Management of *Lantana*, an invasive alien weed, in forest ecosystems of India

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Lantana is one of the world's worst weeds of South American origin that threatens native biodiversity of forest ecosystems across India. It was introduced into India as a garden ornamental and or a biohedge plant in the early part of the 19th century and now it has virtually invaded all the tropical and subtropical regions of India. Although attempts have been made to control Lantana by physical, chemical and biological methods, there is no success either in its control or the prevention of its spread. No effective management strategy is yet available for the containment of this obnoxious alien weed. On the basis of critical assessment of the biological and ecological attributes of Lantana that enabled it to overcome all the existing management practices, we have developed a new management strategy. The new strategy involves (i) its removal by cut rootstock method, (ii) weeding of saplings from beneath the trees used for perching by generalist birds that disperse the seeds throughout their home range and from surface drainage channels originating from the area covered by such trees and (iii) ecological restoration of weed-free landscapes, preferably to the grassland, or forest communities according to the needs of stakeholders to prevent reinvasion of the same species or secondary invasion by another alien species. The new strategy developed has been implemented successfully in demonstration plots of 2–5 hectares at the Corbett Tiger Reserve (Uttarakhand), Kalesar National Park (Haryana) and Satpura Tiger Reserve (Madhya Pradesh). The advantages of the new management strategy over other control methods currently used are: (i) cost effectiveness, (ii) simple and easy to adopt and (iii) ensures successful control of Lantana without using chemicals and exotic biological control agents, and with minimum disturbance of soil.

Keywords: Cut rootstock method, ecological restoration, *Lantana*, soil seed bank, weeding.

IN SITU conservation of biodiversity in the form of National Parks, Wildlife Sanctuaries and Project Tiger Reserves, all of which constitute the protected area network, is the most effective conservation strategy for biodiversity. The critical issue facing the managers of protected areas and conservationists is how to maintain biodiversity in the face of natural- and man-made perturbations in the habitat. Biological invasions – one of the anthropogenically mediated ecological perturbations – are threatening native biodiversity, preventing natural ecological succession and changing the community structure and composition, besides impacting ecosystem services[1,2]. In fact, the Convention on Biological Diversity (CBD) recognizes biological invasions as the second most important causal factor for the loss of biological diversity in natural ecosystems across the world, and thus the management of invasive alien weeds in forest ecosystems is critical for the conservation of biological diversity. In most countries, biological invasions are represented by the alien species introduced accidentally or purposefully outside their native geographical distribution ranges. For example, within 50 years of introduction in India, *Parthenium hysterophorus*, an invasive weed of North American origin, invaded 14.25 million hectares of farm land alone[3]. Similarly, *Prosopis juliflora* invaded 1.8% of the total land area[4] of India. The world's top 100 invasive species include *Lantana camara*, *Parthenium hysterophorus*, *Mikania* and *Chromolaena*. All these species are widely distributed across the five continents. In terms of the extent of distribution, *L. camara* is perhaps one of the most important invasive species in forest ecosystems of India.

India has 778,229 sq. km forest area which is nearly 23.68% of the total area of the country. Of the total forest area, 20.04% comes under the protected areas network of which 24.37% are national parks and 75.59% are wildlife sanctuaries[5]. These protected areas are prime wildlife habitats and harbour diverse forest communities. Forest areas, which have been subjected to anthropogenic dis-

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turbances such as grazing and deforestation, have been invaded by invasive alien species such as *Lantana*, *Mikania*, *Chromolaena* and *Ageratina*.

L. camara is native to Central and South America and has been introduced outside its native geographic range as a garden ornamental or a hedge plant, and it has spread across tropical and sub-tropical Africa, Asia and Australia in around 60 countries[6,7]. *L. camara* is of hybrid origin and is a polyploid complex. In India it is composed of polyploids ranging from $2x$ to $7x$ ($x = 11$)[8]. There is a marked variability in morphological features such as habit, thorniness, characteristics of leaf, flower and inflorescence, and size of fruits among different populations of *L. camara*. We have also reported extensive variability in the yields, composition and distribution of constituents of foliar essential oils among different morphotypes of *Lantana* sampled from habitats having similar ecological characteristics[9]. In India, the genus *Lantana* is represented by four species – *L. camara*, *L. indica*, *L. veronicifoila* and *L. trifolia*, besides species of horticultural value[10]. *L. camara* (hereafter referred to as *Lantana*), as represented in India, is a species complex having more than one aggressive weedy species, the taxonomy of which is being worked out by us.

Lantana has a history of multiple introductions in India as an ornamental, with some records stating that it was introduced into India in 1809 as an ornamental hedge in Calcutta[11]. From the original sites of introduction it escaped cultivation and is now spread across the country. It has invaded most of the tropical and subtropical parts of India. It has become a menace and forms pure stands in protected areas. *Lantana* has many adverse affects on forest ecosystems which include (i) loss of native biodiversity[12,13], (ii) replacing native plant communities in forests ecosystems by forming dense impenetrable thickets, (iii) contributing to erosion of soil[13,14], (iv) adversely impacting the regeneration of forests[12,13], (v) harbouring vectors that carry infectious diseases[15] and (vi) promoting fire hazard[16].

We outline here the different methods of control used in the management of *Lantana*, and their limitations, ecological and biological attributes, due to which these control methods are not effective, and the new management strategy evolved for the control of *Lantana* based on the understanding of its natural history.

Methods used for control of *Lantana*

Mechanical/manual, chemical and biological methods besides fire have been used in the control of *Lantana* across the world including India. These control methods have been reviewed by different workers[13,17]. The chemical and biological methods of control are not favoured because of environmental and ecological reasons, particularly due to their potential adverse effects on other biota present in forest ecosystems, and hence not practised by the managers of protected areas in India. According to Day *et al.*[13], burning of *Lantana* clumps coupled with the use of herbicides or mechanical removal of *Lantana* have been used for control of large-scale infestations of *Lantana*. Due to the limitations of mechanical/manual and chemical methods, biocontrol measures are often considered as the most practical control strategy. However, it has met with little success even in countries like Australia where it has been used to manage *Lantana*[17].

The most common methods used in India for the control of *Lantana* in forests are: (i) hand pulling, (ii) slashing/chopping of the stems, (iii) burning and (iv) manual grubbing with substantial removal of the root system. These methods have had no or little effect in controlling the spread of *Lantana* infestation, due to their inherent limitations and absence of an integrated control strategy. Table 1 gives limitations of different control methods used for *Lantana* infestation in forest ecosystems, particularly in protected areas. Some of these methods such as slashing/chopping and burning of *Lantana* clumps have actually led to the further worsening of the infestation; and in some areas, burning of the weed has promoted its spread to new areas. In other words, management of *Lantana* has become a vicious circle in which the control activity and reappearance and the spread of new infestation of *Lantana* are inextricably linked though inadvertently.

New management strategy

Substantial work has been carried out on the taxonomy, biology, ecology and management of *Lantana*[11–13,18]. A practical strategy for its control and management in forest areas is urgently needed but it is not yet available. Devising an effective and practical management strategy for the control of *Lantana* involves addressing issues of (i) invasiveness of *Lantana*, (ii) invasibility of habitats and (iii) ineffectiveness of the control methods used. Understanding the biology and ecology of *Lantana* is critical to find answers to all the three issues. Under the Centre of Excellence Programme of the Ministry of Environment and Forests, Government of India, field biological studies on *Lantana* were carried out to address these three issues and to develop a new management strategy for eradication of *Lantana* in forest ecosystems. The twin objectives of the new management strategy are: (i) control of *Lantana* infestation in already invaded areas and (ii) to contain the spread of *Lantana* to new areas.

From the implementation point of view, the new management strategy evolved has the following four components.

Component 1: Conceptual and implementation planning

Sites for removal of *Lantana* should be identified through field surveys using the data collected on the extent/

Table 1. Methods practised for the control of *Lantana* in forest ecosystems in India and their limitations

Control method	Limitations
Slashing/chopping	Stimulates the shoot buds from most of the nodes below the chopped portions of *Lantana* clumps leading to proliferation of many branches which get interwoven into each other leading to formation of impenetrable thickets.
Burning	Stimulates the sub-terranean meristem (coppicing zone; see Figure 1 *a* and section on biological and ecological basis for effectiveness of the management strategy developed) which produces profuse shoot buds that develop into shoots. The growth rate of new shoots is also enhanced due to burning[18]; it also leads to increase in germination of *Lantana* seeds from soil seed bank[18]; burning eliminates competition from native plant species as the native species are not fire-resistant. The alteration of habitat due to burning can promote invasion of *Lantana*[16] or secondary invasion of other weeds if not managed properly.
Manual/mechanical grubbing	Manual grubbing, as practised in India, involves both slashing of branches of *Lantana* clumps to be removed and extensive digging of root system of the slashed *Lantana* clumps. There are two major disadvanges of this method: (i) due to extensive digging below the *Lantana* clump, the soil is extensively disturbed leading to exposure of buried *Lantana* seeds to light which leads to gregarious germination and establishment of seedlings, (ii) regeneration and recoppicing from slashed branches that are fallen on the ground and from the base of uprooted clump; regeneration also takes place from the rooted prostrate branches that might have been severed from the clump while grubbing.
	Mechanical grubbing results in extensive loosening of soil leading to enhanced soil erosion and also large scale germination of *Lantana* seeds; it also disturbs the native plant species established between clumps.
Chemical control	Impractical to cover vast tracts infested with *Lantana* and also not cost-effective[13]; potential hazard to the native biota and environment.
Biological control	Limited foraging ability of the insects; variety-specific behaviour of the biocontrol agent; performance of the biocontrol agent is affected by climate[17]; biocontrol agents may also affect native species.

magnitude of infestation and density of *Lantana*. The *Lantana* removal operation should follow the 'inside-out' method wherein *Lantana* is removed first from areas with maximum *Lantana* density and then moving outwards along a decreasing *Lantana* density gradient. In areas having undulating terrain and hilly tracts *Lantana* removal operation should be taken up on the slopes first and then downwards to the valley. Planning for the *Lantana* removal operation should also include the time of removal; the removal operation should be done preferably at a time when a majority of the *Lantana* clumps are not in flowering or fruiting stage. It may be noted that after removal of *Lantana* from a site, ecological restoration of weed-free landscape is critical for the control of *Lantana*. Consequently, based on the requirements of the principal stakeholders an ecological restoration plan should also be available. The ecological restoration plan should include the identification of source for selected plant species to be used in restoration, mode of collection of their propagules, development of nurseries for their mass propagation and their subsequent introduction at the site to be restored.

Component 2: Removal of adult clumps using cut rootstock method

One of the innovations in the new management strategy is the development of a simple and cost-effective manual method for the removal of *Lantana*, known as cut rootstock method. As the name suggests, it involves cutting the main tap root of *Lantana* plant beneath the 'coppicing zone' (transition zone between stem base and rootstock) (Figure 1 *b*). This method of removal involves the engagement of 2–3 individuals to work in a group for the removal of *Lantana* if the clump is large enough that it cannot be handled by one individual after the rootstock is cut.

The steps involved in the cut rootstock method are:

(i) The person, who engages in removal of *Lantana*, is positioned in a way that he stands near centre of the *Lantana* clump with his back facing the clump and holding the handle of digger (kudal) (Figure 2 *c*).

(ii) Using the specially designed digger, the person cuts the main rootstock of *Lantana* 3–5 cm below the soil surface by hitting the rootstock 3 or 4 times (Figure 2 *d*); while hitting the rootstock the blade of the digger gets lodged into the main tap root, and at this point it is useful to move the handle of the digger in the forward direction away from the body of the person so as to severe the connection of the clump with the main tap root (Figure 2 *e*). In case the clumps of *Lantana* form impenetrable thickets, it is advantageous to cut the rootstocks of 3–4 contiguous clumps to make the removal operation convenient.

It may be noted that the branches of *Lantana* clumps should not be slashed/cut to gain access to the centre of the clump for its removal by cut rootstock method. The

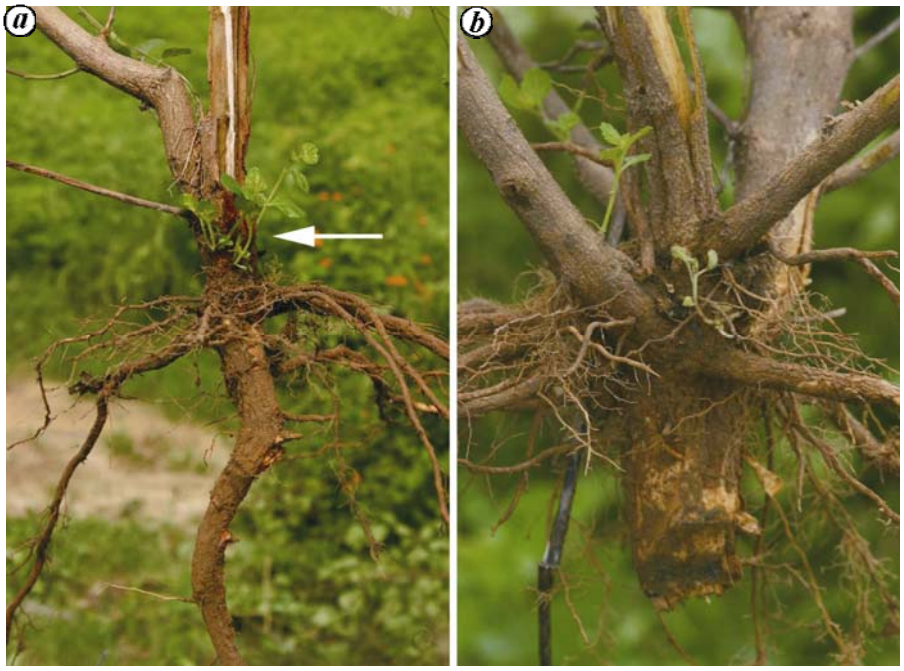

Figure 1. ***a***, Uprooted *Lantana* plant showing coppicing zone at the transition between stem base and root. ***b***, *Lantana* removed by cutting the rootstock below the coppicing zone.

branches of *Lantana* thicket formed by more than one clump should be lifted and tipped over from one end by using a wooden or bamboo pole of about 1.5–2.5 m long and diameter 5–6 cm which is inserted just below the branches from one side and rolled over easily by two workers holding the pole at either end and pressing it so as to reach the centre of the clump (Figure 2 *a* and *b*). Such manual handling of impenetrable thicket is possible because of the umbrella type of canopy which makes it difficult to reach the centre of clump easily. Such physical manoeuvers minimize or prevent regeneration from rooted cut branches when they fall on the ground.

(iii) Lift the clump/s and place the clump/s upside down (Figure 2 *f* and *g*).

If the clump is not placed upside down, the prostrate rooted branches and the aerial old branches having aerial roots at nodes may develop into adult plants when they come in contact with the soil. Therefore, the upside–down orientation of cut clumps is critical in the prevention of regeneration of *Lantana* from cut clumps. It may be noted that *Lantana* does not produce root suckers.

(iv) After drying the clumps, the clumps may be used as fuel or burnt at the same site or all the dried clumps may be collected at one place and then burnt.

The best time for removal of *Lantana* is just before rainy season, i.e. when the plants are not in flowering and fruiting.

Component 3: Weeding out of seedlings/young plantlets of Lantana

A systematic search for trees used by the generalist bird species for perching needs to be carried out after *Lantana*'s removal, both from areas where *Lantana* is removed and its neighbouring areas extending up to a radius of 1 km, which may vary depending upon the size of *Lantana*-infested area and the vulnerability of the area. Habitats subjected to anthropogenic disturbances such as fire are more prone to invasion by *Lantana*. These habitats include habitat edges or ecotones (forest and grassland edge) and abandoned agricultural fields after resettlement of villages from forest areas. After location of the trees used for perching by birds in these habitats, all the saplings found beneath them and along the surface run-off channels originating from the areas covered by them, should be removed manually and burned. Continuous surveillance of the areas, where *Lantana* clumps have been removed and the areas beneath trees used for perching by birds from where the saplings are removed, is necessary consecutively for three growing seasons (monsoons) for the emergence of new saplings.

Component 4: Ecological restoration of weed-free landscapes

If the weed-free landscapes are not ecologically restored, reinvasion by *Lantana* or secondary invasion by some other alien/native weeds such as *Parthenium*, *Cassia tora*, *C. occidentalis* and *Sida* takes place. Therefore, ecological restoration is critical in the management of *Lantana* in the forest ecosystems. Weed-free landscapes in open areas can be easily restored to grassland communities by planting rooted ramets or clumps of native grass species or by broadcasting pellets containing seeds of grass species. If the weed-free landscape has to be developed into

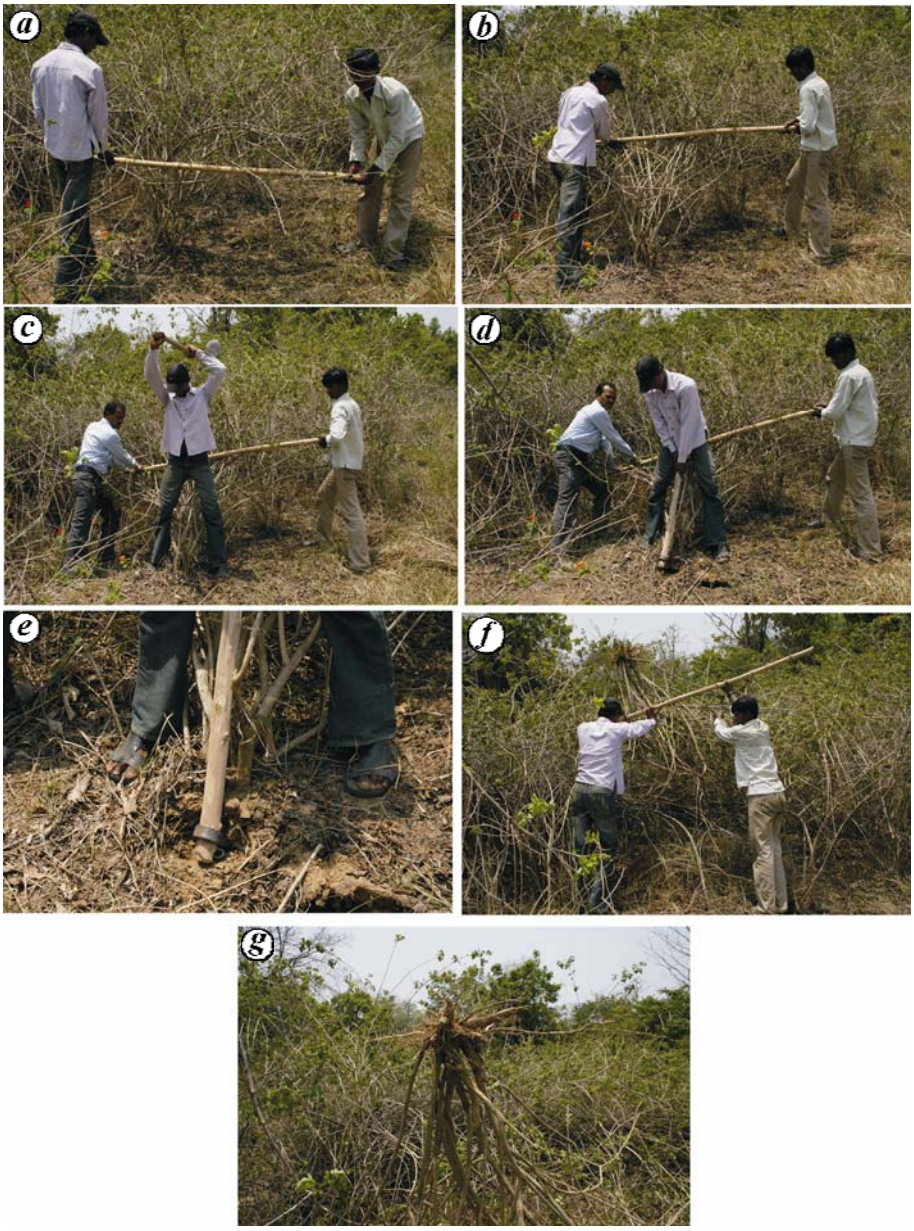

Figure 2. Sequential steps (***a***–***g***) involved in the removal of *Lantana* by cut rootstock method.

a forest ecosystem, the native bottom–up woody species that process the habitat can be planted along with grass species or can be introduced in a sequential manner. Ecological restoration should be carried out concurrently with removal of *Lantana* without much of time lag. The species assemblages of grasses and legumes used for ecological restoration vary across the ecological gradients, and thus the species of grasses and legumes selected for restoration are site-, locality- and region-specific.

Cost of eradication

On an average, the approximate expenditure for the removal of *Lantana* by cut rootstock method and the restoration of weed-free landscapes is about Rs 9000 per hectare. The cost depends upon the intensity of *Lantana* invasion and landscape characteristics among other things. Removal and control of *Lantana* from spreading in protected areas is time-consuming and requires meticulous adoption of the strategy described here as a part of the long-term management plans of protected areas, with continuous financial support.

Biological and ecological basis of the new management strategy

We discuss here how the information on field biology and ecology of *Lantana* has aided in the development of the

management strategy described and how it is different from the currently practised control methods used for the management of *Lantana*.

Implications of plant form and soil seed bank of Lantana on its management

The branching pattern of *Lantana* is determined by the distribution and location of growth points (shoot buds – points from where fresh growth takes place). In *Lantana* new branches arise from the shoot buds present almost at every node of the main stem and its branches. These axillary shoot buds are usually dormant till the apical meristem is active. The axillary buds get stimulated either when the apical growth is stopped or in response to chopping/slashing leading to rapid elongation and development of shoots. Besides the axillary shoot buds, there is a narrow strip of meristematic zone just at the transition between the main stem base and main tap root (Figure 1). This zone is referred to as 'coppicing zone' in this article. The coppicing zone is subterranean and is covered by soil. It has the capacity to proliferate and give rise to several shoots. It generally remains dormant as long as the growth of aerial shoots continues. It gets activated when the aerial branches are chopped near the base or the *Lantana* clump is burnt. When chopping/slashing/mowing and or burning of *Lantana* clumps is carried out to contain it, proliferation of subterranean shoots from coppicing zone occurs. It is, therefore, important that any physical method of control of *Lantana* should involve removal of coppicing zone. In the cut rootstock method the main tap root of *Lantana* is cut 3–5 cm below the soil surface to remove the coppicing zone.

Lantana has a characteristic root system with a main taproot that penetrates vertically up to a depth of 1 m and with lateral roots that grow horizontally up to 5 m in the top 6 cm soil horizon. Such root architecture makes it easier for pulling the clump after cutting the taproot beneath the coppicing zone, i.e. at 3–5 cm depth of soil without much disturbance of the soil. In cut rootstock method the disturbance of soil is minimal, and therefore least number of scarified seeds from the soil seed bank are exposed to light resulting in sprouting of few seedlings of *Lantana* at the site from where mother clumps are removed. It has been shown that the seeds of *Lantana* present in the soil seed bank require high light intensity for germination[18,19]. Further, lifting the clump after cutting the main taproot and keeping the clump upside down and drying it decreases the regeneration potential of *Lantana* dramatically.

Although manual and mechanical grubbing – a method followed by managers of forests – removes the whole clump of *Lantana* with the roots, it has certain major disadvantages. For example, (i) it is labour intensive, (ii) it causes extensive disturbance of soil leading to exposure of *Lantana* seeds present in the soil seed bank to the light resulting in gregarious germination of seeds, (iii) it contributes to the regeneration from the severed rooted prostrate branches that remain on the ground and or aerial rooted branches that come in contact with the ground. The net result is rapid multiplication in an area where mother clumps were removed by grubbing. In other words, grubbing aids in enhancing the density of *Lantana* per unit area on the sites from where it was removed.

It is clear from the above account how important it is to understand the biology of the invasive weeds not only to gain an insight into the response of the weed to overcome the control methods but also to evolve an effective physical method of control that eliminates the drawbacks of the currently practised physical/mechanical control methods. The cut rootstock method developed by us is the outcome of our understanding of the biology and ecology of *Lantana* and the reasons for the failure of established control methods. The advantages of the cut rootstock method over other methods are: (i) less labour intensive, (ii) practically no regeneration from the cut *Lantana* clumps, (iii) minimum disturbance of the soil, (iv) reduced germination of *Lantana* seeds on the eradicated site near the mother clumps, and (v) cost effectiveness (removal of *Lantana* by cut rootstock method costs about Rs 4000–5000 per hectare depending upon the intensity of *Lantana* invasion and topography of the area). These observations were based on the analyses of the sites where physical grubbing and cut rootstock methods were used for the removal of *Lantana* in forest areas. The cut rootstock method is a modified form of grubbing method; although the modifications made in the cut rootstock appear small, the small modifications enhanced the efficiency and effectiveness of the cut rootstock method dramatically with practically no regeneration or recoppicing from the removed *Lantana* clumps and reduced germination of saplings in areas where *Lantana* removal is carried out, the consequence of which is saving on time and cost.

Dispersal and germination of seeds and new management strategy

One of the important aspects in the management of *Lantana* invasion is the prevention of spread, reinvasion and secondary invasions by other weedy aliens in areas from where *Lantana* is removed. One of the attributes of *Lantana* that has made it to colonize vast tracts is the copious fruit production[12] throughout the greater part of the year and their dispersal by frugivorous birds. The fruit of *Lantana* is drupaceous with sweetish pulpy pericarp and boney endocarp enclosing the seed (pyrene). The fruits fallen beneath and around the mother clump do not germinate immediately because of the boney endocarp

around the seed; only after natural scarification of boney endocarp by microbial degradation and subsequent exposure to light, the seeds germinate. Consequently, seedlings are seldom found beneath the mother clump; however, some old buried seeds brought to the surface through the activities of soil animals may germinate. On the other hand, the seeds defecated by fruit foraging birds/herbivores germinate whenever sufficient moisture is available, as boney endocarp is scarified as it passes through the digestive tracts of frugivores.

The bulk of fruits of *Lantana* are dispersed by vertebrate dispersal agents especially birds[13]. According to Buckley *et al.*[20], the role of mutualistic interactions between invasive plant species and their animal dispersal agents has become crucial for the management of invasive species. In our field studies, we have found that the fruits of *Lantana* are foraged by generalist birds and these birds perch on other fruit-bearing trees/shrubs and defecate the seeds beneath them. Some of the defecated seeds are carried by monsoon water and deposited all along the surface drainage channels and along riverbeds. In Corbett Tiger Reserve *Gardinia turgida* and *Zizyphus maurtiana* are the most common perching trees. In fact, we observed 500 saplings of *Lantana* under a single tree of *G. turgida*. In this way, *Lantana* seeds are dispersed throughout the home range of generalist birds rapidly. Consequently, majority of *Lantana* saplings can be located under perching trees in invaded areas and in adjoining uninvaded areas or areas with less *Lantana* density. It has been shown that *Lantana* saplings can be found up to 1.3 km away from the boundary of the *Lantana* infestation[21]. It is because of these field observations that the search for saplings/plants of *Lantana* has become easier, focused and less time-consuming. In fact, in the absence of such search protocol the location of seedling/plants of *Lantana* is time-consuming and labour-intensive. The need for an effective search protocol for sapling of invasive species has also been highlighted by other workers[22]. The consequence of the availability of a search protocol for *Lantana* saplings/plants is the dramatic reduction in chances for new invasions to occur in adjoining open areas.

It may be noted that the timing of removal of *Lantana* in India should be before the onset of 'seasonal rains' to avoid the flowering and fruiting of a number of *Lantana* clumps. Otherwise, these clumps will set fruit and provide seed material which can be dispersed by birds and other animal dispersal agents over a large area to start new invasions after monsoon. According to Panetta[23], seed production has to be virtually eliminated, if a weed has to be eradicated successfully.

Continuous surveillance of the areas from where the *Lantana* is eradicated is necessary for at least three growing seasons, as the seeds of *Lantana* present in the soil-seed bank beneath the mother clump, will start germinating when they are exposed to abundant light through soil disturbance and enough soil moisture. The germination of new saplings from the soil-seed bank decreases with time. The importance of seed bank of weed species in the soils has been highlighted for their management[24]. Seeds of *Lantana* remain viable for many years and can contribute to nearly 50–70% to the total soil seed bank where *Lantana* is present[25]. One of the major reasons for recolonization of weed-free areas is that the seeds of *Lantana* remain viable in soil for a long time and sprouting of *Lantana* seeds take place whenever the seed is exposed to light. The sprouting of *Lantana* seeds and their establishment can be further prevented by restoration of the weed-free landscapes to grassland communities, in the absence of which reinvasion by *Lantana* itself or secondary invasion by other alien weedy species may take place.

Ecological restoration of weed-free landscapes

Another important component of the new management strategy is to ecologically restore the weed-free landscapes. Habitats where eradication of the weed has been undertaken, are open habitats for recolonization by different plant species. These habitats, if left to themselves, will be reinfested by the same or new weed species. According to Buckely *et al.*[26], invasive species, whose recruitment is promoted by disturbance, as is the case with *Lantana*, weed management itself may cause a 'weed-shaped hole' where disturbance imposed by the weed managers would result in the reinvasion of the target or other weedy species. Therefore, ecological restoration of the weed-free landscapes is a must to contain the weed. Further, in the case of *Lantana*-infested areas the weed-free habitats are practically devoid of any native plant species and their associated microbes in the soil. It is, therefore, imperative to introduce native plant species and their associated microbes which eventually lead to ecosystem redevelopment through ecological succession. The species assemblages that need to be developed on weed-free landscapes through ecological restoration depend upon the stakeholder interests. In case of protected areas, where grasslands are rapidly vanishing/degraded, particularly due to invasion of *Lantana*, the best strategy is to develop native grassland communities after removal of *Lantana*. If the management is keen to develop the original forest community, these grassland communities can be transformed into original forest communities through introduction of native woody species. In any case, the managers should have a clear ecological restoration plan for the area before undertaking the removal of *Lantana* from the forests. In fact, Bakker and Wilson[27] have suggested the use of ecological restoration to constrain biological invasions. The ecological restoration protocol developed by us for landscapes, after removal of *Lantana*, has been discussed in detail by Babu *et al.*[28].

Advantages of the new management strategy evolved

The management strategy evolved by us consists of a set of simple and implementable steps which are able to contain the menace of *Lantana* in forest ecosystems. The strategy is effective and efficient not only in the removal but also in preventing the spread of *Lantana* as compared to other control methods in practice, because it involves (i) the removal of *Lantana* effectively and efficiently by cut rootstock method, (ii) preventing the spread of *Lantana* by weeding out saplings beneath the trees used for perching by birds and surface drainage channels originating from such areas, (iii) preventing the reinvasion of *Lantana* and secondary invasions by other weeds in weed-free landscapes through ecological restoration, (iv) the ease with which it can be put to practice and (v) the cost effectiveness.

Success stories

Using the new management strategy outlined here, *Lantana* has been successfully removed from the three plots of varying size (2–5 hectares) in Corbett Tiger Reserve and the weed-free areas have been restored into luxuriant grasslands. After three years, the newly developed grasslands are visited by large herds of deers, along with wild boars and elephants. The frequency of wildlife sighting has also increased in these plots. Several grassland birds have been using these restored habitats for foraging and nesting. Following the strategy developed, the Management of Corbett Tiger Reserve has successfully removed *Lantana* from 1600 hectares and restored the weed-free landscapes to grasslands. The Forest Department of Uttarakhand has undertaken eradication of *Lantana* on a massive scale using the new management strategy. The new management strategy has also been successfully put to work in 5 ha plots at both Kalesar National Park (Haryana) and Satpura Tiger Reserve (Madhya Pradesh).

It may be noted that the weed management programmes require relatively long-term funding and institutional commitment as compared to the control of other pest organisms especially due to their persistent seed banks[29,30]. Odom *et al.*[31] analysed the economic issues relevant to invasive plants with specific reference to Scotch Broom in Barrington Tops National Park. They found that for the given parameter values, management of weed species in national parks was economically justified. Keeping in view, the fact that the national parks and wildlife sanctuaries are repositories of biological heritage and that the invasive species such as *Lantana* threatening the very biological heritage for which the protected areas were established, a long-term financial allocation to the weed management is critical for ensuring the conservation of biodiversity in forest ecosystems.

Conclusion

Lantana has become a menace in forest ecosystems and is distributed across the tropical and subtropical India. A wide range of physical control measures have been followed in the management of *Lantana* weed, but without success. The failure of the physical methods used is due to certain biological and ecological attributes of the weed that made the methods of control ineffective, and enabled the weed to invade rapidly far and wide through dispersal of seeds by mutualistic frugivorous birds. The new cut rootstock method coupled with weeding of saplings under the trees used for perching by generalist birds and subsequent restoration of weed-free landscapes to grassland/forest community can eradicate *Lantana* successfully. This new management strategy evolved has been already put to work not only in the selected demonstration plots but it is being practised at regional level by some state forest departments. A long-term funding and commitment from forest departments are must to free the forest ecosystems from the scourge of *Lantana* menace. Understanding of the natural histories of other invasive weeds will enable to evolve effective and efficient management strategies for their containment in the forest ecosystems.

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