *L. camara* in advance. The western part of Jharkhand comprising Betla National Park is a tiger reserve and many important forest species with immense medicinal properties existing in this part, and thus it has significant socio-economic aspects.

Materials and methods

Study area

The focus area of the present study, Jharkhand in eastern India, is primarily a plateau (Chotanagpur plateau), located between 25°30′ N to 22° N latitudes, and 83° E to 88° E in longitudes, comprising 79,714 km^2 of geographical area (Fig. 1). Approximately 29.61% (23,506 km^2) of the geographical area is dominated by tropical moist deciduous and tropical dry deciduous forests (FSI 2017). Agro-climatically, there are three sub-zones i.e. IV, V, and VI characterised by humid, tropical, and subtropical climates (Mishra et al. 2021). Being a tribal-dominated state, a large part of the population depends on forest products. The Chotanagpur plateau has a repository of various mineral resources as well as many forest species, with the socio-economic aspect.

Occurrence data

Occurrence of *L. camara* was recorded from 425 locations of Jharkhand encompassing agro-climatic subzones IV, V, and VI, during the pre- and post-monsoon months of 2016–2018 using a transact method (0.01 ha) in 10 km × 10 km grids. Geographical coordinates of species occurrences were recorded using GPS (Garmin Oregon) at accuracy ≤ 10 m. At least a 2 km distance was maintained between two transects to cover representatives approximately uniformly in the entire study area. Verification of some of the potential distribution sites of *L. camara* modelled through the present study was performed during January–February, 2019 for on-the-ground validation.

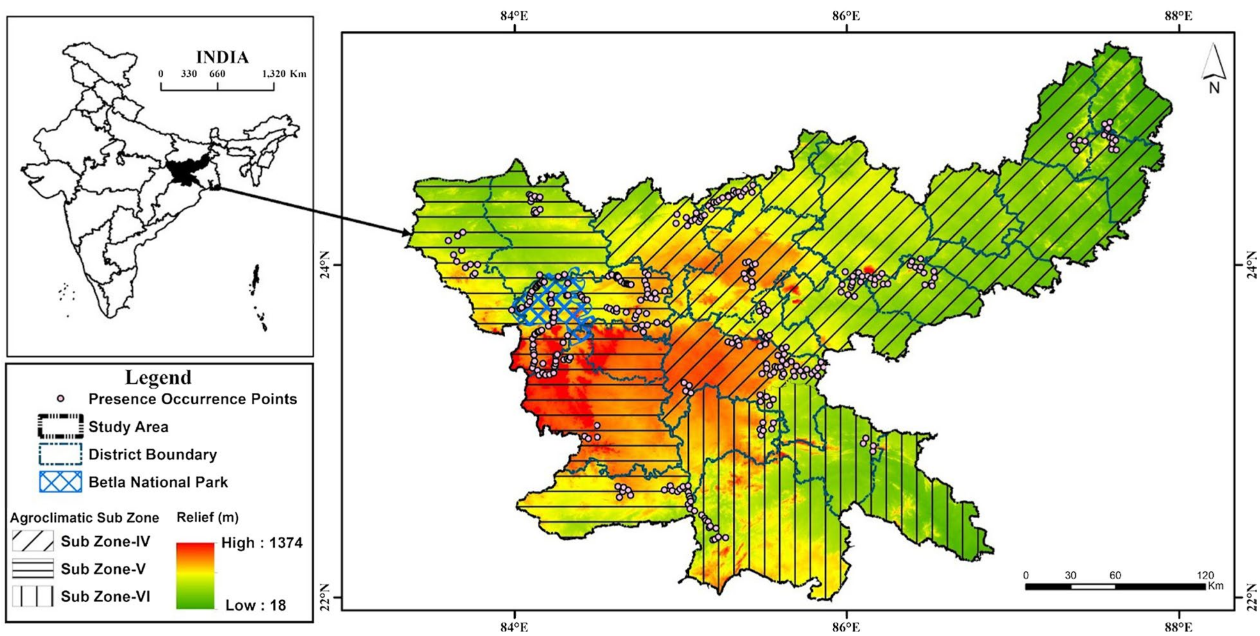

Fig. 1 Location map of the study area encompassing all the three agro-climatic sub-zones viz sub-zones IV, V and VI and Betla National Park. The points representing occurrence distribution locations of *L. camara* recorded across Jharkhand

Environmental variables

Bioclimatic variables, ranging from Bio_1 to Bio_19 with 30 arc seconds (~ 1 × 1 km resolution) resolution were acquired from the Worldclim site (www.worldclim.org) and converted to ASCII (or ESRI ASCII) (Fick and Hijmans 2017). We used Shuttle Radar Topography Mission (SRTM) DEM data of 30 arc seconds resolution from the Worldclim site to derive relief, slope, aspect, and hillshade data layers of the study area (Mishra et al. 2019). Food and Agriculture Organization (FAO) soil vector data (http://www.fao.org/geonetwork/srv) was employed as one of the environment variables that influence species distribution (FAO 2003). Prepared land use/land cover (LULC) map of the study area using LANDSAT 8 OLI data with 30-m spatial resolution secured from the United States Geological Survey (USGS) site (https://earthexplorer.usgs.gov). A total of 9 tiles of LANDSAT OLI images (path/row: 139/043, 139/044, 139/045, 140/043, 140/044, 140/045, 141/043, 141/044, and 142/043) with > 5% cloud coverage were acquired for the Jharkhand state for the year 2018 (October–December). LANDSAT OLI (https://earthexplorer.usgs.gov) was employed to delineate LULC using a support vector machine (SVM) method to classify the study area into 5 major classes viz., natural vegetation, waterbody, built-up, agriculture land and others. The overall accuracy of the classified LULC was 92% with kappa coefficient 0.88. The final map was compared with the National Remote Sensing Centre (NRSC) LULC map for 2015–16 (Bhuvan 2021) and found very higher similarity. The environmental variable dataset was resampled to a uniform extent and cell size (30 arc second) using QGIS and converted to ASCII format. The layers for different RCP pathways i.e., 2.6, 4.5, 6.0, and 8.5 in ASCII grid format at 30-s resolution for the year 2050 were acquired from the Climate Change, Agriculture and Food Security data portal (www.ccafs-climate.org) (Navarro-Racines et al. 2020). We used IPSL-CM5A-LR having a resolution of 1.9° × 3.75° (96 × 96 × L39), to simulate climatic scenarios for 2050. The term 1.9° × 3.75° (96 × 96 × L39) represents the low resolution version of the IPSL-CM5A-LR model, where (96 × 96 × L39) refers to the model has 96 number of points each on geographical coordinates corresponding to a resolution of 1.9° × 3.75° in combination with the 39 layers of the atmospheric variables (Dufresne et al. 2013).

Model training and evaluation

The potential risk zone vulnerable to *L. camara* in Jharkhand, Chotanagpur plateau was modelled using Maxent ver 3.3.3k (Phillips et al. 2020) with input samples (.csv files of occurrence of *L. camara*) for 425 sample locations. The Jackknife test was employed, to estimate the most contributing predictor variable to best fit the model. To evaluate model accuracy, the area under the Receiver Operating Characteristic (ROC) Curve (AUC) was estimated using test data in Maxent. The model was iterated 10 times to assess the threshold, while the random sample test percentage was set to 30 (Fig. 2).

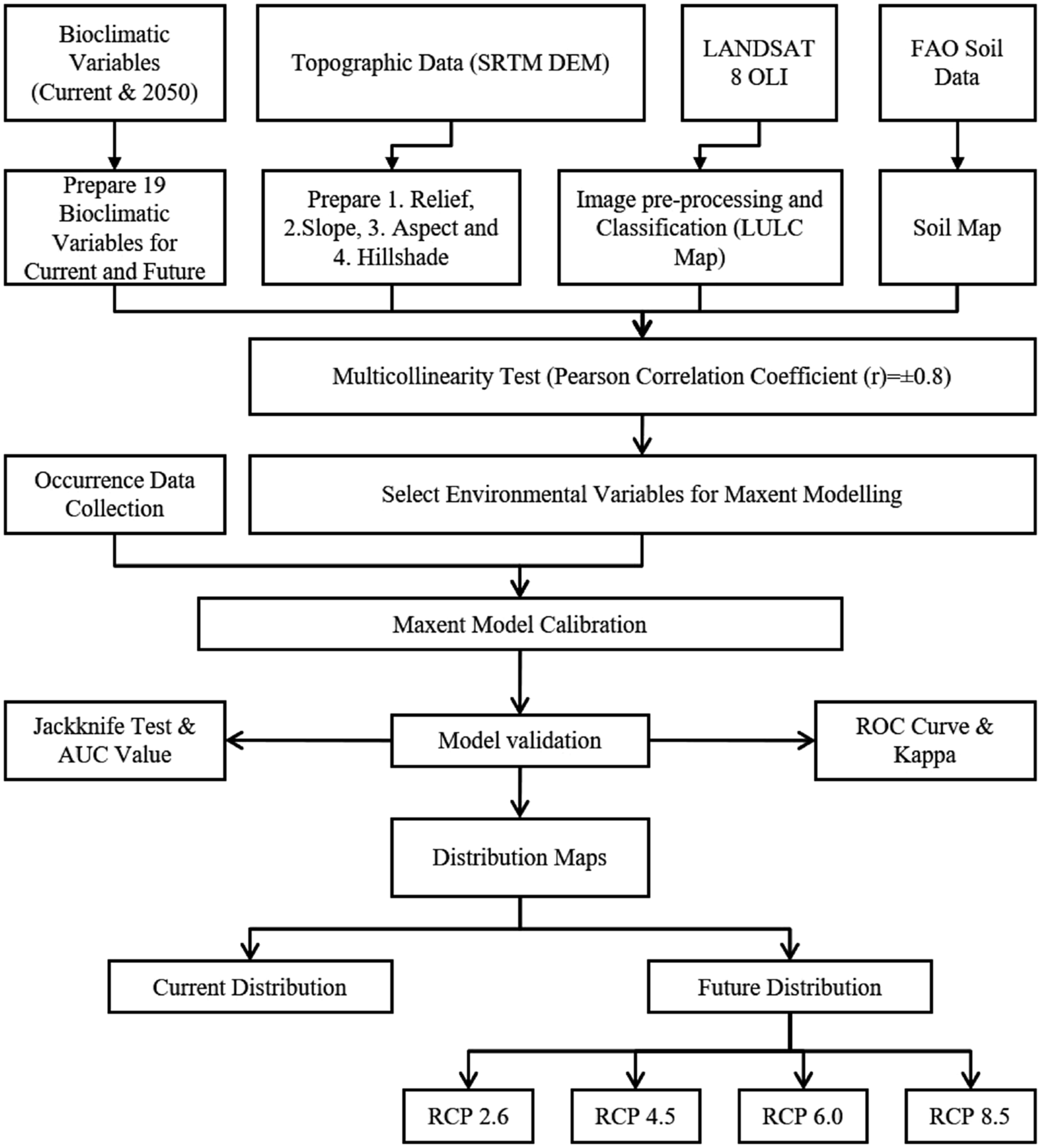

Fig. 2 Flow diagram of the methodology adopted

Delineation of the risk zone area

Maxent does not categorize the suitability of area in different classes, rather it assigns only the suitable or unsuitable area based on AUC values ranging from 0 to 1, where AUC value < 0.5 is considered unsuitable and > 0.5–1 is considered as suitable. In the present study, the AUCs were classified as low risk (< 0.49), high risk (0.5–0.7), and critical risk (> 0.7) of *L. camara* invasion using the geospatial environment analysis. The suitability class is categorised based on the probable risk zones of the selected species (Padalia et al. 2014). The Forest Survey of India (FSI 2017) cover map was utilized to estimate the risk zone area for *L. camara* distribution under different forest cover classes in the study area.

Model performance and predictor variable analysis

The potential distribution range map of *L. camara* was modelled for the current (2020) and future (2050) climatic scenarios under different RCPs i.e., 2.6, 4.5, 6.0, and 8.5. The average test AUC value for 2020 was 0.783

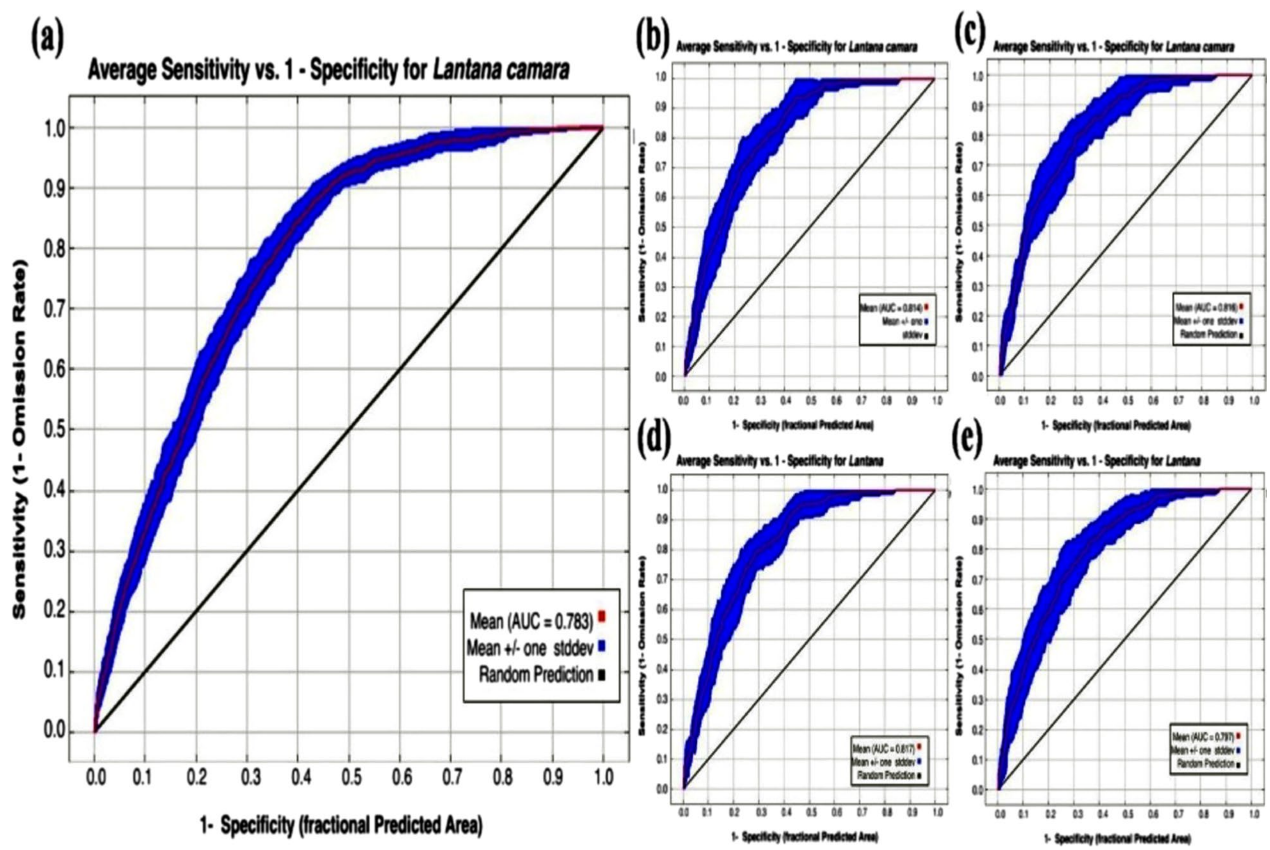

Fig. 3 AUC graph for model performance evaluation under (**a**) current scenario, (**b**) RCP 2.6, (**c**) RCP 4.5 (**d**) RCP 6.0 and (**e**) RCP 8.5 for the year 2050

with a standard deviation of 0.017. For 2050, the calculated average test AUC values were 0.814 with a standard deviation of 0.032 under RCP 2.6, 0.817 with a standard deviation of 0.031 under RCP 4.5, 0.816 with a standard deviation of 0.040 under RCP 6.0 and 0.797 with a standard deviation of 0.035 under RCP 8.5 (Fig. 3).

The Jackknife test analyses for each and every predictor variable contribute to model fitting individually as well as in combination with other variables (Fig. 4a–e). Depending upon the model gain, the process describes the contribution significance of the predictor variables on their inclusion. The predictor variable analysis shows that variable Bio_4 (temperature seasonality) followed by variable Bio_14 (precipitation of driest month), contributed most under current climatic conditions. For 2050, analysis shows that Bio_4 (temperature seasonality), Bio_7 (temperature annual range) and Bio_9 (mean temperature of the driest quarter) were the major contributing factors for RCP 2.6, 4.5, and 6.0, whereas under scenario RCP 8.5, Bio_4, Bio_2 (mean diurnal range), and Bio_7 were the most influential variables.

Validation and accuracy assessment

The projected suitable sites for invasion of *L. camara* in Jharkhand used for validation through physical verification at 38 fresh locations, which were not part of the initial field survey. The calculated overall accuracy was 85% and Kappa Coefficient 65%, which shows model strength with high accuracy (Table 1).

Results and discussion

Distribution pattern of *L. camara*

Projected potential distribution range in the eastern region

The potential distribution range of *L. camara* was modelled and its distribution patterns were analysed in Jharkhand for the years 2020 and 2050. The results showed that the distribution of *L. camara* led to increasing critical risk in all future scenarios in Jharkhand (7.51–8.18% of the total area) with a minor decrease under RCP 6.0 (6.87%) compared to the current scenario (5.25%) (Fig. 5a–e). The area under high risk comprised a large part of the future climatic scenario across all RCPs (16.25% under 2.6; 13.91% under 4.5; 12.33% under 6.0; and 17.80% under 8.5 scenario) compared to the current scenario (7.55% area). Notably, the high and critical

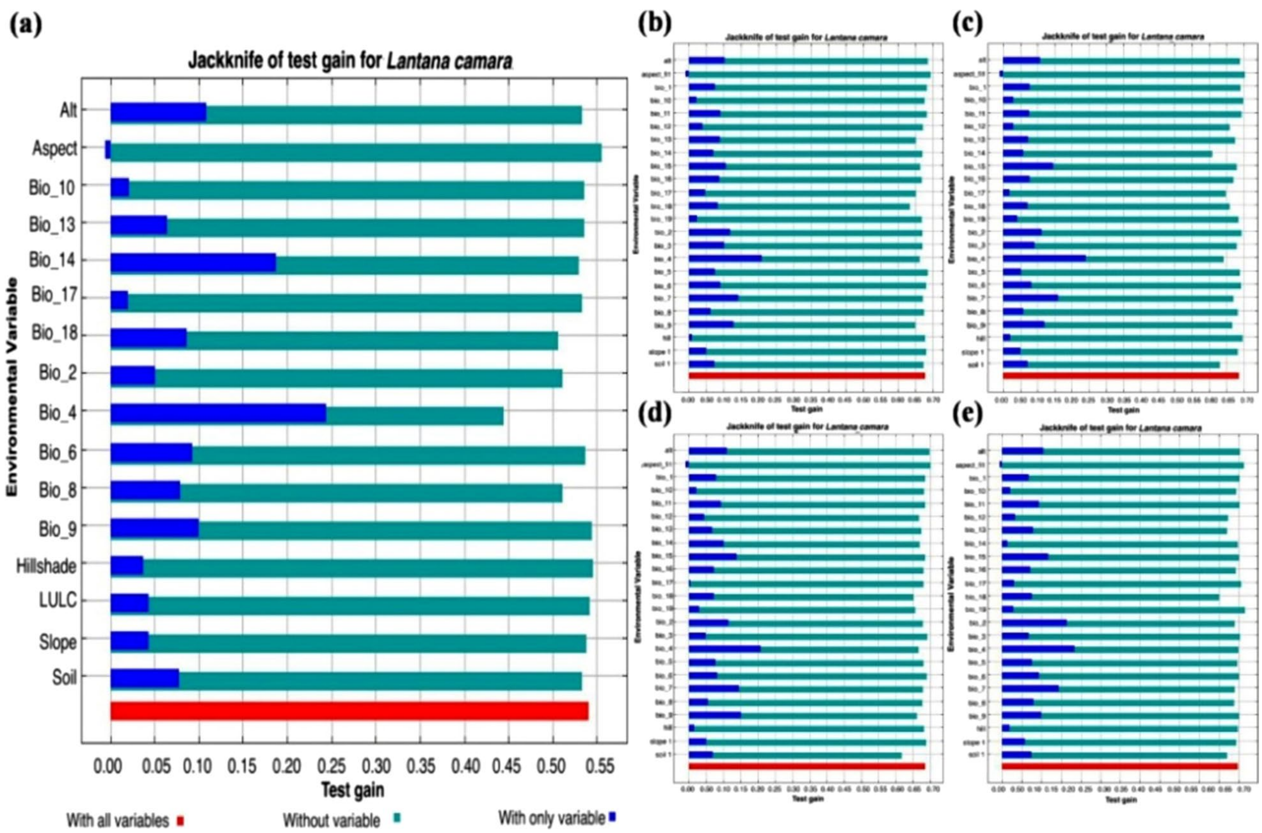

Fig. 4 Jackknife test gain result on area under curve (AUC) value for evaluation of predictor variable significance for (**a**) 2020, and (**b**–**e**) 2050 for different RCP Scenario (**b** 2.6, **c** 4.5, **d** 6.0, and **e** 8.5)

risk to *L. camara* invasion was projected primarily in the north-western, eastern, and southern parts of Jharkhand state, while the remaining areas were under low risk to invasion in the current (87%) and future RCP scenarios (76% under 2.6; 78% under 4.5; 80% under 6.0; and 74% under 8.5) (Fig. 6).

Predicted potential distribution for a invasion risk of *L. camara* exhibited approximately similar trends primarily in the north-western and central parts with the lowest invasion in the current scenario in contrast to an increased invasion by 2050, in the large parts (>20% geographical area of Jharkhand) in the north-western, and eastern parts, while its dominance and continuous expansion was observed in the existing areas of invasion. This indicates that in the future, about one-fifth of the geographical area of Jharkhand may contain invasion of *L. camara,* which may have serious implications on the health of native ecosystems (Gooden et al. 2009).

Table 1 Error matrix for validation of projected distribution area of *Lantana Camara* under different classes

	Predicted						
		LRZ	**HRZ**	**CRZ**	**Total = N2**	**EC**	**UA**
Observed	LRZ	4	4	1	9	0.56	0.44
	HRZ	0	2	1	3	0.34	0.67
	CRZ	0	0	26	26	0	1
	Total = N1	4	6	28	n = 38		
	EO	0	0.67	0.07			
	PA	1	0.34	0.93			

LRZ low risk zone, *HRZ* high risk zone, *CRZ* critical risk zone, *EC* error of commission, *UA* user's accuracy, *EO* error of omission, *PA* producer's accuracy

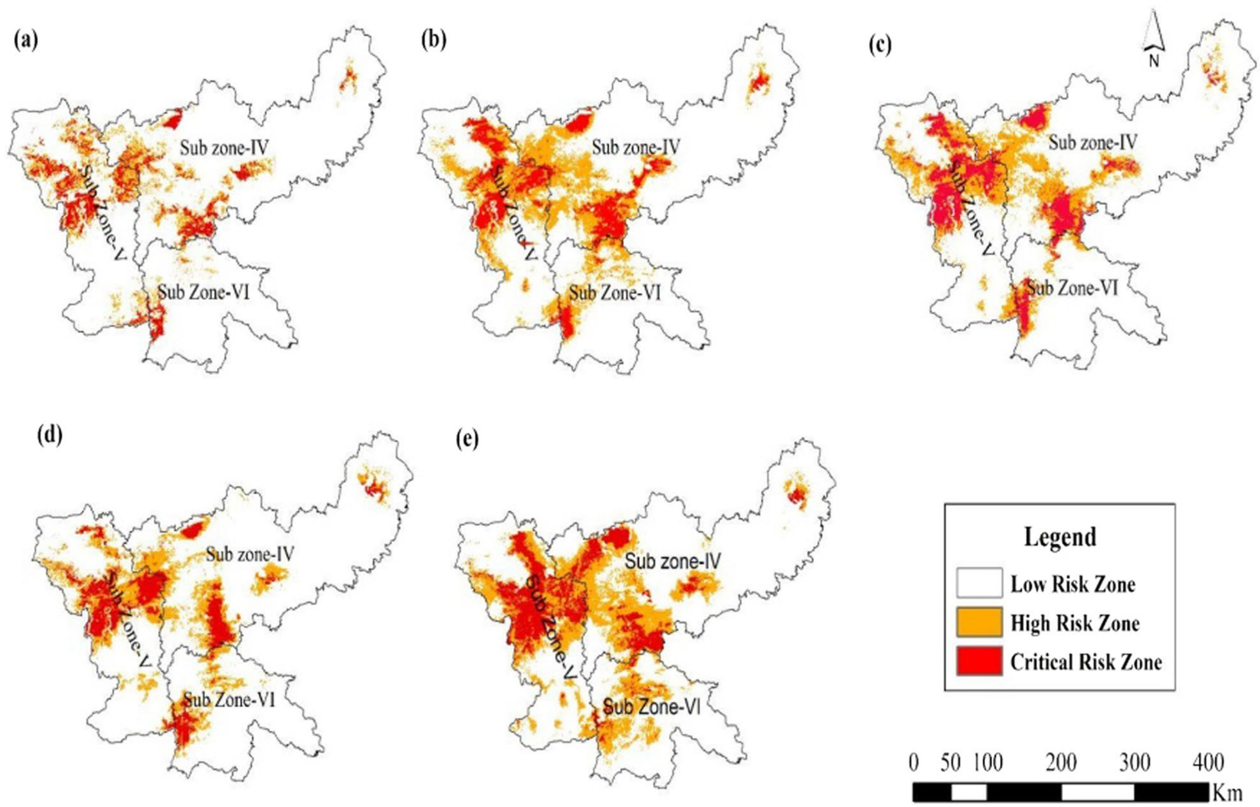

Fig. 5 Map showing potential distribution range of suitable habitats of *L. camara* for (**a**) 2020 and 2050 under RCPs (**b**) 2.6, (**c**) 4.5, (**d**) 6.0, and (**e**) 8.5 in Jharkhand. Map demonstrates further expansion in potential distribution range of *L. camara* by 2050 in Jharkhand encompassing the agro-climatic sub-zones IV, V and VI across all the RCPs i.e. 2.6, 4.5, 6.0 and 8.5 with maximum possible expansion under the scenario RCP 8.5. The probability of distribution is higher in high and critical risk zones than low risk zones

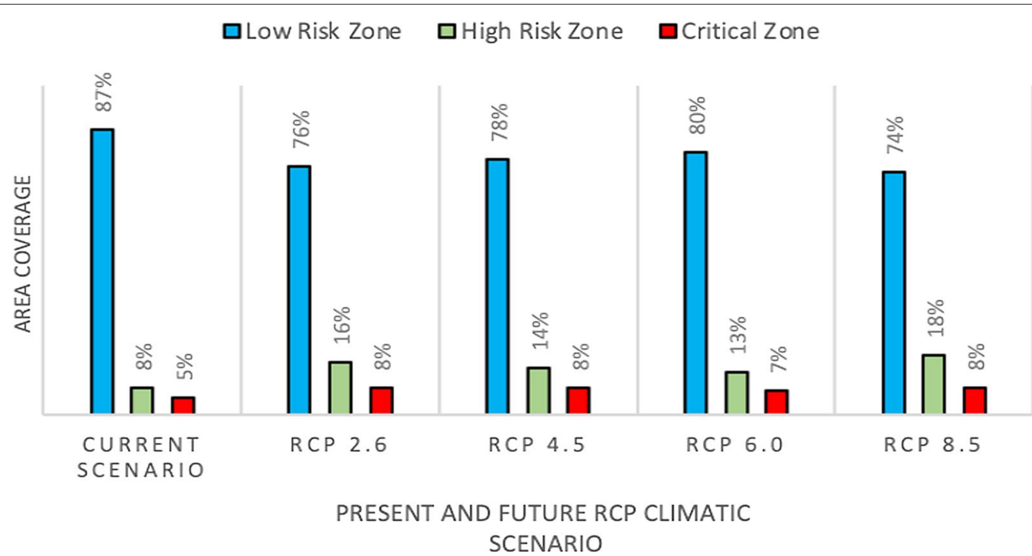

Fig. 6 Variation in a projected suitable area for distribution of *L. camara* spread for present and future climatic scenarios under different RCPs (AUC value > 0.49: Low, 0.5–0.7: High, > 0.7: Critical). The chart demonstrates probable increase in potential distribution area of *L. camara* in the range of 20–26% from the current ~ 13% with maximum probable increase upto ~ 26% under the RCP 8.5 by 2050

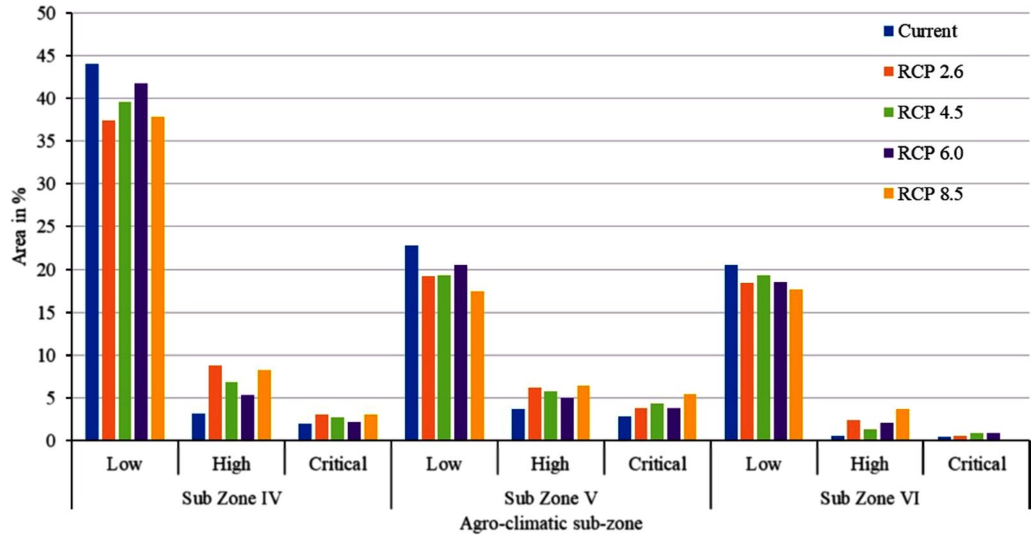

Fig. 7 Variation in the projected suitable habitat area (in percentage) for *L. camara* in different agro-climatic sub-zones of Jharkhand for the year 2020 and for 2050 under different RCPs i.e. 2.6, 4.5, 6.0, and 8.5 (AUC value < 0.49: Low, 0.5–0.7: High, > 0.7: Critical)

Agro-climatic zone wise projection of potential invasion sites

The potential habitats to *L. camara* invasion exhibited susceptibility in larger parts of Jharkhand, across different agro-climatic sub-zones which will further be increased by 2050, across all the agro-climatic sub-zones in Jharkhand. The study revealed an increasing risk of *L. camara* invasion primarily in sub-zone V, while the dominance of *L. camara* under sub-zones IV and V under the current scenario (Fig. 7). The probability of occurrence of *L. camara* invasion in future scenarios was observed approximately similar to the current scenario with prominence of distribution in sub-zone V. An average increase in the area of potential invasion was observed up to 2.39–7.29% in Jharkhand under HRZ compared to the existing scenario (0.54–3.18%) across sub-zones IV, V and VI, while the area under CRZ increased up to ~0.61–4.26% compared to the existing scenario (0.47–2.79%) under CRZ across sub-zones in Jharkhand. In contrast, the area under low risk zones to invasion reduced by 9.81–11.19% under the future scenario compared to the current scenario. The probability of occurrence of *L. camara* was observed higher in HRZ and CRZ compared to LRZ across all the sub-zones. Bioclimatic variables Bio_4, Bio_7, Bio_9 and Bio_2 along

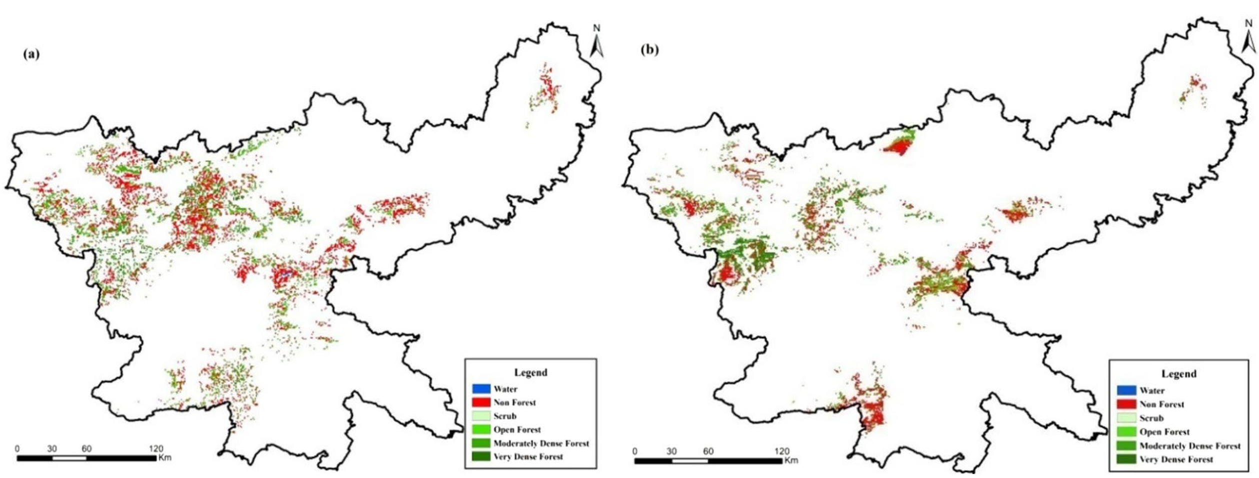

Fig. 8 Map depicting projected habitat distribution area of *L. camara* for (**a**) high risk zone (AUC: 0.50–0.70), (**b**) critical risk zone (AUC: > 0.70) vulnerable to infestation under different forest cover in Jharkhand for the year 2020

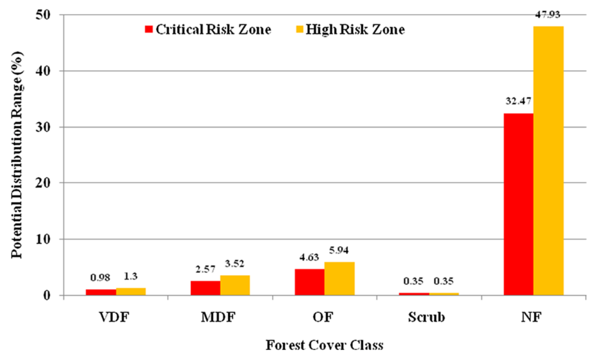

Fig. 9 Potential distribution range of *L. camara* in different forest cover classes under high risk zone (AUC value: 0.50–0.70), and critical risk zone (AUC value > 0.70) in Jharkhand under the current climate scenario. Chart demonstrates that the majority of the distribution occurs under the non-forest (NF) and open forest (OF) area

with Bio_15 (precipitation seasonality) most explain the distribution of *L. camara*. The distribution of *L. camara* varies with abundance of temperature and precipitation under different agro-climatic conditions across the sub-zones i.e., IV, V, and VI, highlighting the adoption across varied climatic conditions and terrains (Mungi et al. 2020). Our findings were consistent with Qin et al. (2015), indicating higher suitability of *L. camara* in tropical, subtropical, warm regions as in Jharkhand. The distribution of *L. camara* is characterised by warmer and humid climates, suggesting that it could invade habitats with similar niche conditions in other regions (Goncalves et al. 2014).

Projected distribution of L. camara in forest landscape

Approximately 44% of Indian forests, particularly those with habitats having warm, humid and fertile areas are prone to *L. camara* invasion (Mungi et al. 2020). The study highlighted a potential infestation of *L. camara* under high risk (HRZ), and critical risk category (CRZ) primarily in non-forest regions (HRZ: 47.93%; 32.47%) followed by open forest (HRZ: 5.94%, CRZ: 4.63%), moderately dense forest (HRZ: 3.52%, CRZ: 2.57%), very dense forest (HRZ: 1.3%, CRZ: 0.98%), and least in scrub (HRZ: 0.35%, CRZ: 0.35%) (Figs. 8, 9). Approximately ~ 91% of the occurrence of *L. camara* was observed mostly in non-forest and open forest areas, in contrast to moderately dense and very dense forests (8–9%). This endorsed the findings that it does not thrive under compact tree canopies of taller native forest species (Oosterhout et al. 2004; Negi et al. 2019). The higher distribution of *L. camara* was observed in open, sparse and disturbed forested landscapes as recorded during the field investigation while the distribution of *L. camara* diminishes significantly in dense forest areas with high canopy density (Negi et al. 2019). However, besides anthropogenic disturbances, the increased instances of forest fire due to climate change impact the compactness of the forests and modulate the expansion of invasive species (Brooks et al. 2004). The presence of invasive species (viz., *L. camara*) adjacent to forests poses a great threat to native forest composition as it may quickly invade the disturbed sites and limit the expansion of native vegetation by restricting natural regeneration (Hiremath et al. 2018), altering biodiversity, and wildlife habitat (Mao and Gogoi 2010; Berry et al. 2011).

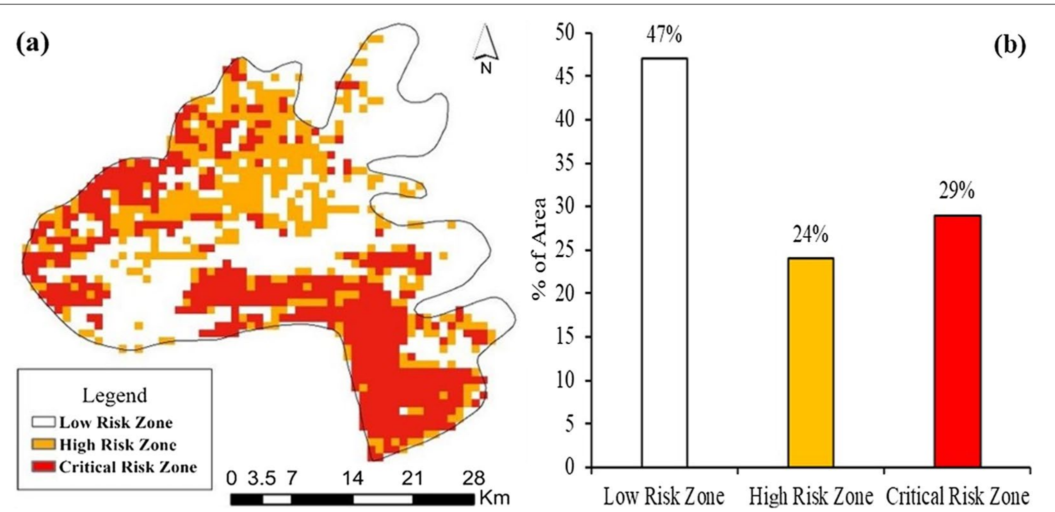

Fig. 10 Map illustrating potential distribution range prone to invasion of *L. camara* in Betla National Park; (**a**) for the year 2020 and (**b**) different risk zone category wise projected potential distribution area of invasion. The map shows that the majority of the area of Betla National Park is under high to critical risk zone of *L. camara* distribution

Table 2 LULC wise projected potential distribution range of *L. camara* under different risk zones (area in km^2)

LULC class	Critical risk zone	% of Total CRZ	High risk zone	% of Total HRZ	Low risk zone	% of Total LRZ
Natural vegetation	2762.24	66.05	3653.51	60.71	21,164.45	30.45
Water body	20.35	0.49	22.00	0.37	2030.37	2.92
Built-up	20.19	0.48	50.19	0.83	4487.79	6.46
Agriculture	1234.10	29.51	2075.00	34.48	36,541.9	52.57
Other	144.66	3.47	216.82	3.61	5290.43	7.60
Total	4181.54	100	6017.52	100	69,514.94	100

The higher invasion of *L. camara* in forest fringes compared to the core forest regions may be attributed to the high anthropogenic influencesthat augment the tendency of select species to invade more in disturbed forest regions (Richardson et al. 2004). In contrast, the core forest areas are mostly restricted parts and are less anthropogenically exposed, retaining the composition and virginity of the natural forest. Thus, core areas are less vulnerable to invasion than open and disturbed forests, which, due to high anthropogenic disturbances and open spaces, provide conditions that facilitate spread and success of *L. camara* (Stock et al. 2009). The open and disturbed spaces, forest fire, and anthropogenic factors are some of the major contributing factors that influence rapid expansion of *L. camara* invasion leading to depletion and altered composition of natives. Our findings indicate that the disturbed areas both in forest and agricultural landscapes stimulate the formation of invasive alien species (Theoharides and Dukes 2007), and that *L. camara* thrives better in disturbed forests (Prasad 2012) due to high adaptive capability to new niche dimensions under varying climatic conditions (Mungi et al. 2020).

Invasion of L. camara in Betla National Park

Research on invasive plant species in reserved forest areas in India is scarce and focuses mostly on *L. camara* (Hiremath et al. 2013). Betla National Park (BNP) is a very significant part of the Chotanagpur plateau as this is a designated protected area for conservation and promotion of tigers. It comprises ~ 5.6% (1323.90 km^2) of the total forest area of Jharkhand while largely ~ 53% area of BNP, primarily in southern and western parts provides a highly suitable habitat for *L. camara* invasion (Fig. 10). The high to critical risk zones to *L. camara* invasion are primarily under high disturbances, whereas the core regions due to least anthropogenic disturbances are under low risk zones. Field investigations confirmed the thick and dense patches of *L. camara* spread across the park as the area was recurrently affected by open grazing, largely leading to limited resources to native species and augmenting further forest fire susceptibility through the provision of fuel beds (Berry et al. 2011). Approximately 43% area of Betla National Park has been observed high to very high fire incidences (Kumari and Pandey 2020) and is primarily affected by the invasion of *L. camara* (> 75% area) (Priyanka and Joshi 2013b). The extensive spread of *L. camara* in Betla National Park may also be attributed to the tourist movement that induces stressed conditions for native species simultaneously promoting the spread of invasion (Sunlu 2003). The richness of invasive species was consistently and significantly higher in tourist-dominated sites as compared to control areas (Anderson et al. 2015).

Land use/land class (LULC) wise infestation analysis

The impact of potential *L. camara* invasion on LULC exhibited a larger *L. camara* invasion in natural vegetation and agricultural land (Table 2). Considerable parts of river banks and ponds were affected by *L. camara* invasion (Vardien et al. 2012), as also established during the field verification, while in urban landscapes, *L. camara* was witnessed in abundance along roadsides, along railway tracks, and around open abundant areas (Thakur et al. 1992; Kohli et al. 2006). In villages, people use it as a protection fence around their homes on agriculture bund. A systematic outreach approach to create awareness among farmers, urban settlers, and tribals living in forest fringe villages needs to be conducted, regarding the harmful effects of *L. camara* and other similar weeds.

Our findings endorsed the effectiveness of Maxent in projecting potentially suitable habitat sites of *L. camara*. Areas predicted by the model are in consonance with *L. camara* distribution (Divakar et al. 2013; Ray and Ray 2014). The present study suggests an increasing invasion of *L. camara* to new areas (Vardien et al. 2012) but in contrasts to the finding of Goncalves et al. (2014). A possible explanation for this might be the varied study area size; since our study was restricted to Chotanagpur plateau eastern India, whereas Goncalves et al. (2014) had considered a global perspective.

Taken together these results suggested a wide invasion of *L. camara* across different landscapes of Jharkhand due to robust adaptive capability to survive and grow across varied environmental conditions particularly in the open and disturbed forest areas, and agriculture landscapes. The study indicated that distribution of *L. camara* does not follow any specific pattern; rather it is well spread across different agro-climatic sub-zones of Jharkhand. The findings of this investigation complement those of earlier studies that demonstrated the adaptability of *L. camara* to diverse environmental conditions and distribution across different landscapes and aid understanding of distribution ecology of *L. camara*. The strengths of this study included comprehensive analysis of distribution of *L. camara* in the region that represents forest cover, LULC and protection site wise examination and physical corroboration of projected potential distribution ranges through the extensive field surveys. These findings are directly relevant to the forest managers and have significant implications in forest management as it enables identification and prioritisation of areas already invaded or potential sites for future invasion threat of *L. camara*. The prior identification of potential sites at invasion risk shall be very useful in planning strategies to control expansion of *L. camara* in new spaces. The quantified estimation of the invaded area has direct implications in associated cost assessment for the conservation initiatives. With regard to the research methods, some limitations need to be acknowledged. Although the study has successfully demonstrated the potential distribution range of *L. camara* across different landscapes of Jharkhand, it has certain limitations in terms of use of coarser resolution of bioclimatic variables, which may have led to overestimation of projected areas. We have used Maxent in the present study, which is considered highly accurate and robust (Elith et al. 2006) but many researchers advocated applying an ensemble approach to address model overfitting issues and more accurate and precise area estimation (Araújo 2007). We recommend prioritisation of sensitive natural sites at the verge of greater invasion threat and adoption of native tree and grass based intervention models to address invasion issues, support richer biodiversity and environmental amelioration and outreach programs to educate people with the harmful effects of *L. camara* and other similar invasive species.

Conclusion

This study set out to assess the potential distribution areas of *L. camara* invasion in Jharkhand, a major part of Chotanagpur plateau region in the eastern India, for the years 2020 and 2050 under climate change scenarios. The study highlighted a wide distribution of *L. camara* across different landscapes of Jharkhand. The distribution of *L. camara* not only retains the existing area but shall also expand across the entire Jharkhand encompassing agro-climatic sub-zones IV, V and VI under future projections (2050). The investigation showed inability of *L. camara* to penetrate through the intact native virgin forests, in contrast to its abundant distribution along agricultural land and in open and disturbed forest areas including wide distribution in Betla National Park. The presence of *L. camara* in forest areas poses a great threat to native forest species and wildlife habitat in Chotanagpur plateau region as it restricts the regeneration and extension of natives. Another major finding of the study suggests urgent interventions to curtail its further expansion to support a better environment for the tigers in Betla National Park as well as reverse the ecosystem imbalance due to rapid invasion and removal of native species. We recommend prioritisation of sensitive natural sites at the verge of greater invasion threat and adoption of native tree and grass based intervention models to address invasion issues, support richer biodiversity and environmental amelioration and outreach programs to educate people with the harmful effects of *L. camara* and other similar invasive species.

Abbreviations

IUCN: International Union for Conservation of Nature; GARP: Genetic Algorithm for Rule Set Production; RCP: Representative concentration pathways; FSI: Forest Survey of India; ASCII: American Standard Code For Information Interchange; ESRI: Environmental Systems Research Institute; SRTM: Shuttler Radar Topographic Mission; DEM: Digital elevation model; FAO: Food and Agriculture Organization; LULC: Land use/land cover; SVM: Support vector machine; NRSC: National Remote Sensing Centre; IPSL-CM5A-LR: Institut Pierre Simon Laplace Climate Model 5th Assessment-Low Resolution; ROC: Receiver operation characteristics; AUC: Area under curve; LRZ: Low risk zone; HRZ: High risk zone; CRZ: Critical risk zone; EO: Error of omission; EC: Error of commission; UA: User accuracy; PA: Producer accuracy; VDF: Very dense forest; MDF: Moderate dense forest; OF: Open forest; NF: Non-forest; BNP: Betla National Park.

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Authors' contributions

ST: Project conceptualization, Analysis, First draft and editing. SNM: Designing field layout, Field Survey. DK: Literature review, Field Survey. BK: Field Survey. SNV: Field survey. BG: Developing model through Maxent, GIS layers preparation. SkMR: GIS analysis, Forest Cover related analysis, Data validation, Writing. MK: Data cleaning, literature review. SG: Maxent modeling, field survey for validation. AK: Discussion, manuscript writing. All authors read and approved the final manuscript.

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Availability of data and materials

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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