INDIGENOUS WISDOM IN ECOSYSTEM RESTORATION: MANAGING INVASIVE SPECIES

SOCIETAL PROJECT REPORT

Submitted to

Academy of Scientific and Innovative Research

AcSIR

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1. BACKGROUND

Invasive alien species (IAS) are globally recognised as a significant threat to biodiversity, ecosystem services, human livelihoods, health, and regional economies (Kumar Arya *et al.*, 2021; Premakumari *et al.*, 2022). These species, introduced outside their native distribution either deliberately or inadvertently, can become problematic by establishing themselves, invading, out-competing native species, and transforming new environments (Wehi *et al.*, 2023). The ecological effects of exotic species have been observed across all habitats, leading to biodiversity loss, including species extinctions, and alterations in hydrology and ecological function (Asner *et al.*, 2006; Field *et al.*, 2007). Emerging research continues to highlight that invasive species can also influence climate systems at both regional and global scales. For instance, certain invasive plants expedite nitrogen and CO2 deposition, leading to heightened levels in earth systems, consequently contributing to global warming. This, in turn, results in alterations to regional and global precipitation patterns (Vilà *et al.*, 2011).

Biological invasions are intricately linked to both past and present human endeavors. The risk of introducing non-native species is escalating globally, propelled by the expansion of new and rapid transportation systems, which facilitate increased trade and tourism worldwide (Meyerson & Mooney, 2007). Presently, invasive alien species (IAS) are recognized as one of the foremost contributors to biodiversity loss and a key driver of global change (Sala *et al.*, 2000). However, despite their detrimental impacts, some IAS also hold economic value (Kendle & Rose, 2000). Generally, each instance of invasion results in some sector of society benefiting economically (Baskin, 2002).

Considering the potential socioeconomic significance of invasive alien species (IAS), it is imperative to take into account both ecological and social factors (Zavaleta *et al.*, 2001). Humans play various roles throughout the invasive process, acting as vectors for introductions (whether accidental or intentional), experiencing the consequences of IAS, and possessing the ability to make decisions regarding their management. Thus, IAS can be regarded as a socioeconomic challenge that necessitates solutions from the realms of economics and sociology (Perrings *et al.*, 2002).

On one hand, economic inquiry into biological invasions commenced nearly a decade ago, primarily focusing on quantifying the direct economic costs of IAS through ex-post assessments. However, these studies often have methodological deficiencies compared to their theoretical foundations (Born *et al.*, 2005). Consequently, while the economic aspects of IAS remain incompletely understood or documented, estimates suggest that the costs associated with damages, losses, and control measures amount to millions to billions of dollars annually (Pimentel *et al.*, 2005). This presents a dilemma for policymakers who strive to promote trade while minimizing the costs of IAS (Keller & Lodge, 2007).

On the other hand, public attitudes toward IAS have received relatively little attention, likely due to challenges in measuring social impacts and navigating conflicts among stakeholders. Nonetheless, recent years have witnessed increasing efforts to study public attitudes toward eradication and control management plans (Bremner & Park, 2007; Fraser, 2006; Simberloff, 2005). Additionally, some studies have explored different approaches to conducting IAS risk analysis and underscored the importance of involving diverse sectors of society in IAS management (Keller & Lodge, 2007; Simberloff, 2003). Despite these advancements, significant knowledge gaps persist regarding the prevention, control, eradication, and management of IAS. Therefore, there is an urgent need to enhance our understanding of IAS and societal perceptions toward them. Addressing these gaps remains a critical and pressing imperative.

Conventional approaches to managing IAS often focus on eradication, but this may not always be feasible or satisfactory due to factors such as efficacy, cost, ethics, and community perspectives. Increasingly, there is a recognition that assessing the socioeconomic and ecological impacts of IAS, both negative and positive, is an important step in their management (Wehi *et al.*, 2023). This study aims to explore how local, traditional, and indigenous knowledge can be harnessed for the management and utilisation of invasive plant species, beginning with a global overview and narrowing the focus to India, with particular emphasis on the state of Uttarakhand. This study builds on existing literature, along with field interviews conducted in Uttarakhand, to examine the role of indigenous knowledge and practices in the management of invasive species. It considers how local knowledge systems contribute to managing invasive plants, highlighting how communities in villages near Dehradun use and manage *Lantana camara* as part of their livelihoods, and assesses the current distribution of this species in the Bhagirathi basin to identify areas vulnerable to further spread.

1.1 Objectives of the Study

a. To review how indigenous and local knowledge systems are being used to manage invasive plant species in different ecological and cultural contexts.
b. To document, through case studies, how local communities in Uttarakhand utilize and manage *Lantana camara* for livelihoods and traditional practices.
c. To map where *Lantana camara* is currently found in the Bhagirathi basin and identify areas at risk of further spread.

2. METHODS

This study adopts a mixed-methods approach to understand the role of indigenous and local knowledge (ILK) in managing invasive plant species, with a focus on *Lantana camara* in Uttarakhand. The methods are structured around the three main objectives of the report.

2.1 Literature Review

A detailed review of peer-reviewed literature, grey literature, policy reports, and case studies was conducted to explore the use of indigenous knowledge in managing invasive plant species. The review covered both global and Indian examples, with emphasis on community-based practices, in ecosystem restoration strategies. Sources were identified using academic databases such as Google Scholar, Scopus, and Web of Science, along articles published in newspapers.

2.2 Field-Based Case Studies

This study employed a qualitative, exploratory research design aimed at documenting community knowledge, perceptions, and practices related to the use and management of *Lantana camara*. Given logistical and funding constraints, a case study approach was adopted to allow in-depth exploration of diverse perspectives within limited field sites.

Data were collected through semi-structured interviews, informal discussions, and field notes, supplemented by audio recordings where feasible. Interviews were conducted in Hindi and

English depending on respondent preference, and informed verbal consent was obtained. Notes and transcripts were thematically analysed to identify recurring patterns in perceptions, uses, and challenges associated with lantana management.

Three case studies were developed:

1. Institutional Perspective: An interview with a senior trainer from the Himalayan Environmental Studies and Conservation Organization (HESCO) provided insights into community-based interventions promoting lantana utilisation across Uttarakhand (including Dehradun, Tehri, Chamoli, and Pauri districts).
2. Household Livelihood Perspective: An in-depth interview with a craftsman from Lacchiwala village (Dehradun district) captured local experiences of using lantana for household needs, income generation, and community perceptions of sustainability.
3. Community Perceptions Across Districts: A purposive convenience sample of five adults (aged 27–48) was interviewed in Uttarkashi (Maneri, Bayana, Bhatwari), Kotdwar, and Dehradun during April–May 2024. These semi-structured interviews (10–20 minutes each) explored perceptions, ecological impacts, household uses, awareness of NGOs, and willingness to adopt training programmes.

Across all sites, respondents were selected purposively to capture variation in age, livelihood, and familiarity with lantana. Themes covered included:

- Historical spread and local perceptions of *Lantana camara*
- Traditional knowledge and household use
- Ecological and economic impacts
- Resource use practices and livelihood value
- NGO or institutional support and restoration efforts
- Willingness to adopt future interventions

Due to small sample sizes and reliance on convenience sampling, findings are not statistically representative but serve as illustrative narratives. The qualitative design prioritises depth over breadth, highlighting how institutional interventions, individual livelihood practices, and community-level perceptions differently shape the framing of *Lantana camara* as both an ecological challenge and a socio-economic resource.

2.3 Field Survey and Distribution Patterns for Species Distribution Modelling (SDM)

An extensive field survey was conducted across Uttarkashi and Tehri districts (2023–2025) to document the distribution of Lantana camara in the Bhagirathi River basin, covering elevations from 1,000 to 6,000 m a.s.l. Using the LOCUS GPS app, 450 georeferenced presence points were recorded with latitude, longitude, elevation, and habitat notes. Presence was confined to the 1,000–2,500 m belt, with detections declining above ~2,300 m and absent beyond 2,500 m, indicating that environmental stressors such as low temperatures, reduced precipitation suitability, and greater seasonality limit establishment at higher elevations. Records were cleaned by removing duplicates within 100 m, cross-checked against DEM data, and thinned to 1 km resolution before being exported for use in MaxEnt species distribution modelling. Thus, the SDM primarily reflects habitat suitability patterns within the 1,000–2,500 m elevation range where the species currently occurs.

To model the potential distribution of Lantana camara, a total of 19 bioclimatic variables, along with terrain variables (aspect, slope, elevation), were initially considered. Pearson correlation analysis was used to address multicollinearity, and only weakly correlated variables were retained for the final model. The selected predictors were: aspect, slope, precipitation seasonality (bio15), precipitation of the warmest quarter (bio18), mean diurnal temperature range (bio2), isothermality (bio3), and mean temperature of the driest quarter (bio9).

The Maxent algorithm (five bootstrap replicates) was applied, generating models under both current and future climate scenarios (ssp245 and ssp585 for 2081–2100).

3. REVIEW AND FINDINGS

3.1 Review of Indigenous and Local Knowledge Practices

3.1.1 Indigenous wisdom in ecosystem restoration: overview

Traditional knowledge, also referred to as Indigenous knowledge, traditional ecological knowledge (TEK), or local ecological knowledge, is gaining significant interest in research and development, particularly for its contribution to conservation and management (Berkes *et al.*, 2000; Huntington, 2011). This knowledge, developed over generations through sustained interactions between traditional peoples and ecosystems, offers a valuable foundation for ecological restoration. It is increasingly respected as a source of information that can inform scientific approaches to conservation, management, and sustainable use of natural resources (Uprety *et al.*, 2012).

The integration of TEK and scientific knowledge is crucial for successful ecological restoration, as it can contribute to adaptive management and address complex environmental issues (Higgs, 2005). TEK is often site-specific, place-based, and deeply linked to local social mechanisms, making it particularly applicable to restoration design (Berkes *et al.*, 2000). This holistic approach considers not only ecological processes but also cultural practices, societal values, and human well-being. Importantly, in the context of invasive species, traditional knowledge systems can inform sustainable control and utilization strategies, such as using invasive plants for fuel, fodder, or craft, thus turning a challenge into an opportunity for livelihood support and ecological balance (Uprety *et al.*, 2012).

3.1.2 Managing invasive species through indigenous and local knowledge: broader contexts and approaches

Indigenous communities worldwide have suffered from the spread of IAS, which impact their livelihoods and stewardship practices (Wehi *et al.*, 2023). This includes impacts on food sources and medicinal plants and can lead to negative economic consequences (Invasive Species Council of BC, 2011). For example, the Soliga Adivasis in Karnataka have been impacted by *Lantana camara*, which affects the regeneration of amla, an important non-timber forest product they rely on (Sundaram *et al.*, 2012). This particular IAS is considered a severe threat to the livelihoods of stakeholders proximal to its invasion. The dense understory created by lantana also exposes forest-dependent communities to increased encounters with large animals like elephants, leading to human-animal conflicts as herbivores may raid farmlands (Hariharan *et al.*, 2024). On a broader scale, IAS have caused the decline of forest health and treasured species in the Tuawhenua area due to logging and the presence of species like deer and possums (Wehi *et al.*, 2023).

Indigenous communities' responses to invasive species are diverse, ranging from eradication and mitigation to adaptation, where new species are integrated into cultural practices, food systems, or material uses (Ticktin *et al.*, 2006). Indigenous management frameworks do not necessarily default to eradication as a fundamental approach to alien species that are becoming invasive. Instead, they often focus on a finer texture of relationships among all species, including humans, within a given location and region (Wehi *et al.*, 2023).

One emerging approach is "management by utilisation," which involves harnessing the economic or cultural potential of invasive species to meet human needs while simultaneously controlling their spread. This strategy challenges the narrow conservation definitions of "native" and "alien" that often carry negative connotations, overlooking the complex relationships and potential benefits introduced species might offer (Raj & Syriac, 2016; Tabe-Ojong, 2023).

Invasive alien species, despite their ecological risks, can offer benefits such as food and medicine. Some were intentionally introduced for these purposes and have become valued resources, with communities finding ways to turn their negative impacts into useful opportunities (Premakumari *et al.*, 2022; Rahman & Roy, 2014; Roy *et al.*, 2023). The cultural adoption of uses for introduced species, however, can be extremely slow if not accompanied by significant human migrations, indicating that availability alone does not guarantee adoption (Branco *et al.*, 2023). Nevertheless, some species have become valued components of local socio-ecological systems. Himalayan blackberries, for instance, are harvested as a delicious food source in British Columbia, with communities maintaining controlled areas for their harvest (Invasive Species Council of BC, 2011). Similar patterns of local valuation and use can be observed in other invasive species, which are integrated into socio-ecological systems in diverse ways. The following sections illustrate these examples in detail.

i. *Lantana camara* (Wild sage), despite being among the world’s 100 worst invasive species, has found significant value in traditional medicine and rural livelihoods. Its leaves are used to treat cuts, ulcers, swellings, coughs, fevers, abdominal ailments, rheumatism, malaria, and even cancer. Decoctions and teas made from its leaves and flowers are traditional remedies for influenza and stomach issues, while its oil is applied externally for leprosy, scabies, and itching. Scientific research supports its potential in drug development, identifying bioactive compounds with antifilarial, antibacterial, antioxidant, anti-inflammatory, hepatoprotective, anticancer, and other therapeutic properties. Beyond medicinal uses, lantana provides economic opportunities through the production of low-cost, termite-resistant furniture, baskets, and handicrafts. It also serves as a substitute for firewood, a biofuel source, and a material for green manure, which improves soil fertility and prevents erosion. Its nectar-rich flowers support pollinators like butterflies and bees, while the fruits are consumed by birds. Additionally, its stalks are used in paper and pulp production and as natural hedges in rural landscape (Kumar *et al.*, 2022; Negi *et al.*, 2019; Raj & Syriac, 2016).

ii. *Prosopis juliflora* (Mesquite/Vilayati kikar) was introduced in countries like Kenya to address environmental challenges such as desertification, deforestation, and declining soil fertility. Its fast growth and resilience make it valuable for providing shade, windbreaks, fuelwood, construction material, and improving degraded lands. The tree's pods serve as a nutritious fodder source for livestock like goats and sheep and are sometimes consumed by humans during food shortages. Prosopis also supports beekeeping, as its flowers produce abundant nectar, and mature trees offer ideal sites for hanging traditional beehives. Being evergreen, it provides consistent shade, which helps moderate temperatures and protect beehives in arid and semi-arid regions (Tabe-Ojong, 2023).

iii. *Centaurea solstitialis* (yellow star-thistle), though widely recognized as an invasive weed across the Americas and Australia, has a long history of traditional use in its native Eurasian range. It has been used medicinally to treat respiratory and digestive ailments, skin conditions, eye disorders, viral and protozoan infections, and kidney stones. It also serves as an antipyretic, stomach tonic, and diuretic. These traditional uses are supported by pharmacological studies highlighting its antiviral, antimicrobial, antioxidant, and anticancer properties. The plant is also used as a raw material, its stems for making brooms in Turkey and is consumed as food in several countries, either boiled, added to soups, or fried with eggs. Dried aerial parts are commonly fed to livestock in winter. Notably, *Centaurea solstitialis* is a major nectar source for honey production. In introduced regions like California, Argentina, and Australia, where it forms dense monocultures, it has gained economic value through apiculture, with honey yields in California alone once valued at up to $200,000 annually. The plant's rich chemical profile comprising sesquiterpene lactones, flavonoids, and other bioactive compounds offers potential for future ethnobotanical and pharmacological exploration, especially as some compounds may be more concentrated in its non-native ranges (Branco *et al.*, 2023).

Indigenous relational frameworks offer a pluralistic perspective that recognizes nuanced relationships with introduced species. Rather than using binary classifications, these approaches encourage a deeper inquiry into the origins, impacts, and potential contributions of new species, prompting questions such as: Where did this species come from? How did it arrive here? What effects is it having on the local system? And can it offer any value or be integrated into the community? This relationship-centred perspective can help identify which introduced species are deemed "invasive" and how to interact with useful ones, offering a path towards vibrant futures where all elements of society, including those in the natural world, can flourish (Wehi *et al.*, 2023).

3.1.3 The Indian Scenario: Key Invasive Plants and Local Adaptations

India's diverse ecosystems are significantly impacted by IAS, with 169 invasive alien species documented across terrestrial, aquatic, agriculture, and island ecosystems. While research on IAS in India has increased since 2000, there is a noted lack of a comprehensive national database, with most studies being local and species-specific (Kumar Arya *et al.*, 2021; Sandilyan *et al.*, 2019). Although invasive plants often have negative impacts, local communities have developed adaptive strategies for their management and use (Hariharan *et al.*, 2024; Negi *et al.*, 2019; Premakumari *et al.*, 2022), as shown in the examples below.

i. *Lantana camara* (Lantana) listed among the world's 100 most invasive species and one of the 10 worst weeds, has aggressively spread across India, occupying approximately 13.2 million hectares of dry to moist forests, pasturelands, and culturable wastelands (Negi *et al.*, 2019; Sharma *et al.*, 2005). Its rapid growth, chemical interference with native plants (allelopathy), resistance to control methods like cutting and burning, and prolific reproduction make it a highly persistent invader (Negi *et al.*, 2019; R. Raj *et al.*, 2018). Ecologically, lantana reduces biodiversity, disrupts fire regimes, increases competition for forage among herbivores, and may lower wildlife densities (Hariharan *et al.*, 2024). Socio-economically, it diminishes access to non-timber forest products, heightens human-wildlife conflict in forest fringe areas, and contributes to rising conservation costs (Sundaram & Hiremath, 2012). The dense thickets can also provide shelter to wild boars, leading to crop damage and threats to local communities. In agricultural contexts, such as the Gangetic plains of central Nepal, it is particularly problematic due to its lack of fodder value and interference with productive land use (Negi *et al.*, 2019). Despite these negative impacts, local communities and researchers have explored its potential for utilisation:

- Furniture and Handicrafts: Lantana stems are tough and durable, making them suitable for furniture and handicrafts, resembling cane furniture but at a lower cost (Architectural Digest, 2022).
- The Soliga Adivasis of Karnataka use lantana in wickerwork as a substitute for scarce and costly bamboo, generating livelihoods and aiding ecosystem recovery (Raj *et al.*, 2018; Figure 1).
- Irula tribal community in Tamil Nadu (e.g., Sengattiyur Irula tribal village, Coimbatore) is trained to make furniture, handicrafts, and toys from lantana wood, improving their livelihoods (Gaon Connection, 2023).
- Similar initiatives have been proposed and implemented in areas like Mudumalai Tiger Reserve and Sathyamangalam Tiger Reserve (Kumar *et al.*, 2022).
- Biofuel and Firewood: Lantana biomass has potential for bioethanol production and is used as firewood in some Himalayan Mountain villages, accounting for about 20% of total firewood consumption (Hariharan *et al.*, 2024).
- Lantana sticks are used for making baskets for packing and transporting vegetables (Raj & Syriac, 2016).
- Leafy twigs are placed at the bottom of grain containers to deter termites, mice, and other insects (Raj *et al.*, 2018).
- The plant provides shelter and winter food for many birds and is a major nectar source for butterflies and moths (Negi *et al.*, 2019).
- Leaves have been used to make excellent mosquito repellents and incense sticks (Kumar *et al.*, 2022).

Figure 1. Soliga tribal community at MM Hills utilizing invasive Lantana to craft furniture and wicker products. (Photo Credit: Bhagya Prakash K)

ii. *Eichhornia crassipes* (Water Hyacinth) is a highly problematic aquatic invasive species, particularly in regions like Assam, where it has overrun vast stretches of water bodies (Raj *et al.*, 2018; Raj & Syriac, 2016; Figure 2). Its rapid proliferation leads to the formation of dense mats that choke freshwater ecosystems by blocking sunlight, thereby hindering aquatic plant growth and reducing fish populations. Ecologically, this disrupts the balance of native aquatic life (Antony & Aishwariya, 2021). Socio-economically, the weed creates breeding grounds for mosquitoes and disease-causing pathogens, impedes the movement of passenger boats and houseboats, damages boat engines, and severely affects fishing activities (ChangeStarted, 2025). In areas like Kuttanad, Kerala, managing water hyacinth is both labor-intensive and costly, resulting in significant financial losses for local farmers (Premakumari *et al.*, 2022). Attempts at control using physical, mechanical, chemical, and biological methods have often failed, and the problem has multiplied over the years. Despite its harmful impacts, water hyacinth offers several utilisation opportunities:

- Papermaking: It is a lignin-poor plant, with over 85% cellulose and hemicellulose, making it a strong candidate for papermaking (Raj & Syriac, 2016).
- Kumbhi Kagaz in Assam successfully produces handmade paper from water hyacinth biomass (ChangeStarted, 2025; Figure 3).
- Residents in Kottapuram, Kerala, have innovatively used the weed to create jobs for underprivileged women by making value-added products (Premakumari *et al.*, 2022).
- Handicrafts: Local artisans make bags and handicraft items from dried water hyacinths (Antony & Aishwariya, 2021).
- Biofuel: It can be converted into briquettes for energy production (Raj *et al.*, 2018).
- Traditional Medicine: It has traditional medicinal uses in regions like Chhattisgarh, India (Antony & Aishwariya, 2021).
- Mushroom Cultivation: It has been used as a substrate for oyster mushroom cultivation, though with lower bioconversion than wheat straw (Raj & Syriac, 2016).

Figure 2. Water hyacinth, popularly known as the 'Terror of Bengal,' densely covers waterbodies in Assam, severely disrupting aquatic ecosystems. (Image source: The Better India)

Figure 3. Handmade products made from Kumbhi Kagaz paper — tree-free, chemical-free, and created using water hyacinth pulp. (Image source: The Better India)

iii. *Mikania micrantha* (Mile-a-minute weed) introduced in West Bengal in the early 20th century and reportedly used in Assam to camouflage airstrips during World War II, has since become a serious economic and ecological threat. Ecologically, it alters soil microbial communities and chemical properties—raising soil pH, nitrogen, and phosphorus levels while depleting organic matter. Its strong allelopathic properties negatively affect surrounding crops, native plants, insects, and even pathogens. Agriculturally, *Mikania* poses a major risk to tea, pineapple, banana, ginger, acacia, and rubber plantations (Sandilyan *et al.*, 2019).

Despite its status as a problematic perennial weed causing significant economic losses in various ecosystems and crops, *Mikania micrantha* is subject to various local and indigenous utilisation practices in India, which can be interpreted as adaptive strategies for engagement with the invasive plant. For example, in Kerala, India, *M. micrantha* is used as fodder for sheep and other cattle, particularly during the summer when other fodder options are limited. Indigenous communities, such as the Kabi tribes in Assam, apply the leaf juice of Mikania as an antidote for insect bites and scorpion stings, and its leaves are also traditionally used to treat stomach aches. Furthermore, there are reports from Northeastern India regarding the plant's antibacterial effects and its efficacy in wound healing within traditional medicine. In Mizoram, India, Mikania has been utilised to produce green manure, which has reportedly led to an increase in rice yield. It is noted, however, that these local benefits and uses in India and other countries are not yet scientifically supported (Bora *et al.*, 2023).

iv. *Parthenium hysterophorus* (Parthenium), an aggressive invasive weed, is considered particularly harmful in the Gangetic plain of central Nepal due to its lack of fodder value and adverse ecological effects (Vishwakarma, 2019). Believed to have entered India from Mexico with wheat consignments in the 1950s, it rapidly colonized landscapes, especially along railway tracks (Sandilyan *et al.*, 2019). Its health impacts are severe: the pollen can cause pollenosis and asthma, and nervous disorders have also been reported (Oli & Bohara, 2023; Vishwakarma, 2019). While early mechanical and chemical control measures proved largely ineffective, biological control using agents like *Zygogramma bicolorata* (Mexican beetle) has shown mixed success, with climatic limitations and concerns about non-target effects, such as potential impacts on crops like sunflower posing additional challenges (Sandilyan *et al.*, 2019).

Despite its reputation as a harmful invasive weed, Parthenium possesses several economic applications by providing various utilisation opportunities for local communities. When uprooted before flowering and buried, it can be transformed into superior quality organic manure which is significantly richer in nitrogen, phosphorus, and potassium than traditional farmyard manure (FYM). This composting process not only aids in the eradication of the weed but also provides a valuable resource for enhanced crop production, potentially substituting synthetic chemical fertilisers and serving as a source of employment and income for villagers (Bhoyar *et al.*, 2014). When used as green manure, Parthenium has been shown to increase the height of rice plants, yield of grains and straw, enhance maize growth, and can potentially reduce the need for chemical fertilisers by approximately 25% (Oli & Bohara, 2023). Its insecticidal properties, attributed to compounds like parthenin, allow extracts from the plant to effectively control pests such as mustard aphids, offering a way to reduce reliance on synthetic pesticides for crops like *Brassica juncea*, potato, and okra. Furthermore, Parthenium can be managed through vermicomposting to create a value-added organic fertiliser, improving nutrient quality and remarkably decreasing phenolic components and heavy metals, making it suitable for organic farming. The dense growth of the weed can also be utilised as mulching material in agriculture to conserve soil moisture, reduce weed growth, prevent erosion, and increase crop yields, as demonstrated in soybean cultivation. Its biomass holds potential for biochar preparation, which, when incorporated into soil, increases microbial biomass and improves soil quality for crops like Zea mays. Lastly, Parthenium has demonstrated potential in phyto-remediation due to its ability to absorb and accumulate heavy metals from contaminated soils (Bhoyar *et al.*, 2014; Oli & Bohara, 2023; Vishwakarma, 2019).

v. *Prosopis juliflora* (Mesquite), a leguminous tree introduced into the arid and semi-arid lands (ASALs) of countries like Kenya to combat desertification, deforestation, and improve soil fertility, has rapidly turned into one of the most problematic invasive species. Its unchecked spread has led to severe ecological and socio-economic impacts. It reduces the availability of farm and pastureland by forming dense thickets, suppresses native vegetation through allelopathic effects, increases the risk of flooding, and poses dangers to livestock, often causing injuries or even death due to its thorny branches. These effects have significantly affected smallholder farmers, further deepening welfare challenges in already vulnerable communities (Tabe-Ojong, 2023).

Despite its adverse effects, *Prosopis juliflora* has become deeply integrated into the economic and indigenous practices of local communities, offering a "management by utilization" strategy. Traditionally, it has been harvested as a fuel for domestic use and small-scale businesses, and recognised as a "tree for the poor" and an important income source for poor inhabitants in India's semi-arid zones. Its pods serve as nutritious fodder for livestock, particularly goats and sheep. The tree's wood is extensively used for firewood and charcoal production, creating vital income opportunities through the sale of woody biomass (Tabe-Ojong, 2023; Figure 4).

Figure 4. *Prosopis juliflora* – The wood of this invasive tree is widely used for firewood and charcoal production (Image source: IndiaMART)

Furthermore, in regions like Tamil Nadu, the establishment of biomass power plants since 2003 has created a new and significant demand for Prosopis wood as an energy source, leading to a rapid increase in its price and compensating for declines in agricultural cropping, thereby boosting net household income for landless labourers and middle-class landholders (Sato, 2013). The tree's sweet nectar supports beekeeping, and its evergreen canopy provides valuable shade for hives in hot, dry climates. Beyond these uses, local communities in Banni also utilise *Prosopis juliflora* for construction material, fencing, tools, and for medicinal and religious purposes (Ravi & Krishnan, 2024). This diverse range of uses highlights its crucial role in rural livelihoods, especially in water-scarce regions.

3.2 Uttarakhand Case Studies: Local knowledge and livelihoods around *Lantana camara*

Among the many invasive species in India, *Lantana camara* was selected as the focal species for this study due to its widespread ecological and socio-economic impact across the Indian Himalayan Region, especially in Uttarakhand (Negi *et al.*, 2019). Having invaded millions of hectares of forest and agricultural land, lantana is notorious for displacing native vegetation and reducing biodiversity (Sharma *et al.*, 2005). Yet, paradoxically, it also offers a unique opportunity: in various parts of India, including Uttarakhand, communities have developed adaptive and economically beneficial uses for the plant (Kumar *et al.*, 2022). This dual nature, being both a serious ecological threat and a potential livelihood resource, makes lantana a compelling case for examining how indigenous knowledge contributes to ecosystem restoration through locally grounded management and utilisation strategies (Sandilyan *et al.*, 2019).

Beyond anecdotal accounts, scientific literature has begun to acknowledge lantana's value-added potential (Negi *et al.*, 2019; Premakumari *et al.*, 2022; Raj & Syriac, 2016). Studies from the Forest Research Institute, Dehradun, have explored its applications in livestock feed and fodder (Kumar *et al.*, 2022). Communities in Uttarakhand and Himachal Pradesh craft their stems into durable, eco-friendly products such as baskets, foot mats, and pen cases (Negi *et al.*, 2019). These practices, often supported by NGOs like the Himalayan Environmental Studies and Conservation Organization (HESCO), highlight the role of traditional knowledge and grassroots innovation in transforming an ecological challenge into a socio-economic asset (Raj *et al.*, 2018). Building on these community-driven approaches, the following case studies illustrate how invasive species can be managed and utilized in ways that support both local livelihoods and ecosystem restoration.

3.2.1 Case Study 1: Community-Based Lantana Management – HESCO Initiative

In 2002, the Himalayan Environmental Studies and Conservation Organization (HESCO) under the leadership of Dr. Anil Joshi, initiated an innovative program in the Lachhiwala village to manage the invasive species *Lantana camara* by promoting its sustainable use within the local community. Instead of allowing this aggressive shrub to degrade forests and farmlands, local communities were trained to convert lantana into useful products such as furniture, baskets, handicrafts, and fencing material, thereby turning an ecological challenge into a livelihood opportunity. This initiative not only helped reduce the spread of lantana but also empowered the community by providing alternative income sources, enhancing self-reliance, and fostering a sense of stewardship toward their surrounding environment.

During a field interaction, Mr. Prem Khandelwal, a senior HESCO trainer with over two decades of experience in community-based conservation and livelihood generation, explained how these initiatives have been implemented across Uttarakhand, including Dehradun, Tehri, Chamoli, and Pauri districts. Over the years, he has trained hundreds of villagers to convert *Lantana camara* wood into durable furniture, dustbins, and handicraft items (Figure 5), providing sustainable livelihood options while simultaneously reducing pressure on natural forests. His training sessions emphasize not only craftsmanship but also the ecological benefits of utilizing an invasive species for constructive purposes.

Figure 5. Furniture, dustbins, and handicraft items prepared by HESCO during their *Lantana camara* management training

Mr. Khandelwal also described the development of briquettes from lantana leaves through the pyrolysis process, a technology he has been promoting with HESCO since 2005.

These briquettes, now adopted in several villages, serve as a clean and renewable substitute for charcoal, reducing household dependence on unsustainable energy sources. Additionally, HESCO organizes training sessions for college students and young learners from Dehradun and nearby areas to raise awareness about the ecological impacts of invasive species and provides hands-on training on the practical utility of *Lantana camara*. According to Mr. Khandelwal, these interventions have effectively transformed the invasive *species* from a serious ecological threat into a valued livelihood resource.

3.2.2 Case Study 2: Use and Management of *Lantana camara* in Lacchiwala, Dehradun

This case study focuses on the experiences of Mr. Vijap Pal Singh, a 50-year-old craftsman from Lacchiwala village near Dehradun. The interview aimed to understand how local communities perceive, use, and manage *Lantana camara* within their daily lives and livelihoods.

Community Perceptions and Ecological Impacts: Mr. Singh recalled that lantana spread noticeably in the area around 1985. While its spread has altered cropland ecology, his overall perception of the species is positive, largely due to its livelihood contributions. Community perceptions reflect a balance between recognizing ecological drawbacks, such as cropland encroachment, and the opportunities the species provides.

Resource Use and Economic Value: Lantana is harvested in an unsystematic manner, yet villagers have developed multiple uses for the plant. Mr. Singh uses it for firewood, furniture, and craft production, with firewood being the primary household use. Income from lantana-based products can exceed ₹10,000 per month, highlighting its role as a supplementary livelihood resource. However, the broader community views its economic value as moderate due to limited market access and small-scale production.

Institutional Support and Restoration Efforts: Institutional support from organizations like HESCO has included training on removal and alternative uses. Mr. Singh found the removal projects to be very effective and the training moderately useful. Nevertheless, challenges remain in ensuring consistent benefits, particularly in marketing products and sustaining labour availability.

Sustainability and Future Prospects: Mr. Singh believes that lantana use is sustainable in the long term if market and institutional support improve. With better access to markets and resources, the community could transform *Lantana camara* from a destructive invasive species into a sustainable livelihood opportunity. This case illustrates how indigenous knowledge and adaptive practices allow communities to reframe lantana from an ecological challenge to a socio-economic resource, though market and policy gaps currently limit its full potential.

3.2.3 Case Study 3: People's Perceptions of *Lantana camara* in Uttarkashi, Dehradun, and Kotdwar

Unlike Lacchiwala, where NGO interventions structured community use of *Lantana camara*, perspectives from other regions of Uttarakhand present a different reality. To capture this diversity, household questionnaires were conducted in three villages of Uttarkashi district (Maneri, Bayana, Bhatwari), in Dehradun, and in Kotdwar in the foothills. These responses reveal contrasting perceptions, limited household uses, and low awareness of institutional programmes.

Individual Responses

- Vinod Rana (Maneri, 43, trek guide and farmer): First noticed lantana in 1990, observed its spread into croplands. Neutral perception, reluctant use as firewood, no income, no awareness of NGOs, but open to training if profitable.
- Tirthan Singh (Bayana, 33, professional trekker): Reported lantana spread since 1994, used only for firewood, no recognised value, no NGO involvement. Stressed the need for knowledge before considering its utility.
- Uttam Rana (Bhatwari, 48, driver): Saw lantana expansion since 1989, recognised cropland impacts, uses it as firewood, unaware of removal or NGO efforts. Willing to engage if training opportunities arise.

- Anuj Joshi (Dehradun, 27, researcher): First noticed lantana in 1994, acknowledged its spread into croplands. Uses it only as firewood, never earned income, unaware of NGOs or training. Views community knowledge as low but expressed readiness to adopt alternatives if profitable.
- Udita Rawat (Kotdwar, 40, business owner): First noticed lantana around 2000, identified its use in temples and for aesthetics, but was uncertain about ecological impacts. No NGO support reported, though willing to adopt profitable uses if introduced.

Interpretation

Across Uttarkashi and Dehradun, respondents consistently described lantana as a spreading invasive with negative effects on croplands and very limited household value, restricted to reluctant firewood use. None reported income generation, NGO involvement, or training opportunities. Community knowledge was described as low, yet there was a clear willingness to engage in new livelihood uses if linked to training and markets. Kotdwar presented a slightly different perspective, with lantana recognised for cultural and aesthetic uses, particularly in temples, even in the absence of formal projects.

Comparative Insight

Taken together, these findings contrast sharply with the Lacchiwala case. Whereas HESCO's intervention enabled lantana to be reframed as a socio-economic resource, the Uttarkashi and Dehradun sites highlight underutilisation and limited awareness, while Kotdwar suggests pathways of cultural adaptation. These comparisons underscore the uneven distribution of knowledge and opportunity across Uttarakhand, revealing both the transformative potential of institutional support and the untapped possibilities in regions yet to benefit from such initiatives.

3.3 Current Distribution and Risk Assessment of *Lantana camara* in the Bhagirathi Basin

The species distribution models for *Lantana camara* exhibited high predictive accuracy, with AUC values of 0.977 (ssp245) and 0.979 (ssp585), indicating a strong ability to distinguish areas of presence from background locations. Omission–commission analyses further confirmed the reliability of the models. Based on these predictions, maps were generated to illustrate the current distribution of *Lantana camara* across the Bhagirathi basin and to identify regions at risk of further spread.

3.3.1 Variable Contributions

The most influential predictors across scenarios were bio9 (mean temperature of the driest quarter) and bio15 (precipitation seasonality).

- In the ssp245 scenario, bio15 (34.3% contribution, 38.1% permutation importance) and bio9 (29.8%, 42.6%) were the dominant drivers.
- In the ssp585 scenario, bio9 (39% contribution, 51.3% permutation importance) was the most important, followed by bio15 (29.2%, 28.2%).

Other variables (bio2, bio3, bio18, aspect, slope) contributed moderately to marginally, highlighting that seasonal climatic extremes are the primary determinants of habitat suitability for *Lantana camara* in the basin.

3.3.2 Current and Future Projections

The present-day distribution models were consistent with field observations, predicting high suitability across the lower and mid-elevation zones (1000–2500 m) (Figure 1a).

- Under **ssp245 (stabilization pathway)**, projections indicated a moderate expansion of suitable areas, with most habitats below 2500 m continuing to remain highly suitable and some upslope expansion into marginally higher elevations (Figure 1b).
- Under **ssp585 (high-emission pathway)**, suitability expanded substantially, suggesting significant potential for invasion into new areas by the end of the century. This reflects the species' ability to capitalize on warmer and more variable climates under high greenhouse gas emissions (Figure 1 c).

The combined field and modelling results clearly indicate that the distribution of *Lantana camara* in the lower Bhagirathi River basin is concentrated below 2500 m, where climatic and ecological conditions are favorable for its growth. Above this elevation, strong environmental filters (low temperatures, moisture limitations, and steep gradients in seasonality) restrict its establishment.

The SDM results highlight that climate change is likely to facilitate further spread of *Lantana camara*, particularly under high-emission scenarios (ssp585), with precipitation seasonality and temperature extremes as the main climatic drivers. These findings underscore the urgent need for targeted management interventions in mid-elevation forests, which are projected to become increasingly vulnerable to invasion in the coming decades.

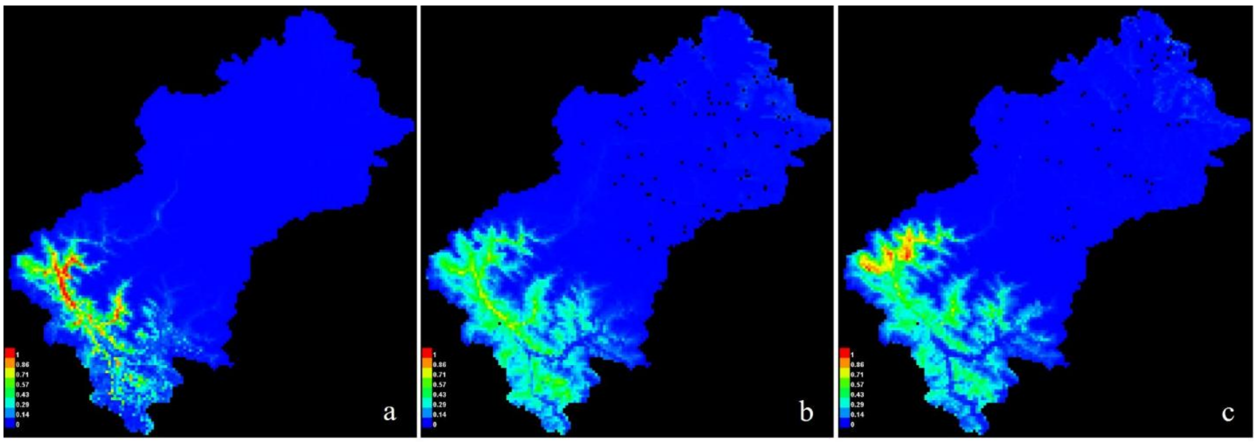

Figure 2 Present and projected habitat suitability for *Lantana camara* in the Bhagirathi River basin, Uttarakhand. (a) Present-day distribution showing high suitability across the lower and mid-elevation zones (1000–2500 m). (b) Future projection under the ssp245 (2081–2100, stabilization pathway), indicating moderate expansion of suitable areas with upslope spread into higher elevations. (c) Future projection under the ssp585 (2081–2100, high-emission pathway), showing substantial expansion of suitability, highlighting increased invasion potential under warmer and more variable climates.

4. CHALLENGES, OPPORTUNITIES AND SAFETY CONSIDERATIONS FOR INTEGRATING INDIGENOUS AND LOCAL KNOWLEDGE

Integrating traditional knowledge with scientific approaches in ecological restoration and IAS management presents both challenges and opportunities (Kumar Arya *et al.*, 2021; Sundaram *et al.*, 2012; Uprety *et al.*, 2012):

4.1 Challenges

- Scientific Skepticism: Some scientists remain reluctant to use TEK, and there is ongoing debate on how the two knowledge types can be effectively integrated.

- Accessibility and Documentation: Relevant TEK can be difficult for researchers to access due to cultural, communication, and language barriers. While historical documents and artefacts offer some information, informal interviews and group discussions are primary methods, which raise questions about interviewee selection and data weighting.
- Ownership and Legitimacy: Concerns exist among TEK proponents about the incorporation of TEK into science without it being considered on its own grounds or without recognising the Indigenous people who are its bearers.
- Policy Gaps: Policy formulation is often driven by scientifically trained individuals, who may be unaware of relevant traditional knowledge, and there is a lack of strategies to incorporate TEK into state-driven restoration programs. India also lacks a comprehensive database on IAS.

4.2 Opportunities

- Holistic Understanding: ILK offers a deeper, more nuanced understanding of ecosystem dynamics and the long-term impacts of invasions, often complementing the immediate effects typically studied by science.
- Adaptive Management: TEK systems, with their emphasis on feedback learning and treatment of uncertainty, are analogous to adaptive management and can contribute to flexible, site-specific solutions.
- Community Engagement and Partnerships: Involving local communities and their traditional knowledge is essential for successful restoration, leading to strong partnerships, increased social acceptability, and facilitated activities. This also promotes early conflict resolution among stakeholders.
- Cost-Effectiveness: Traditional monitoring methods are often rapid, low-cost, and easily comprehensible, providing timely information for planning and assessing restoration outcomes.
- Livelihood Generation: Utilising invasive species for economic purposes (e.g., handicrafts, biofuel, medicinal products) can provide alternative livelihoods for local communities, turning a problem into a resource.

- Biodiversity Conservation: Integrating ILK can lead to better species selection for restoration plantations and effective control strategies for alien invasive species, thereby improving biological diversity and ecosystem integrity.

4.3 Risks and Hazards Associated with Toxic Invasive Alien Species

While Indigenous knowledge and community-based strategies provide valuable pathways for managing and utilizing IAS, particularly through turning ecological challenges into socio-economic assets, the inherent dangers posed by certain toxic species necessitate strict precautions and safety protocols during processing, handling, and control efforts. IAS pose a significant threat to human health globally, potentially affecting health through direct exposure, serving as disease vectors, or transferring toxins via edibles (Premakumari *et al.*, 2022; Raj *et al.*, 2018). The risks associated with handling or processing different invasive alien plants can be broadly categorised based on the mechanism of harm (Invasive Species Council of BC., 2011; Premakumari *et al.*, 2022).

a) **Direct Contact Toxins and Physical Hazards**: Several invasive species can cause harm through direct physical contact or exposure to their chemical compounds. These effects may include skin irritation, allergic reactions, burns, or injuries from physical structures such as spines and sharp edges. For example:

- Giant hogweed (*Heracleum mantegazzianum*): Produces substances that cause severe skin burns, blisters, and long-term scarring.
- Tree of heaven (*Ailanthus altissima*): Sap can cause myocarditis upon direct skin contact.
- Congress grass (*Parthenium hysterophorus*): Pollen causes pollenosis and is harmful to people with asthma; roots may exude chemicals affecting the nervous system.
- Prickly Pear (*Opuntia stricta*): Sharp glochids can cause eye irritation.
- Sharp-edged plants (e.g., *Senecio inaequidens*, *Cortaderia selloana*, *Spartina anglica*, *Caesalpinia decapetala*, *Rosa rugosa*): Can cause skin cuts and injuries due to sharp edges and silicate crystal depositions on leaves.

b) **Ingestion Toxins (Poisoning):** Some species, if ingested by humans or livestock, can cause severe health issues or death. For example:

- Tansy ragwort (*Senecio jacobaea*): Contains alkaloids toxic to deer, cattle, pigs, horses, and goats which can cause cumulative liver damage.
- Bittersweet nightshade (*Solanum dulcamara*) and spurge laurel (*Daphne laureola*): Berries are poisonous.
- Common rhododendron (*Rhododendron ponticum*): Grayanotoxins can contaminate honey, posing a hazard to humans.

4.4 Necessary Precautions for IAS Processing and Management

To safeguard human health, livestock, and the environment during the removal or utilization of toxic IAS, careful preparation, safety gear, and specific knowledge are essential.

a) Safety During Handling and Manual Removal

- **Protective Gear**: When dealing with plants known to cause contact burns or irritation (e.g., Giant hogweed or plants with sharp parts), workers must wear appropriate personal protective equipment (PPE), including long sleeves, gloves, eye protection, and potentially respiratory masks, particularly when handling allergenic pollens or dust (Invasive Species Council of BC., 2011; Premakumari *et al.*, 2022).
- **Physical Control Methods**: When using physical or mechanical removal (which is often preferred over chemicals in complex ecosystems), caution is needed (Hariharan *et al.*, 2024). For example, uprooting is a simple method for initial stage management of weeds like *Parthenium*, but this must be done safely (Sandilyan *et al.*, 2019).
- **Training and Expertise**: Indigenous communities should be supported with Pesticide Applicator Training or other specialised invasive species training to ensure safe handling practices and proper application of control methods, especially if herbicides are integrated into management plans (Invasive Species Council of BC., 2011).

b) Precautions in Utilization and Consumption

- **Food Safety Screening**: The utilization of IAS for livelihoods (e.g., crafts, biofuel, charcoal production) must be rigorously separated from consumption where toxicity is a risk, and any IAS considered for food, fodder, or medicinal use must first undergo thorough research and safety screening to distinguish harmful species from harmless ones (Ravi & Krishnan, 2024; Rahman, 2014). This is critical for species like *Lantana camara*, which has ethno-medicinal uses, but can also host disease vectors (Premakumari *et al.*, 2022).
- **Product Contamination**: If utilizing species that are known toxins or allergen producers (e.g., Parthenium), processing methods must mitigate risk. For instance, when processing IAS for biomass or compost, measures like anaerobic digestion must be assessed for potential inhibition or toxin residues to ensure safe end-products (Sandilyan et al 2019).
- **Honey Production**: Specific vigilance is required in beekeeping areas infested with toxic plants like *Rhododendron ponticum* to prevent the contamination of honey with hazardous toxins (Premakumari *et al.*, 2022).

c) Managing Control Methods (Chemical and Biological)

- **Chemical Control** (Herbicides): Chemical sprays should generally be avoided in sensitive areas, as they can harm other useful plants. In cases where they are necessary, plans must include measures to clarify and diminish safety concerns such as the fear of water supply contamination (Caceres-Escobar *et al.*, 2019).
- **Biocontrol Agent Safety**: The implementation of biological control agents requires stringent protocols and testing. Imported agents must be rigorously checked to ensure they are hazard-free (e.g., they do not produce toxic scales or dust that could harm humans) and that they are strictly host-specific. The risk of biocontrol agents becoming pests themselves must be carefully managed (Sandilyan et al 2019).

d) Post-Management Disposal:

- **Handling and Disposal of Toxic or Contaminated IAS Material:** IAS biomass removed from sites may still contain toxins or viable seeds/reproductive parts. Protocols, potentially referencing local guidelines such as the British Columbia First Nations Fill Management Guide (which addresses managing invasive species spread through soil fill), should be followed for safe disposal of toxic materials and contaminated soil, such as via designated landfills (Invasive Species Council of BC., 2011).

5. CONCLUSION AND RECOMMENDATIONS

This project highlights that Indigenous wisdom offers invaluable contributions to ecosystem restoration and the management of invasive species. Traditional and local communities, through generations of interaction with their environment, have developed knowledge systems and adaptive practices that can complement and enhance scientific approaches. In India, despite the severe ecological and socio-economic impacts of invasive plants such as *Lantana camara*, *Eichhornia crassipes*, and *Prosopis juliflora*, communities have demonstrated remarkable ingenuity in transforming them into livelihood resources, medicinal substitutes, and everyday utilities. The example of Lacchiwala village in Uttarakhand illustrates this potential clearly, where households were able to convert *Lantana camara* into furniture, handicrafts, and fuel. With targeted training and market access provided by organisations such as HESCO, this ecological threat was transformed into a sustainable economic opportunity.

By contrast, in other areas such as Uttarkashi, Dehradun, and Kotdwar, *Lantana* remains largely perceived as a nuisance spreading into croplands. Here, its use is restricted to firewood, and awareness of value-addition initiatives is limited. These differences highlight the transformative role of institutional support. Where communities receive training, resources, and market linkages, invasive species can be reframed as opportunities, whereas in the absence of such support, they remain ecological burdens.

Ecological findings reinforce this dual picture. Across the Bhagirathi basin, *Lantana* was recorded only between 1,000 and 2,500 m, declining sharply above 2,300 m and absent beyond 2,500 m. Species distribution models suggest that this elevational belt will remain highly suitable under future climates, with potential expansion into higher zones under high-emission scenarios. Together, these results reveal both the social constraints and ecological risks posed by *Lantana* in Uttarakhand, underscoring the need for proactive, community-driven management.

The way forward must therefore integrate ecological realities with social opportunities. Pilot projects in mid-elevation forests should combine skill development with reliable market linkages, ensuring that utilisation contributes to reducing spread rather than incentivising it. Participatory monitoring and locally led decision-making are essential, with indigenous knowledge recognised as a complement to scientific expertise.

While the socio-economic component of this study was based on a modest sample and self-reported accounts, the ecological survey generated robust presence records across the basin, providing a reliable basis for species distribution modelling and future projections. The findings highlight the urgent need for larger social surveys, cost–benefit analyses of *Lantana* and other invasive species (e.g., *Ageratina adenophora*, *Ageratum conyzoides*, *Parthenium hysterophorus*, *Eichhornia crassipes*), and long-term assessments of training and value-chain programmes. Regularly updating ecological models with new field records will also be crucial. With such integrated approaches, invasive species management in India can move beyond control-focused interventions, simultaneously safeguarding biodiversity and creating sustainable livelihood opportunities.

To foster a more effective and sustainable approach to managing invasive species in India, the following recommendations are put forward:

1. *Integrate Traditional and Scientific Knowledge*: Promote multidisciplinary research that combines Indigenous ecological knowledge with scientific understanding, valuing both systems equally.
2. *Support Community-Based Management*: Recognise and empower Indigenous Peoples and local communities as key stakeholders in IAS management, providing legal, financial, and technical support.
3. *Develop National Data Infrastructure*: Establish a centralised, accessible database on IAS, documenting distribution, impacts, and traditional/local management practices.
4. *Promote Adaptive and Decentralised Management*: Shift from rigid, centralised control measures toward flexible, locally responsive strategies, including pilot projects for phased management.

5. *Invest in Research on Utilisation Potential*: Explore the bio-economic value of major invasive species for products such as biofuels, paper, handicrafts, and medicinal compounds, ensuring sustainability.

6. *Enhance Capacity Building*: Provide training for communities, researchers, and officials on documenting TEK, sustainable harvesting, value-added product development, and marketing channels.

7. *Address Policy and Legislative Gaps*: Reform policies to support integration of Indigenous and local knowledge, including recognition of traditional land rights and co-management models.

8. *Public Awareness and Education*: Raise awareness about IAS impacts and opportunities for sustainable utilisation, fostering collaboration across sectors.

By embracing Indigenous wisdom, strengthening institutional support, and fostering collaborative approaches, India can transform the challenge of invasive species into an opportunity for ecological restoration and improved human welfare.

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