Presence & Spread

- Present in >10,000 km^2 of Jharkhand, 231 km^2 of Upper Ganga Valley, and 45,262 km^2 in Western Ghats.
- Highest biomass density: Vindhyan Highlands (61–100% cover) and Rajaji Hills (daily harvestable patches).

Why These Regions Work for Biochar

- 🚀 Priority Clusters:
  - Rajaji & Shivalik Hills: 9 dry streambed clusters for daily harvesting.
  - Vindhyan Highlands (MP): 200+ km^2 with 61–100% cover (highest biomass/area).
  - Mudumalai (TN): 150 road-side patches (87% mapping accuracy).
- Supply Stability: Invasion >50% = continuous biomass.

Region	Area Invaded (km^2)	Invasion Density	Notes
Western Ghats	45,262 km^2	30–40% forest floor	Craft & biomass hotspot — esp. Nilgiri Biosphere
Jharkhand (Chotanagpur)	~10,000 km^2 est.	Up to 26% by 2050	Agro-climatic zones V & IV most dense
Rajaji & Shivalik Hills	9 patch clusters	Small-world clusters	Easily harvestable via dry streambeds
Vindhyan Highlands (MP)	200+ km^2	61–100% cover (dense)	Biomass-rich; highest light suppression areas
Upper Ganga Valley	231 km^2 (+375 km^2)	~94% in subtropical zone	Near plains; ideal for collection hubs
Mudumalai TR (TN)	~150 harvestable patches	Clustered near roads & trails	High accuracy mapping (AVIRIS, 87%)

- https://doi.org/10.1016/j.gecco.2020.e01080

Figure Panels Explained

1. Panel (a): Observed Presence (Grid Cells)
   - Red cells: Observed Lantana presence in field surveys.
   - Blue cells: Areas where it was not detected during sampling.
   - Reflects actual, on-ground data from extensive National Tiger Estimation Project (117,000+ plots)
2. Panel (b): Survey-Corrected Occupancy Probability
   - Derived using occupancy models to adjust for imperfect detection.
   - Highlights regions with higher true probability of presence, even where not directly observed.
3. Panel (c): MaxEnt Modelled Probability of Occurrence
   - Uses MaxEnt (species distribution modeling software) with environmental variables (climate, terrain).
   - Warmer colors indicate higher suitability.
   - Captures areas that surveys may have missed.
   - Overlay of observed presence and predicted suitable habitat.

Shows the full potential range of Lantana in Indian forests, including tiger reserves.

BIOCHAR INSIGHT:

- 44% of Indian forests have Lantana – high biomass potential.
- MaxEnt models predict 37% more area than field surveys – prioritize these underdetected zones (e.g., Central India).
- Target: Shivalik Hills, Central India, Western Ghats (40% of tiger reserves).

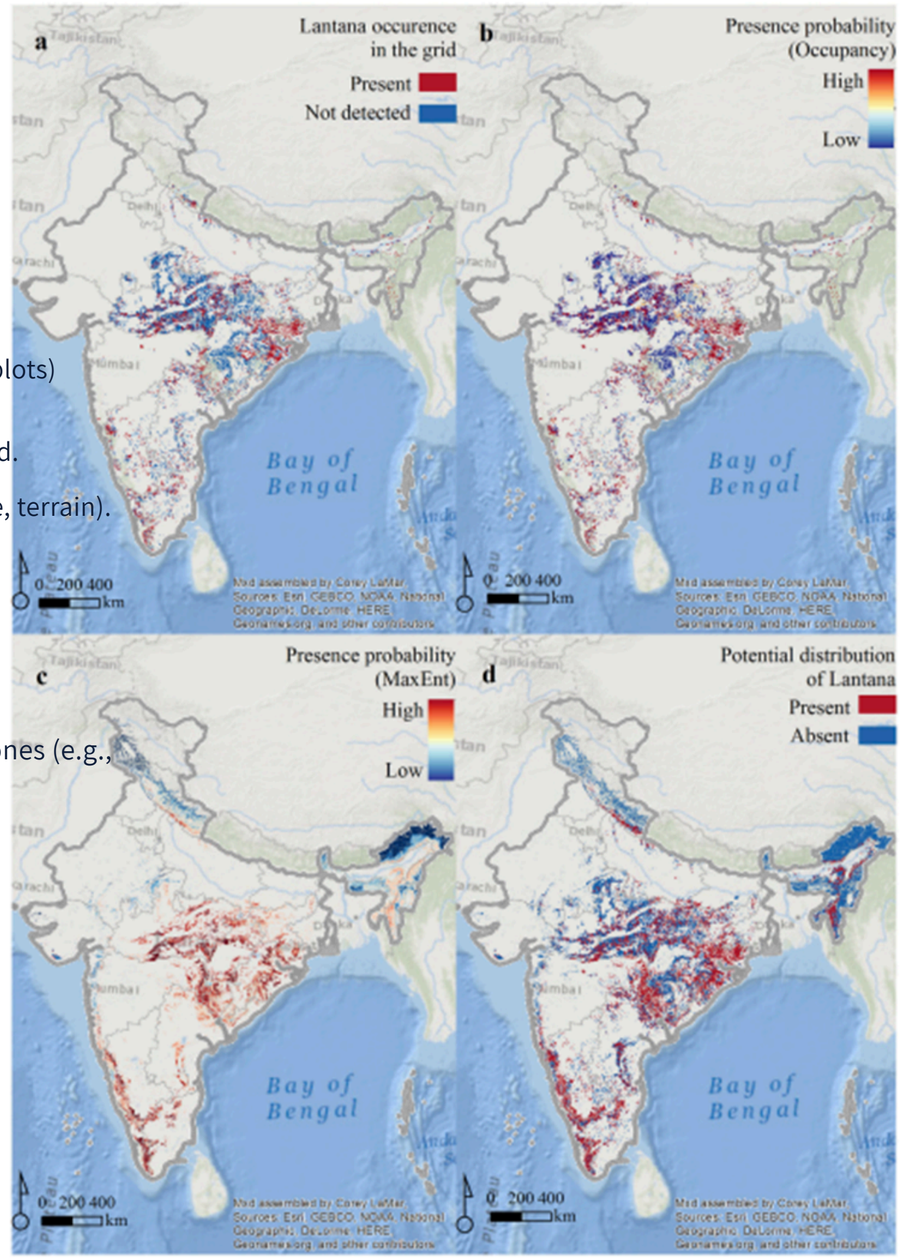


Fig. 2. *Lantana camara* distribution in India. (a) Grid cells with Lantana presence (red) and where Lantana was not detected (blue), (b) Potential distribution of Lantana corrected for imperfect detection and site covariates in an occupancy framework (c) Areas susceptible for Lantana invasion modeled by MaxEnt for non-surveyed area using the information from surveyed area and, (d) An aggregated distribution of Lantana in forests of India, obtained by ensembling occupancy estimates for ground surveyed areas (in the year 2010) and MaxEnt models beyond ground surveyed areas.

- https://doi.org/10.1016/j.ecoinf.2023.102425

Key Points:
Study Area
– Western Ghats, with a zoomed focus on the Nilgiri Biosphere Reserve.
– Overlay of elevation classes (<250 m to >2250 m).
Species & Data
– Occurrence records (points): blue for C. odorata, green for L. camara.
– Altitudinal zonation illustrates species distribution.
Trends/Patterns
– Both species show distinct elevational preferences—most frequent in mid-elevation ranges (500–1500 m).
– L. camara populations extend into higher elevations more than C. odorata.
Implications
– Elevation as a key predictor in ecological niche models.
– Potential shift in invasion zones under climate change scenarios.
– Inform management strategies: targeting mid-elevation belts for early detection and control.

Quantified Invasion by Chromolaena odorata & Lantana camara in Western Ghats
Current Status:
- L. camara: 30.33% coverage

Future Projection (2021–40):
- L. camara: 45,262 km² → 31.33% (SSP-126); +5.83%

Nilgiri Biosphere Reserve Focus:
- L. camara: 5,711 km² (12.6%)

Interpretation:
- L. camara is projected to expand in both area and proportion.
- NBR remains a major hotspot—target for monitoring & control.

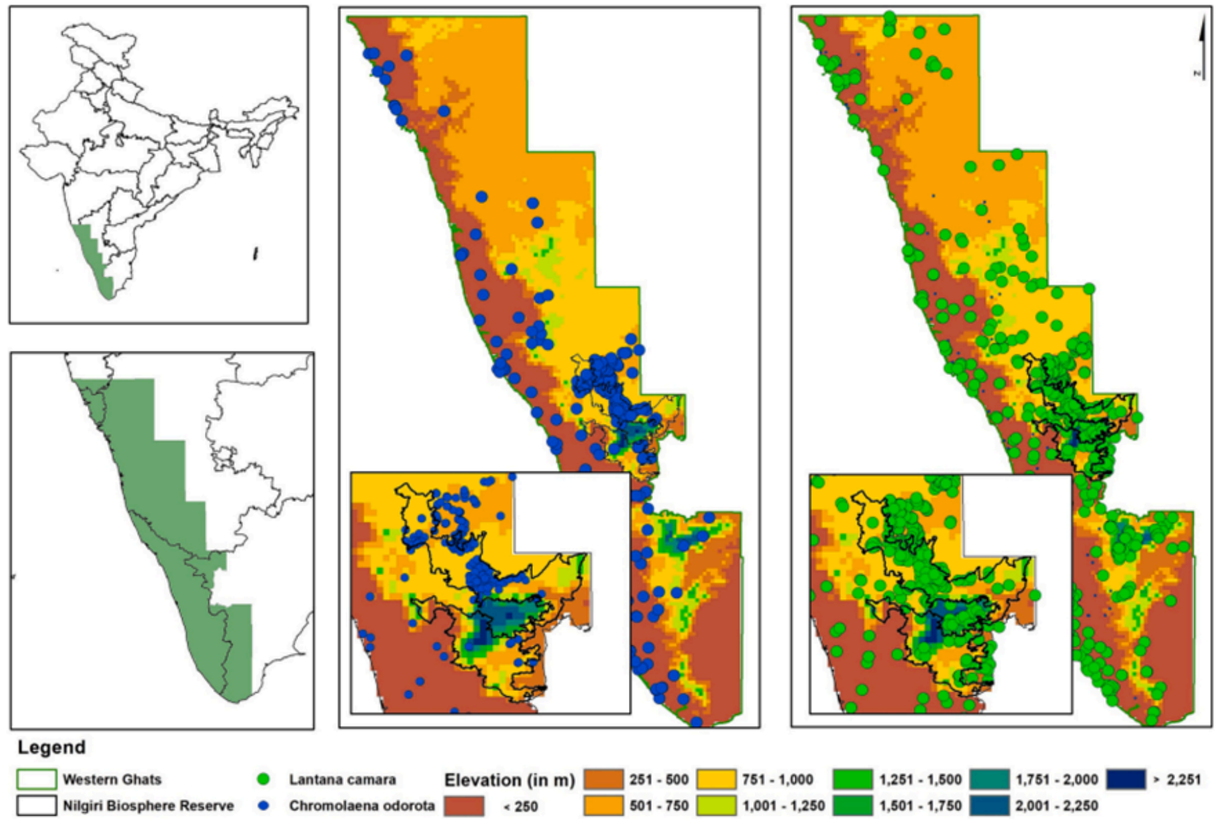


Fig. 2. Altitudinal variations in the Western Ghats (zoom box: Nilgiri Biosphere Reserve) along with occurrence locations (in points) of *Chromolaena odorata* and *Lantana camara*.

- https://doi.org/10.1007/s10530-018-1666-7

Current & Future Spread of Lantana camara in Upper Ganga Valley
Study Design & Data:
- 2,221 plots sampled (covering ~22% of region) across a 1 km² grid in three climate zones.
- L. camara presence mapped as black dots on elevation-gradient map.

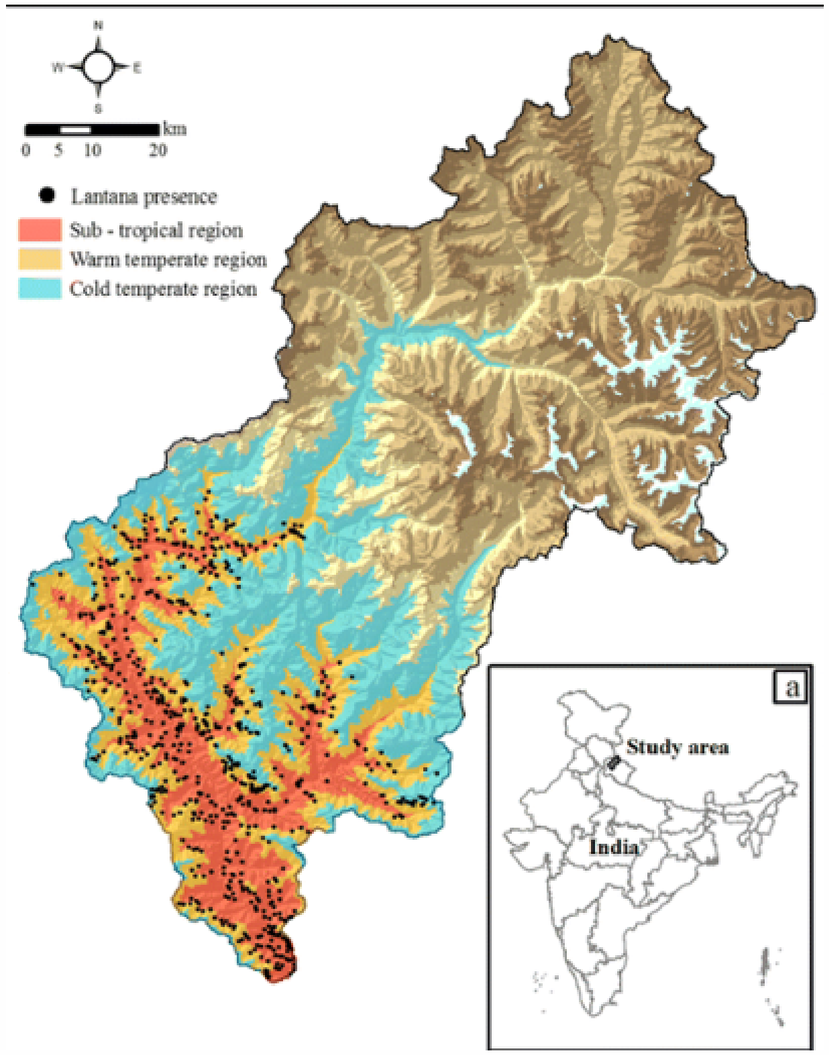
Current Invasion Footprint:
- Total: 231 km²
  - Sub-tropical: 217 km² (≈94%)
  - Warm temperate: 11 km²
  - Cold temperate: 4 km²

Model Reliability:
- MaxEnt model AUCs: 0.70–0.94; Kappa: 0.86–0.98 across zones → high predictive accuracy.

Future Projections:
- Additional 317–375 km² of invasion predicted, representing substantial range expansion due to climate change and disturbance synergy.

Interpretations & Implications:
- Majority of current invasion concentrated in lower elevations.
- Future scenarios hazard significant expansion into higher zones.
- Management strategies should extend focus beyond subtropical zone: address corridors of disturbance (e.g., landslides, fire) as invasion enablers.

BIOCHAR INSIGHT:
- Current: 231 km² (94% subtropical).
- Projected: +317–375 km² expansion.
- Action: Establish collection hubs in subtropical zones.



- https://doi.org/10.48550/arXiv.1808.03160

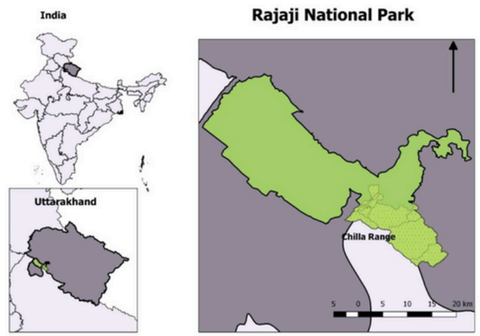
Network-based Spread Potential of Lantana camara in Rajaji Tiger Reserve
Key Takeaways:

1. Network Structure
   - ~150 habitat patches modeled as nodes; linked by least-cost paths.
   - Exhibits strong small-world properties: high local clustering + short inter-patch paths → rapid local & regional spread.
2. Community Partitioning
   - Nine major communities (each ≥30 patches) identified via high modularity (~0.83).
   - Reveals functional groupings of spread-prone zones.
3. Critical Spread Hubs
   - Patches 65 & 124 along dry riverbeds highlighted by centrality metrics.
   - Serve as "strategic nodes" for invasion control and early intervention.
4. Management Insights
   - Dry seasonal streams act as invasion corridors.
   - Path-based interventions (e.g., barrier creation in riverbeds) could disrupt spread.

“Fig. 6 shows the spatial community structure in the Lantana network, with nine major patch communities (coloured), derived via network analysis of MaxEnt-predicted distribution patches and landscape connectivity.”

BIOCHAR INSIGHT:

- 150 habitat patches grouped into 9 communities.
- Critical Hubs: 6 patches along dry riverbeds (e.g., Patch 65 & 124).
- Strategy: Target dry streambeds for barrier-based harvesting.



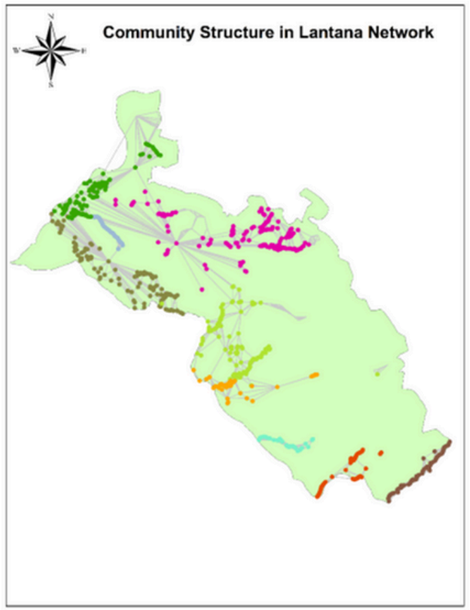


Fig. 6. Community Structure of lantana network showing nine communities, each represented by a different colour, all of which contain at least thirty potential lantana distribution patches as its members.

- https://doi.org/10.3897/neobiota.25.8354

Invasion Dynamics of Lantana camara in Biligiri Rangaswamy Temple Reserve
Visual Description:
Map shows BRT reserve with sampling grid, roads, old/current Soliga settlements ("podus"), and former plantation zones.
Study Design:
- 134 permanent plots surveyed in 1997 and 2007–08 (122 analyzed).
- Plots located within 2 × 2 km grid across the reserve.

Key Invasion Metrics:
- Colonisation: Among initially clean plots (n = 71), 54 (76%) had L. camara after 11 years.
- Density change: Increase in 37/51 originally invaded plots; density more than tripled in most cases.

Statistical Insights:
- Propagule pressure (LNI) → strongest colonisation driver (AICc/weight).
- Fire frequency → strongest predictor of density change: negative influence (23.6% deviance explained, weight = 0.62).

Management Implications:
- Emerging invasion sites likely near existing Lantana stands → prioritize buffer zones.
- Frequent fire reduces Lantana density, suggesting fire management could aid control where appropriate.

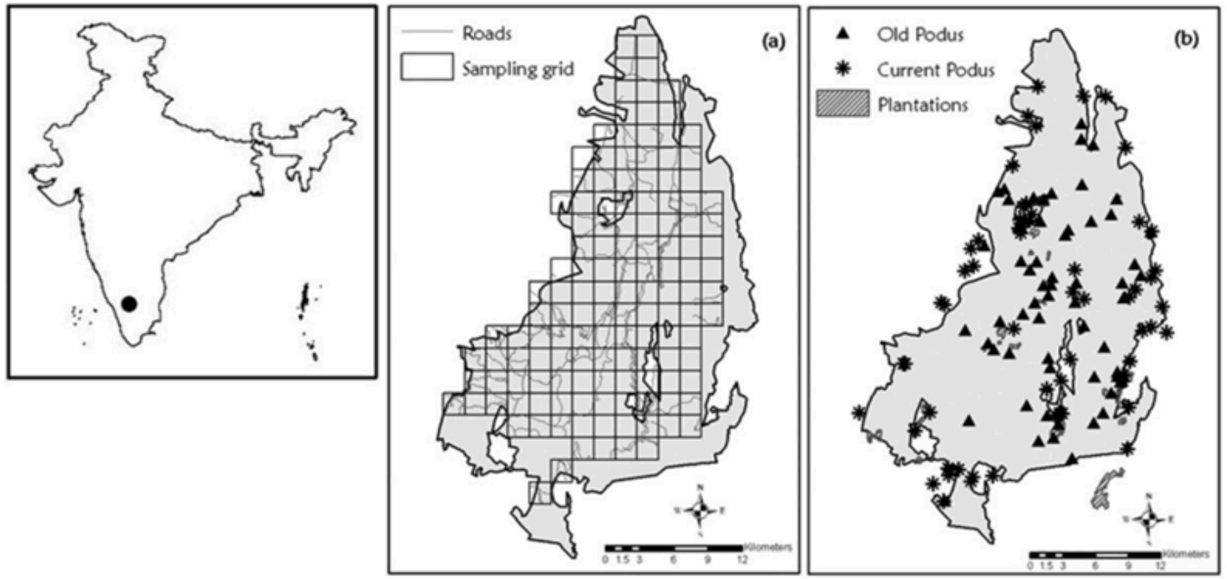


Figure 1. Map of the Biligiri Rangaswamy Temple Tiger Reserve (BRT) showing sampling grids and roads (**a**), old and current podus (Soliga settlements), and areas of historical plantation activity (**b**). Inset map of India shows location of BRT

BIOCHAR INSIGHT:
- Colonization Rate: 76% of clean plots invaded in 11 years.
- Fire Reduces Density: Use controlled burns + harvesting.
- Target Buffer Zones: Near roads/podus (Soliga settlements).

- https://doi.org/10.1186/s13717-021-00354-W

Projected Consumption of Lantana camara in Jharkhand by 2050

Study & Model Setup:

- Field survey: 425 occurrence points across agro-climatic zones IV, V, VI (2020 baseline).
- MaxEnt modeling for current (2020) and future (2050) conditions under RCPs 2.6, 4.5, 6.0, 8.5.

Current Invasion Risk (2020):

- Affects ~13% of Jharkhand (Chotanagpur Plateau).
- High-risk zone (% area): V=12.77%, IV=6.70%, VI=2.49%.
- Critical-risk zone (% area): V=9.50%, IV=4.19%, VI=2.14%.

Projected Expansion (2050):

- 20–26% area invasion under RCPs—maximum under RCP 8.5.
- HRZ increases: +2.4% to +7.3%; CRZ up by +0.6% to +4.3%.
- Low-risk zones shrink by ~10%.

Key Predictors & Habitat Types:

- Temperature seasonality (Bio_4) is the top climatic predictor.
- Suitable habitats: 60–66% in natural forests, 30–35% in agriculture.

Implications:

- Rising invasion risk—especially under severe climate scenarios.
- Intervention needed in sub-zone V hotspots and Betla National Park.
- Protect natural vegetation and buffer agricultural areas.

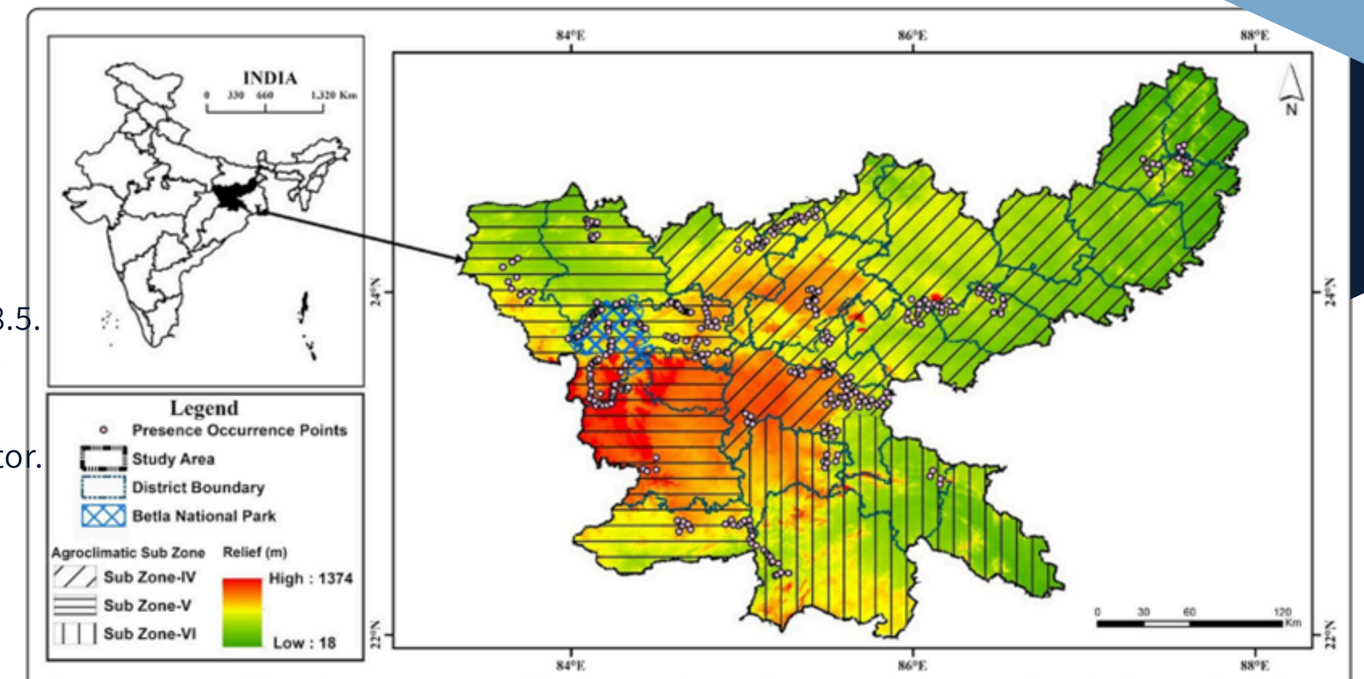


Fig. 1 Location map of the study area encompassing all the three agro-climatic sub-zones viz sub-zones IV, V and VI and Betla National Park. The points representing occurrence distribution locations of *L. camara* recorded across Jharkhand

BIOCHAR INSIGHT:

- Current: 13% area invaded (Sub-zone V: 12.77%).
- 2050 Projection: 20–26% area.
- Hotspots: Sub-zone V (Betla National Park) – 60% in natural forests.

- https://doi.org/10.1016/j.asr.2022.12.026

Hyperspectral detection and spatial patterns of Lantana camara & Chromolaena odorata in Mudumalai TR

Method Overview:

- Field mapping of L. camara (yellow) & C. odorata (blue) over flight campaign (AVIRIS-NG, Mar 2018).
- Analysis via MESMA-derived spectral signals.

Detection Accuracy:

- L. camara: 87%, C. odorata: 84% validated against field surveys.

Distribution Highlights:

- ~150 L. camara clusters; ~120 C. odorata along habitat edges (roads, trails, riparian).
- High cluster density in accessible corridors within reserve.

Spectral Diversity Patterns:

- Eastern low-diversity zone (H′ < 1.0, ~0.13% of area).
- Central & western zones show moderate to high diversity (H′ 1–2: ~13%; >2: ~86%).

Implications:

- Hyperspectral imagery effective for fine-scale invasion mapping in forest interiors.
- Target monitoring along corridors and edge habitats.
- Spectral diversity metrics may serve as early-warning indicators for invasion risk

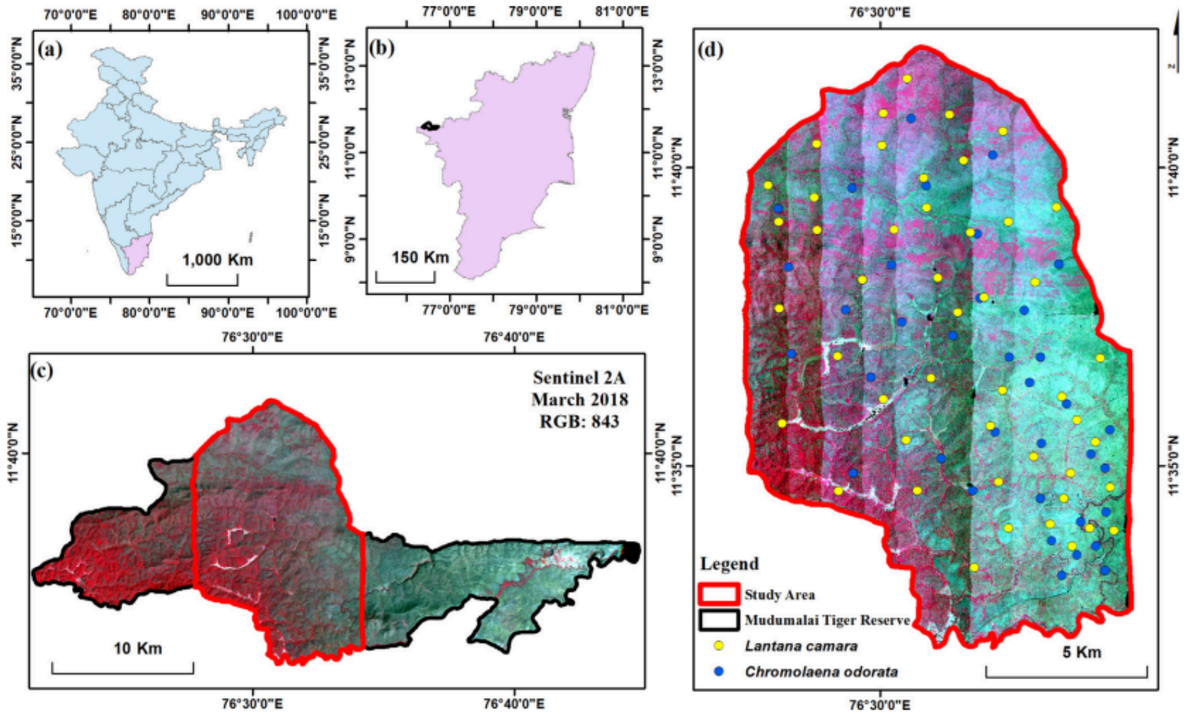


Fig. 1. Location map of the study area representing central parts of Mudumalai Tiger Reserve and field location of major IPS overlaid on AVIRIS-NG images (acquired on 20th March 2018).

BIOCHAR INSIGHT:

- 150 Lantana clusters near roads/trails.
- Detection Accuracy: 87% (AVIRIS-NG).
- Action: Monitor corridors (riparian zones, trails).

- https://doi.org/10.1016/j.catena.2021.105624

Study Sites (Map + Photos):
- Location: Chanfi, Matial, Mehra in Nainital, Uttarakhand
- Forest type: Chir Pine (Pinus roxburghii)
- Each site sampled across 3 categories:
  - (a) NI – Non-invaded
  - (b) LI – Lantana camara invaded
  - (c) AI – Ageratina adenophora invaded

Site	Shrub Density (shrubs/ha)	Basal Area (m^2/ha)
Chanfi	**9,240**	**2.36**
Matial	4,640	0.65
Mehra	4,200	0.60

Ecological Observations:
- Fig. (b) shows Lantana camara forming dense thickets, outcompeting native understory species.
- Compared to non-invaded sites (Fig. a), shrub density and cover nearly doubled.
- Reduced biodiversity and altered forest floor conditions observed.

Visual Guide:
- Top-Left Map: Study locations in India and Uttarakhand
- Photos: Real forest subplots showing contrasting vegetation conditions due to invasion

BIOCHAR INSIGHT:
- Biomass Yield: 2× higher in invaded sites (LI) vs. non-invaded (NI).
- Target: Chir Pine forests (Matial, Chanfi, Mehra).

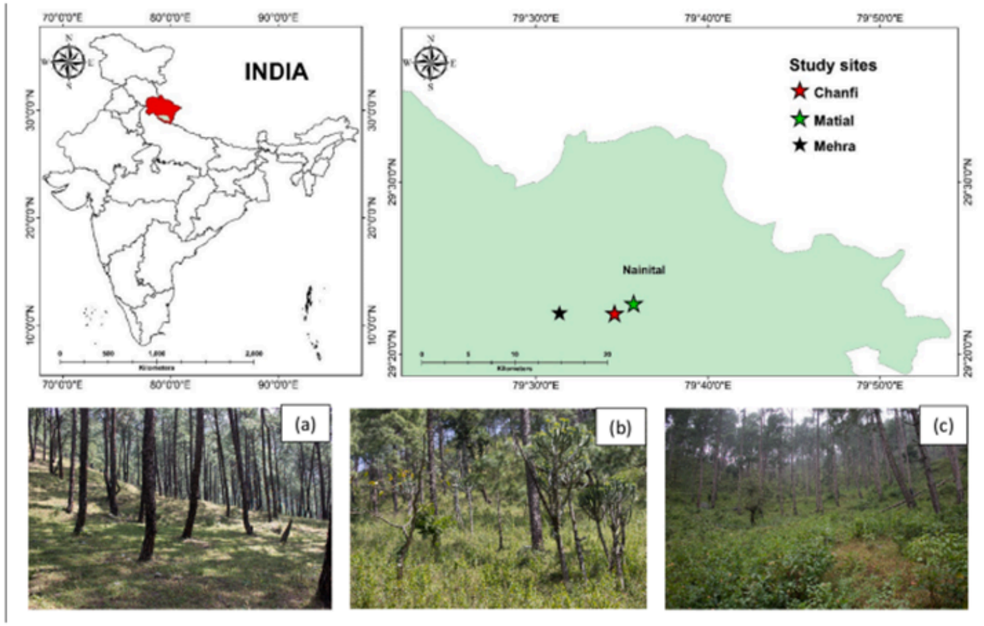


Fig. 1. Study sites location in chir pine forests in Nainital district, Uttarakhand, India. (a) Non-invaded (NI); (b) Lantana camara invaded (LI); (c) *Ageratina adenophora* invaded (AI) subsites in pine forest.

Table 1
Study site location and shrub characteristics in studied chir pine forests in the central Himalaya.

Site	Altitude (m)	Location	Status	Density (ha^{-1})	Basal Area (m^2ha^{-1})	R	Cd	H'	E	Dominant shrub Species
Chanfi	1410	29° 22′ 22.4″ N	NI	6960	0.96	1.36	0.12	2.26	0.88	*B. asiatica, R. ellipticus, A. curillus*
		79° 34′ 33.9″ E	LI	9240	2.36	0.99	0.51	1.08	0.47	*L.camara, A. adenophora*
			AI	12,000	2.24	1.06	0.56	1.05	0.44	*A. adenophora, L.camara*
Matial	1630	29° 22′ 56.5″ N	NI	4640	0.65	1.54	0.13	2.11	0.80	*B. asiatica, R. ellipticus, P. crenulata*
		79° 35′ 40.2″ E	LI	6720	1.64	0.91	0.43	1.18	0.53	*L.camara, A. adenophora*
			AI	10,920	2.03	1.08	0.63	0.85	0.35	*A. adenophora, L.camara*
Mehra	1650	29° 22′ 23.5″ N	NI	4200	0.60	1.20	0.14	1.95	0.81	*B. asiatica, R. ellipticus, P. crenulata*
		79° 31′ 22.0″ E	LI	9680	2.52	0.65	0.56	0.91	0.47	*L.camara, A. adenophora*
			AI	8960	1.79	0.66	0.55	0.93	0.66	*A. adenophora, L.camara*

Different letters represent as NI = non-invaded, LI = *Lantana camara* invaded, AI = *Ageratina adenophora* invaded, R = Richness, Cd = Simpson's dominance, H' = Shannon diversity index, E = Evenness index (adopted from Kumar et al., 2020).

- https://doi.org/10.1186/s13717-021-00354-w

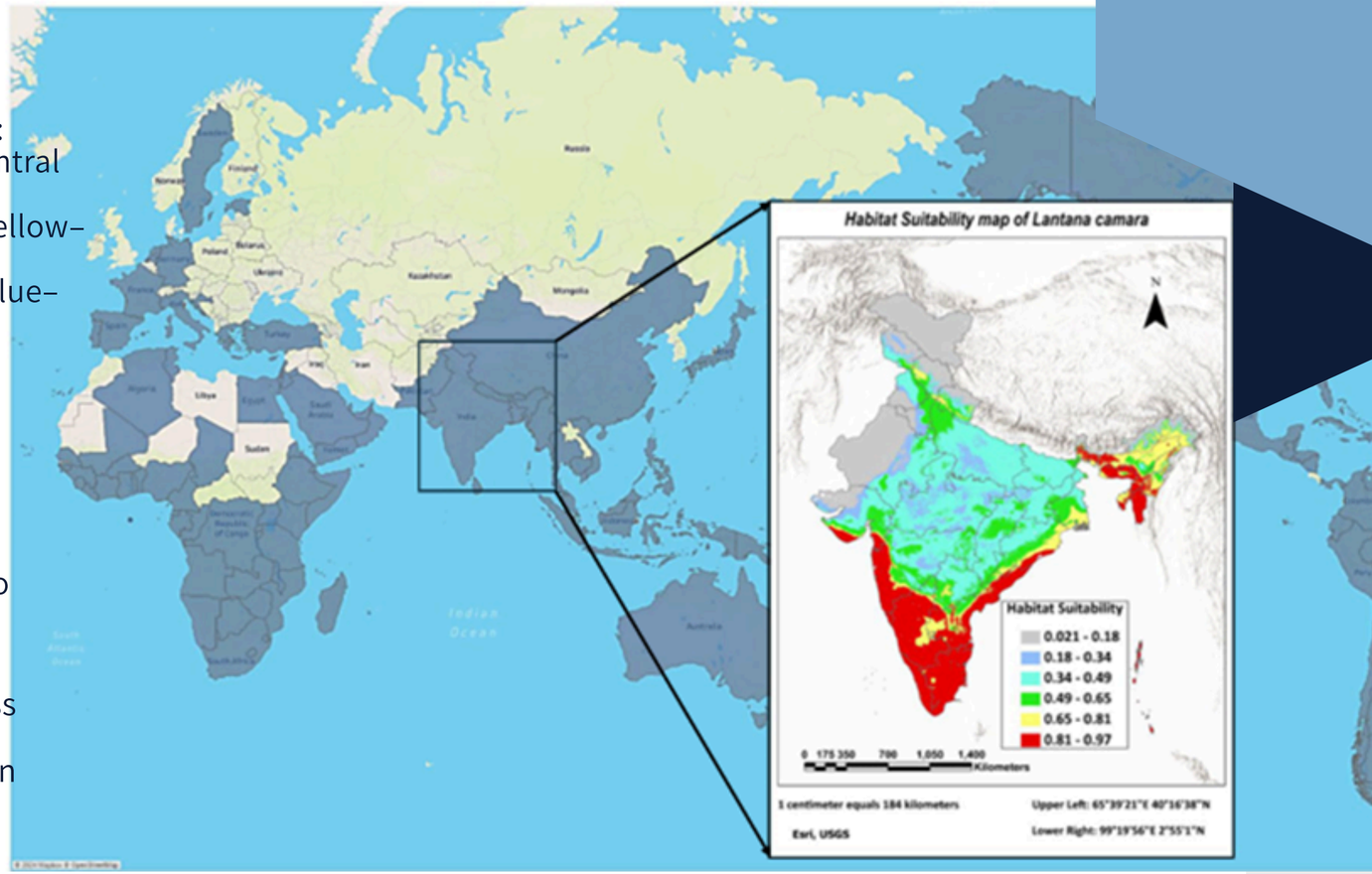
Global & India Context
- Global spread: Shaded countries globally show current invasive presence.
- Inset (India): Habitat suitability mapped using MaxEnt modeling:
  - High suitability (0.81–1.0): Southern India, Eastern Ghats, central plains, lower Himalaya (red)
  - Moderate (0.49–0.81): Broad central, Uttarakhand regions (yellow–orange–light green)
  - Low to negligible (<0.34): Northern mountains, arid zones (blue–white)

📊 India Suitability Breakdown (Index ranges)
- 0.81–1.0 (Red): Highly suitable – Lantana thrives
- 0.65–0.81 (Orange): Moderately high risk
- 0.49–0.65 (Yellow): Moderate risk
- 0.34–0.49 (Light green): Low to moderate
- 0.18–0.34 (Pale blue): Poor habitat
- 0.02–0.18 (White): Unsuitable

📍 Uttarakhand (study region): Falls in 0.49–0.81 zones – moderate to high invasion risk

Model & Methodology
- Model used: MaxEnt species distribution model to assess current & future invasion risk
- Key variables: Temperature seasonality and precipitation patterns drive suitability

🌿 Implications for Management
- Red zones: Priority for early monitoring & control
- Uttarakhand (moderate zones): Watch for further Lantana infiltration — aligns with field observations from Nainital studies
- Recommended actions: Focus on disturbed and open habitats; preemptive management in high-risk periphery regions



BIOCHAR INSIGHT:
- High-Suitability Zones (Red):
  - Southern India, Eastern Ghats, Central Plains.
- Uttarakhand: Moderate-high risk (0.49–0.81 index).
- Action: Prioritize disturbed habitats in red zones.

- Sharma & Raghubanshi, 2010 –Tropical Ecology 51:305–316

Map & Site Overview
- Study Area: Vindhyan dry deciduous forest (~24° N, 82°–83° E)
- Sites with varying Lantana cover:
  a. Hathinala – Low (0–30%)
  b. Bhaheradol – Medium (31–60%)
  c. Rajkhar – High (61–100%)

Quantitative Highlights
- Light attenuation beneath Lantana canopy:
  - Low: ~40%
  - Medium: ~53%
  - High: ~87%

Tree regeneration decline (seedling:adult ratio < 0.5):
- Low: ~16–20% of species affected
- Medium: ~42–60%
- High: ~19–48% across two censuses

Why it Matters
- Map dots (1–3): Show increasing Lantana invasion from Hathinala to Rajkhar.
- Dense thickets reduce light up to 87%, severely inhibiting native plant recruitment.
- Medium invasion intensity leads to nearly half of tree species failing regeneration.
- Feedback loop: Lantana enriches soil nitrogen → grows thicker → further suppresses native flora

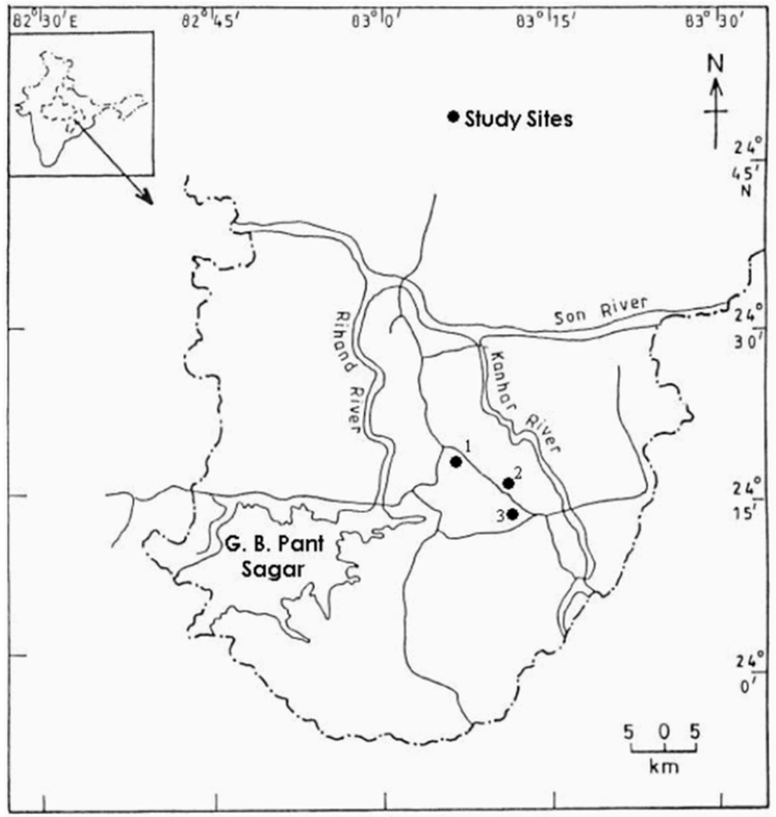


Figure 1. *Location of study sites with low, medium and high lantana cover within Vindhyan highlands, India. 1-Hathinala (low); 2- Bhaheradol (medium); 3- Rajkhar (high).*

BIOCHAR INSIGHT:
- Rajkhar Site: 61–100% cover → 87% light suppression (max biomass).
- Regeneration Decline: 42–60% in medium-density zones – ideal for clearing.

- https://doi.org/10.3389/ffgc.2025.1412130

Study Overview – Image Context

- Geographic Location: Sagar district, Madhya Pradesh (Central India) – highlighted in top map
- Three sites marked:
  - Site-I (green)
  - Site-II (blue)
  - Site-III (purple)
- Each site has both Uninvaded (UI) and Lantana-invaded (LI; >50% shrub cover) plots
- Sampling: 10 plots (50 × 50 m each) per UI/LI region → total 60 plots

Parameter	UI Mean (range)	LI Mean (range)
Tree Density (no./ha)	528–400	343–300
Basal Area (m^2/ha)	22.5–18.2	15.2–16.5
Species Richness	21–30 species	13–24 species
Soil Moisture (%)	15.8–20.3	17.9–22.6
Soil pH	6.2–6.4	5.82–6.14
Bulk Density (g/cm^3)	1.06–1.17	0.89–1.1 frontiersin.org researchgate.net +5 ouci.dntb.gov.ua

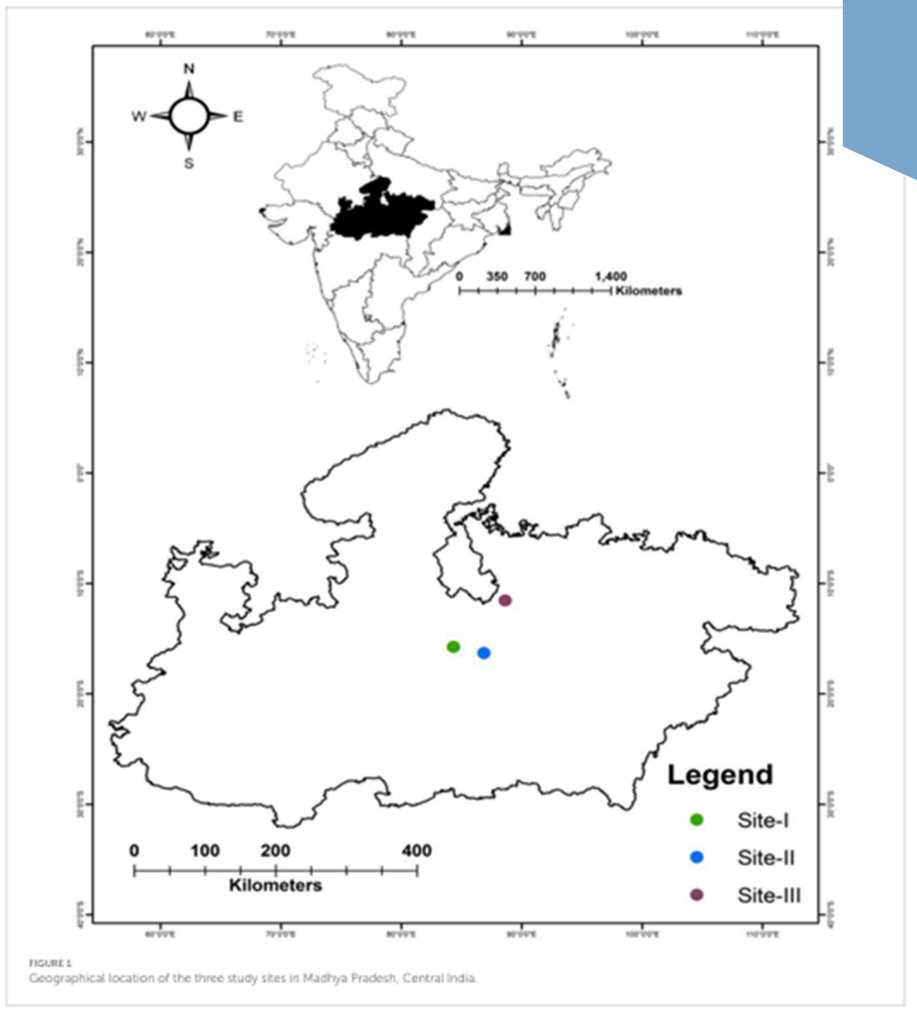


FIGURE 1
Geographical location of the three study sites in Madhya Pradesh, Central India.

BIOCHAR INSIGHT:

- 60 plots sampled: 30 invaded (>50% cover).
- Site III (Purple): Highest invasion – prioritize harvesting.