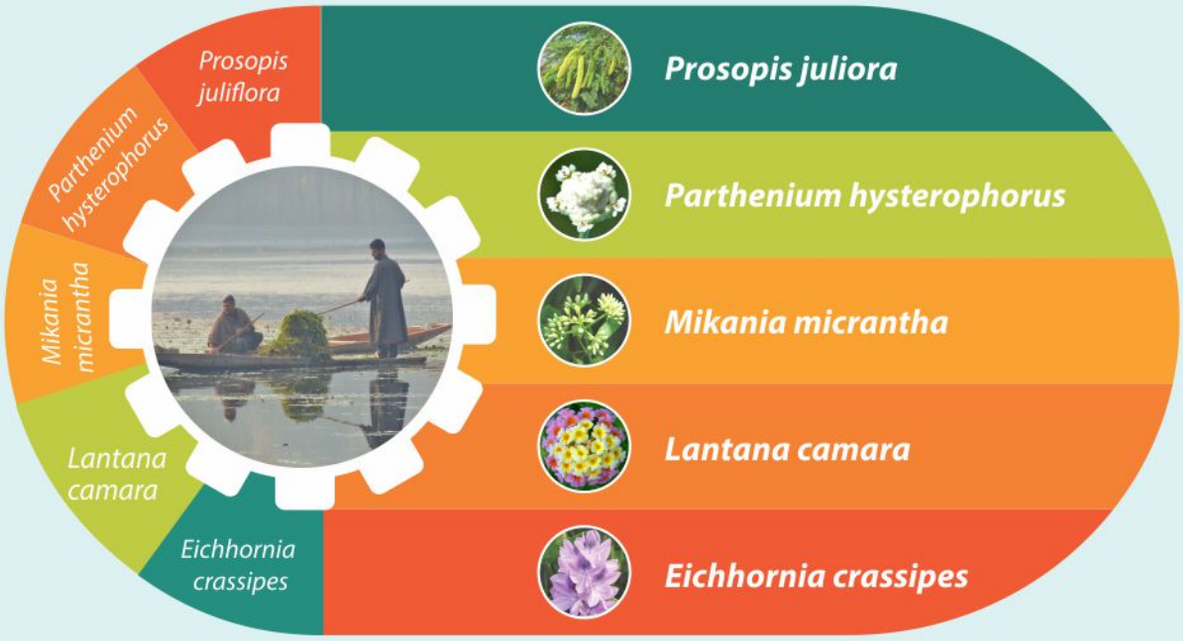
Strategy on Control and Management of the Worst Invasive Alien Plant Species Reported in India



by

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2019

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S. Sandilyan

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Strategy on Control and Management of The Worst Invasive Alien Plant Species Reported in India

Introduction

Invasive alien species (IAS) is a global emergency affecting every aspect of biodiversity, economy and human well-being. Several countries have tried different methods to prevent the entry and to halt the post-entry damages caused by the invasion of alien plant and animal species in their national boundaries. However, every year the problem is spiralling up. Most of the countries fail to identify the gaps in the strategic approaches and control measures, which resulted in great disappointments. Besides, the lack of coordination and inadequate awareness among different stakeholders, managers and common public are the other important reasons for the failures in invasive species management. It is the need of the hour to develop and adopt a robust strategic plan and management methods to curb the invasion menace. Further, it is important to analyse earlier failures faced by the other countries, and the lessons learned by them will help to develop new flawless strategies.

The United States National Invasive Species Council's management plan for the year 2001 clearly stated that an invasive species management strategy is a systematic process mainly meant for the use of different government authorities, NGOs, private companies and individuals. The main aim of any invasive species strategy is to identify the steps that need to be taken to minimize the harmful impacts of IAS on biodiversity, ecology, economy and health-related issues of plants, animals and human (Priyank *et al.* 2013; National Strategy on *Prosopis juliflora* management 2017).

Pertaining to India, so far, we do not have any exclusive national policy, strategies and legal framework to control and manage the IAS reported. In order to initiate such measures, the Centre for Biodiversity Policy and Law (CEBPOL), National Biodiversity Authority (NBA), has developed a strategy and compiled the details available on the control of the five worst invasive plant species reported in India (*Lantana camara,Prosopis juliflora, Mikania micrantha,Parthenium hysterophorus,* and *Eichhornia crassipes*). In addition, we also develop a strategy to control the species in different habitats.

Strategies for the management of invasive alien plant species found in different ecosystems

After reviewing several reports, national strategies, policies and legal measures, the CEBPOL, NBA developed a draft strategy plan to manage the aforesaid invasive species. Once the government establishes a national

level cell to address IAS issues, all the strategies discussed in the draft can be implementable in India. However, it needs further inputs from different stakeholders to increase the compatibility. As mentioned earlier, the draft management strategy has been formulated based on different strategies adopted by several nations and individual researchers. The details of the literature are placed in the references part of this document.

In general, an invasive species management framework should focus on some important areas like prevention, control and management, and creating awareness among different stakeholders. Here, we develop the draft strategy with the following attributes:

1. Prevention
2. Early detection and rapid response
3. Control and management
4. Legislation
5. Education and outreach

1. Prevention

Prevention has been identified as one of the most cost-effective and environment-friendly approaches to minimize/halt the impacts of the IAS. On the other hand, complete prevention is often impossible; however, adhering of certain well-established strategies/methodology will help us to achieve a remarkable success in invasive species management (Priyank *et al.* 2013).

1.1. Primary prevention action need

1.1.1. Pristine habitats situated near the heavily infested areas.

1.1.2. Areas where the natural vegetation/plantation is removed/harvested.

1.1.3. Areas where the new construction/developmental work is in progress (e.g. road and railway track expansion, new building construction sites, minerals, sand and stone quarries).

1.1.4. In and around the wetlands such as lakes, rivers, village ponds, primary and secondary irrigation canals and seasonal wetlands.

1.1.5. Daily and seasonal migratory routes of wild and domestic animals, livestock and the congregation sites of frugivorous birds, bats and animals.

1.2. Areas needing regular surveillance

Some of the habitats need complete protection from the IAS due to their biodiversity and economic and ecological importance. Regular surveillance is needed in these areas to protect the habitats from the deleterious impacts of invasive species. Once the invasion has been reported from these habitats, appropriate actions need to be taken by the concerned authorities.

The list of important areas includes agriculture lands, horticulture gardens, plantation areas (coffee, tea, cocoa), grazing lands, all kinds of wetlands and protected areas.

1.3. Priority actions

Once the invasive species is cleared from the infested habitats, it is vital to go for immediate restoration/ rehabilitation, because the invasive species' eradicated/controlled sites are highly prone to repeated invasion of the same and new species and pave the way for invasion meltdown. To avoid such reinvasion, restoration of the habitats with native species is vital.

1.3.1. Action Points

1.3.1.1. A series of multi-stakeholder consultations need to be organized by the local and regional authorities to identify the priority areas/habitats for effective management.

1.3.1.2. Subject experts and multi-stakeholder consultative meetings are needed before clearing the invasion and rehabilitation. Further, consensus needs to be obtained from multi-stakeholders, researchers and the common public before developing new policies and strategies at the regional and national level.

1.3.1.3. Establishment of national, regional and local invasive cell with full-time employees is needed along with allocated budget to implement the strategies and management plans. The roles and responsibilities of the staff members need to be formulated with the help of international, national and regional experts.

1.3.1.4. For an effective invasive species management, clear national strategies need to be embedded with adequate legislation and policy. Participation of different actors from all possible sectors including researchers and public needs to be ensured. Further, an effective enforcement mechanism and regular monitoring are required for a long-term sustainable management.

1.4. Awareness about invasive species

For effective control and management of IAS, voluntary participation of various stakeholders, the public, researchers and other actors needs to be encouraged. Their active participation may be possible only after the series of awareness campaign/programmes through various media. A common awareness model needs to be developed, which should contain information about the global, national, regional and local impacts of the invasive species on ecosystem, biodiversity, livelihood and economy. It also needs to contain information about the effective public education activities. To achieve the same, a wide variety of training programmes, series of research materials, hand-outs and videos need to be developed and circulated by the concerned authorities.

1.4.1. Awareness about the impacts of invasive species needs to be created among the people living in and around the infested areas. Educate them about how to handle the situation and what things to do and not to do, and orient them where they can get the scientific support to curb the menace. Further, authorities need to educate them on how the invasion can be controlled/ managed in their area. To achieve this, capacity building at national, regional and local level needs to be improved.

1.4.2. Invasive species awareness day/week and regular educational campaign need to be organized by the national, regional and local authorities to create awareness among different stakeholders and public.

1.4.3. Different target groups need to be identified and unique communication channels and material need to be used to make them understand about the importance of the issue.

1.4.4. Circulation of information and awareness materials can be passed through village and community heads, mass media, social media and android applications.

1.4.5. Educate people about the utilization values of IAS in order to collect these from the infested areas.

1.5. Action points

1.5.1. To create awareness among different stakeholders about the national strategies on IAS, different communication channels can be utilized.

1.5.2. Government broadcasting organizations such as Doordarshan and All India Radio (national and regional) can be used for effective communication with regular slots.

1.5.3. Holding hands with Vigyan Prasar to disseminate the knowledge on IAS to public needs to be strengthened.

1.5.4. Different government actors/employees/managers/members of State Biodiversity Board (SBB) and Biodiversity Management Committee (BMC) need to be trained about the risk and the consequences of invasion. Also educate them about the action that can be taken by them during such situation in their jurisdiction.

1.5.5. The role of women self-help groups and the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) needs to be explored.

1.5.6. Share the information about the occurrence of invasive species to the industries, which can use the species for manufacturing furniture, charcoal, medicine, handicrafts, etc.

2. Early detection and rapid response

Early detection and rapid response is basically involved with inventory and mapping of the invasion (National Strategy on *Prosopis juliflora* management 2017). Immediate response of public, stakeholders, researchers and various government actors is vital for early detection and subsequent action. Obviously, continuous monitoring in the areas mentioned in Sections 1.1. Primary prevention action need and 1.2. Areas needing regular surveillance is essential. Identifying and educating the people who frequently encountered/ visited the above-mentioned habitats (e.g. farmers, estate labours, forest guards,fishermen) is an important step for early detection.

Studies clearly established that even the best prevention efforts cannot completely stop all invasive species. Obviously, early detection and rapid response play a crucial role and are one of the best cost-effective steps after prevention. Early detection minimizes the impacts of invasion and most of the time helps in complete eradication (National Strategy on *Prosopis juliflora* management 2017).

For effective early detection and rapid response strategies, researchers have already identified the

following three important components which help in effective control (National Strategy on *Prosopis juliflora* management 2017).

1. Early Detection Establishment of a national, regional and local invasive cell is essential to report about the new invasion by different actors/stakeholders. Common acceptable mechanism needs to be developed for identifying the invasion.
2. Rapid Assessment It includes assessing the area of spread; expected distribution range is within a short period. To achieve the same, trained experts need to be appointed in the national, local and regional invasive cells.
3. Rapid Response Application of appropriate management methods to control/manage/eradicate the early phase of the invasion.

2.1. Action Points

2.1.1. Nationally coordinated invasive species alert and early warning cell needs to be established with implementable surveillance mechanisms. Further, a national invasive species spread prevention module needs to be developed. The role and responsibilities of different actors should be defined in the module.

2.1.2. The areas already mentioned in Sections 1.1. Primary prevention action need and 1.2. Areas needing regular surveillance need to be given priority in order to take measures to prevent the invasion and post-impacts.

2.1.3. Once the invasion has been reported from a new habitat, restrict/prevent the entry of public, livestock and vehicles in and around the habitats. The area needs to be fenced/declared as prohibited site until the invasion is completely cleared.

2.1.4. Periodical surveys need to be carried out to identify the invasive species-free zones which are near to the highly infested areas, and measures need to be in place to maintain the pristine status by protecting the areas from frequent livestock and vehicle movements from the nearby infested areas.

2.1.5. A priority removal of invasive species from the major livestock grazing and transport routes is needed. Entry of livestock to the highly infested areas needs to be avoided and an awareness campaign on the impacts of IAS as well as the role of livestock and vehicle movement on the spread of invasive species needs to be elaborated to the locals.

2.2. Action points for the low infestation areas

2.2.1. Organize awareness campaign for the people living in and around the infested habitat and go for appropriate removal methods with the help of locals. Further, provide training to locals about the control methods and insist on them the importance of regular surveys and eradication.

2.2.2. Panchayat level monitoring committee needs to be set up to monitor the sensitive habitats for the occurrence of new invasion. Members in the committee need to be educated about the important steps to be taken after witnessing the new invasion. Always providing technical

guidelines and circulating the practical manuals to the committee members in the local language need to be encouraged.

2.2.3. Educate and explain to the locals about the importance of fencing/restricted access of people, livestock and vehicles in the highly infested areas.

2.3. Action points for the high infestation areas

A more coordinated and collective response needs to be given in the highly infested areas. Obviously, the degree of problem is higher in these areas; apparently, the individual action will make little difference, so community level action is the ideal option. Further, control of high infestation requires high level of integrated management approach. The control approach also ensures the safe disposal of the collected/removed biomass. Authorities also need to ensure about the effective and environmental friendliness of the control methods (National Strategy on *Prosopis juliflora* management 2017).

2.3.1. The collective management/eradication process needs to be carried out only in the appropriate time/season. The time of collection needs to be announced well in advance to the locals by the appropriate authorities.

2.3.2. Prevent the entry of public, livestock, vehicle by isolating the area with proper fencing and the information needs to be circulated among the residences and other stakeholders. Collection and transport of seeds from the infested areas need to be prevented. However, the collection of seed for manufacturing manure (e.g. *Prosopis* seeds) may be permitted.

2.3.3. Application of proper integrated management strategies after due consultation with experts needs to be identified and implemented.

2.3.4. A local community level (SBB, BMC, panchayat) monitoring is needed to update the current status of the reinvasion process. Continuous monitoring in the cleared areas needs to be ensured by the authorities/managers.

3. Control and Management

The main aim of control and management is to reduce the density, abundance and impacts of the IAS species in an ecosystem. Once the invasive species become well established in a habitat/ecosystem, a strategic approach is essential to halt/minimize further invasion and its impacts to native diversity, ecosystem and economy. For an effective control and management, it is important to know about the biology of the invasive species and its pathways, nature of the infested ecosystem/habitat and the available and applicable effective control methods (mechanical, chemical, biological) and tools. Detailed information on control and management of the five worst species reported in India (*L. camara,P. juliflora, M. micrantha,P. hysterophorus,* and *E. crassipes*) is provided in the following chapters for the reference.

Before implementing a management and control programme, it is better to work out the cost and benefit analysis and ensure about the realized and desired outcomes. Researchers highlighted that control methods need to be selected based on their control efficiency and the undesirable effects caused by the adopted

methods (e.g. chemical control method). In most of the cases, integrated management method is the best option. Besides, once the invasive species are controlled/eradicated from the habitat, it is essential to restore the infested habitats with native species (Genovesi and Shine, 2004; USDA.2004; Priyank et al 2013).

3.1. Action points

3.1.1. A nationally coordinated invasive species early warning alert and management cell needs to be established. The role and responsibility of different actors need to be defined by cell. Definite funding sources need to be identified for all management activities.

3.1.2. It is the mandate of the cell to prioritize the targeted species and the habitat/ecosystem for the management at all levels (panchayat, district, regional, state and national).

3.1.3. To identify the prioritized invasive species, periodical monitoring and inventories are essential. Further, it will also help for the long-term invasive species management.

3.1.4. International cooperation needs to strengthen the process.

4. Legislation

It is the need of the hour to formulate a legal framework to control and minimize the spread of the worst IAS in India. The legislation should also explain about the permission for the use and movement of livestock and vehicles, and other trespassing activity in and around the infected areas. Further, it should also elucidate about the regulatory methods to prevent the spread of the invasive species and provide privileges to the authorities to impose a range of penalties depending on the nature of violation. As part of the management, new guidelines need to be formulated about the collection and removal of invasive species, which possess commercial value (Mauritius. 2008; Priyank *et al* 2013; National Strategy on *Prosopis juliflora* management 2017).

The proposed legal framework needs to explain the role and responsibility of different ministries, institutions, stakeholders and other actors. The legalisation should also address the possible gaps, conflicts of interest, weaknesses and inconsistencies between the available legal framework that addresses IAS in this country (Mauritius. 2008; Priyank et al 2013; National Strategy on *Prosopis juliflora* management 2017).

4.1. Action points

4.1.1. The proposed legislation needs to incorporate the international agreements, which India is a signatory.

4.1.2. The proposed legislation needs to address the amendments to the existing legislation in India if any.

4.1.3. The proposed legislation needs to address the role of local bodies such as panchayat, municipalities and corporation in developing and employing their own bylaws to manage the IAS species in their own jurisdiction.

4.1.4. Subject experts and multi-stakeholder consultative meetings are needed for formulating new

policies, strategies and legislation.

5. Education and Outreach

Educating the public, stakeholders and various government officials about the deleterious impacts of invasive species on biodiversity and regional economy is a vital part in invasive species management. It is important to make them understand how invasive species will affect their livelihood and their day-to-day life. Effective communication should make them understand the magnitude and the importance of the issue.

Awareness programmes need to address the role and responsibilities of the public and other stakeholders in identification, prevention, control and management of IAS species. It is also pave the way to gather new inputs from public and help to strengthen the understanding between the public and the implementation agencies.

5.1. Action points

5.1.1. Circulate the invasive species' best management practice guides/handbooks and video series among concerned authorities and stakeholders.

5.1.2. Incorporation of the invasive species' issues to school and college curriculais needed to create awareness among the younger generation about the deleterious impacts of invasive species.

5.1.3. Risk communication needs to be strengthened with appropriate quality and international standards.

More details are provided in Section 1.4. Awareness about invasive species.

6. Miscellaneous

6.1. The national invasive cell should select multidisciplinary experts (e.g. botanists, foresters, wildlife biologists, researchers, engineers, ecologists, hydrologist, legal advisors and communication experts) for the IAS management in India.

6.2. The multidisciplinary experts need to be employed in different levels (e.g. national, state and district) for better and successful implementation of invasive strategies.

6.3. Appointment of more taxonomists can help to identify new invasive species.

6.4. Cooperation among international agencies and working group will help to strengthen the strategies and its effective implementation.

6.5. National and regional monitoring programmes need to be coordinated and the regular information sharing system needs to be developed.

6.6. Efficient tracking activities need to assess the accomplishment of the invasive strategies.

6.7. There is need to find the financial sources for capacity building and the implementation of invasive strategies.

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Management and Control of *Prosopis juliflora*

1. Introduction

Prosopis juliflora (Sw.) Dc, a woody stemmed, thorned, evergreen shrub/small tree native to northern South America and Central America (Colombia, Ecuador, Mexico, Peru and Venezuela) has been declared as one of the worst invasive species of this century (Pasiecznik 2002; Zachariades *et al*. 2011).

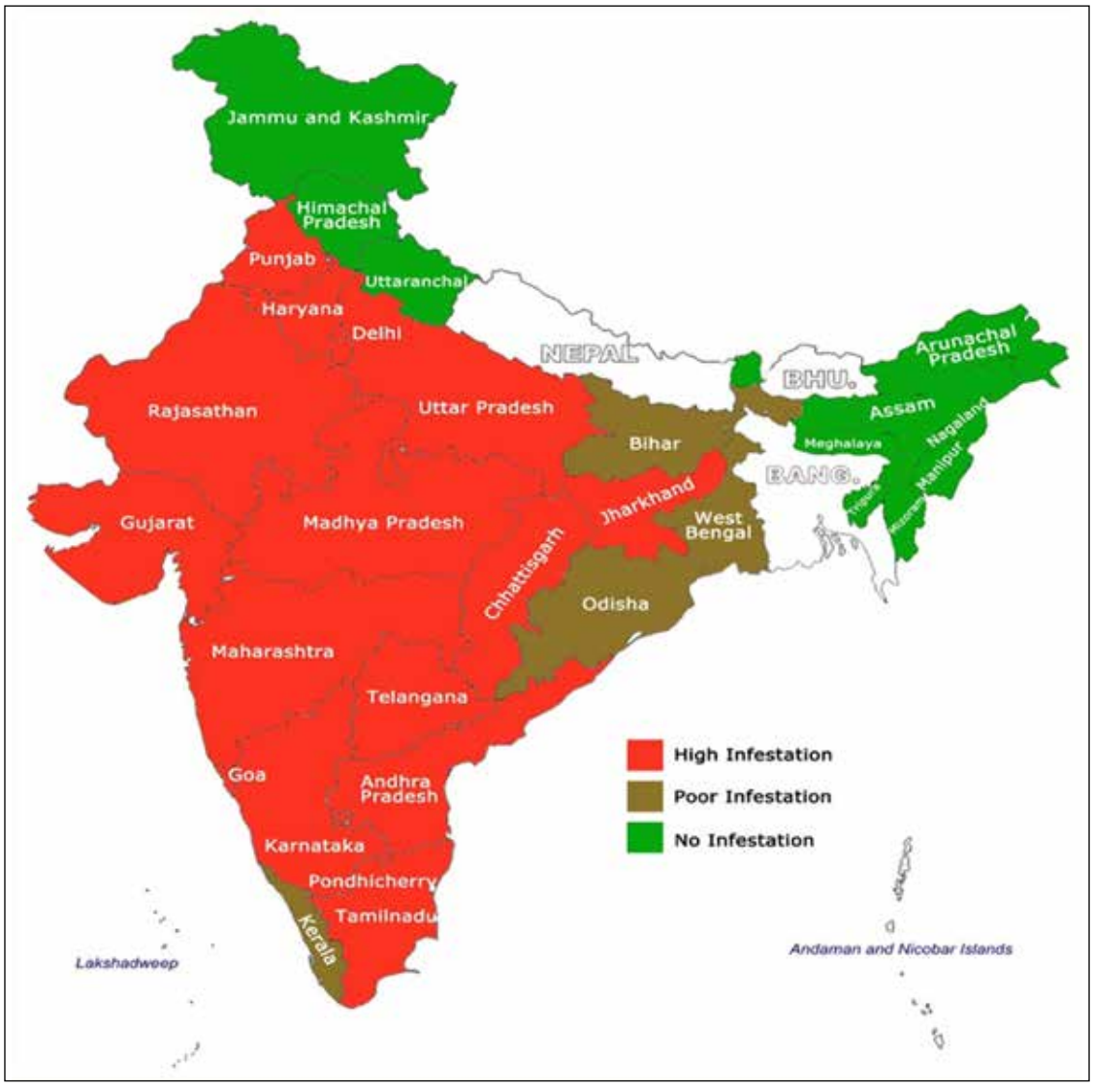
During the mid-nineteenth century *Prosopis juliflora* was introduced to India in order to halt the further expansion of the Thar Desert in northwestern states and to meet the fuel wood crisis of peninsular India. For this introduction, the seeds are received from Mexico, Jamaica, Peru, Argentina and Uruguay (Pasiecznik *et al*. 2001). Most of the Indian states and union territories introduced this species in their provinces in order to overcome the local fuel wood demands. A large-scale plantation of this species took place in Maharashtra in 1934, Tamil Nadu in 1960 and Gujarat in 1984 (Pasiecznik *et al*. 2001). Prosopisplant was intentionally introduced into protected areas such as Keoladeo Ghana and Ranthambore national parks (Robbins 2001; Anoop, 2010; Dayal, 2007).

In India, *P. juliflora* has been reported in different ecosystems and soil regimes (*e.g*. saline areas, alkaline soils, coastal areas, sand dunes). Recently the plant was reported to cause huge damage to riverine areas of southern India and the dry degraded and grasslands of Northern India (Tewari, *et al.* 2000).

Only in the recent past the impacts of the plants in Indian protected areas were recognized by the park authority and managers. For example, in Keoladeo Ghana national park, authorities found that *P. juliflora* replaced the native vegetation cover on a large scale through its allelopathic impacts and drought tolerance behaviour (Anoop, 2010; Kaur *et al*., 2012). Further, the invasion drastically reduced the grassland habitat of the park, which affects the threatened bird *Ardeotis nigriceps* (Indian bustard) (Tiwari 1999). In the same way studies from Ranthambore national park disclosed that the invasion of *P. juliflora* drastically reduced the foraging cover/area for wild and domestic herbivores, which ultimately affects the endangered tiger, a keystone species in this reserve (Dayal 2007).

Even though *P. juliflorais* reported in a variety of ecoregions and soils, surprisingly, it is not found in the Himalayan region including the warm humid tracts such as the northeastern region, West Bengal and Kerala. However, some of the farmers use the species as a live fence around fields and farms in Kerala, Bihar and Odisha (Tewari, *et al* 2000).

Degree of Infeastation of *Prosopis juliflora* in India



Source: Tewari *et al*., 2000; Prasad and Tewari, 2016

2. Biology of *P. juliflora*

Prosopis is athorny evergreen species belonging to the family Fabaceae (Leguminosae) and sub-family Mimosoideae. Wherever the soil and climatic conditions are favourable, *P. juliflora* can reach a height of 12 m (39 ft) and also has a trunk with a diameter of up to 1.2 m.

The leaves of the plants are bipinnate (twice-compound), sometimes with more pairs of pinnae, 6–8 cm long, 12–25 pairs of oblongleaflets per pinna, 6–16 mm long, 1.5–3.2 mm wide. Interestingly, the leavesare not consumed by livestock (Fact sheets on Prosopis).

At three years, *P. juliflora* starts flowering in most of the colonized areas, the flowers are brilliant golden-yellow with dense spikes about 5–10 cm long, which attracts several regional pollinators (Figs 1 and 2). The flowering seasons are generally geared up immediately after the rainy season. Pertaining to India, flowering is reportedtwice in a year (February–March and August–September). The bisexual, pea-like flowers are cross-pollinated by wind and insects. The flowers produce a 10–20 cm long cylindrical or slightly irregularly curved green pod which turns yellow after ripening (Figs 3 and 4). The ripened pod is sweet in taste which contains 10–25 hard oval or elliptic seeds (2–7 mm long) that are difficult to extract. One kg of pods contains 4,000–12,500 seeds, and one tree can produce 35–75 kg of pods/year (the lowest estimate is 140,000 seeds/per year/plant). The seeds are known for its hardness and long dormancy period. In general, *P. juliflora* seeds can stay viable in the soil for 2–10 years; it starts to germinate only during favourable condition. Besides, the seeds are often consumed by herbivores such as goats, cattle, camels, and other wild species and eventually expelled through dung, which can immediately germinate. It is a bitter fact that herbivores highly facilitate the spread of the species to several new areas. Besides, the seeds are also spread along water courses and run-off areas during rain and then spread laterally from the defecated sites (Orwa *et al* 2009; Fact sheets on *Prosopis* and National Strategy on *Prosopis*).

The roots develop rapidly after germination and it can reach a depth of 40 cm within 8 weeks (Pasiecznik, 2002). Interestingly, the species develop two different root systems: (a) surface and lateral roots and (b) deep taproots. Studies underscore that these root systems are highly useful for the hydraulic redistribution and help individuals to survive even in heavy drought conditions (Jenkins *et al*. 1987, Bristow, 1996; Pasiecznik *et al*., 2001; Hultine *et al*., 2004).

Figure 1. Mature and immature flowers of *P. juliflora* (Photo by Sandilyan)

Figure 2. Insect pollinators in the matured flowers of *P. juliflora* (Photo by Sandilyan)

Figure 3. Immature pods of *P. juliflora* (Photo by Sandilyan)

Figure 4. Mature pods of *P. juliflora* (Photo by Sandilyan)

3. Impacts of *P. juliflora*

P. juliflora is known for its deleterious impacts on the ecosystem and biodiversity. In due course of invasion, *P. juliflora* develop impenetrable shrubby thickets around the habitat wherever they invade. Most often we can see this shrubby thickets on the paths near human settlements which often injures human and domestic animals. Especially the farm workers and their machinery are often damaged by the thorns; incidents of human casualty have also been reported (Mwangiand Swallow, 2008; Gordon and Arne, 2013). Pertaining to India, large-scale mortality due to *P. juliflora* was reported during the 2004 tsunami near Parangipettai, Tamil Nadu (Kathiresan and Rajendran, 2005). The authors reported that thorny bushes caused heavy wounding and damage to humans and resulted in a large number of deaths and most of the dead bodies got entangled in the bushes.

P. julifloracan easily be established in pasturelands, irrigated cultivated lands, and irrigation canals and other water bodies, ultimately reducing the surface and groundwater table and driving out the native species from the invaded sites (Kassahun *et al*., 2004; Gordon and Arne, 2013). Studies from South Africa established that invasion of *P. juliflora* reduces mean annual runoff by about 481 million cubic meters across the country and also accelerated the soil erosion (Mwangi and Swallow, 2008). Further, invasion of *P. juliflora* on the bunds of the lakes and the adjacent areas makes fishing more difficult and increased disease incidence associated with microclimate change due to the intensified invasion. Besides, it also reduces the utility of indigenous herbs, trees and wild animals by the local community (Haji, and Mohammed 2013). Recent reports from India established that invasion of *P. juliflora* emerged a great threat to the endangered Great Indian bustard *Ardeotis nigriceps* (Tiwari 1999) and endangered Indian tiger (Dayal 2007).

4. Management

For an effective invasive alien plant management, a number of factors should be taken into account. For instance, the intensity of invasion, nature of the terrain and distribution range, data of co-occurrence of invasive species and the occurrence and status of the native species around the invaded area, room for integrated management approach and the availability and cost of labour should be analysed well in advance (Fact sheets on *Prosopis*).

Once the plant escaped from quarantine/culture/garden and established a population into a larger area, control of the invasion is highly difficult and labour intensive and may not be successful in several occasions. Researchers observed that regeneration potential of the soil-deposited seeds/seedbank and also the regeneration ability of the treesfrom cut stems are significant invasion attributes exhibited by the plants which help them to maintain a sustainable population in the habitat (Fact sheets on *Prosopis*).

Eventually, prevention is the globally accepted cost-effective invasive management method. If prevention is no longer possible, the next viable option is to halt the further expansion of invasive species through early detection and rapid response. Especially, controlling and containment of seed formation and dispersal are highly recommended by the researchers (Fact sheets on *Prosopis*).

The major aim of invasive species control and management programme is to lessen the abundance and density of invasion and to reduce the harmful impacts as much as possible (Gordon and Arne, 2013). In general, there are three types of control methods/strategies (mechanical, chemical and biological control methods) practised by researchers and managers (Abdulahi *et al*., 2017). Besides, most of the conventional control methods are expensive in nature, and researchers also recommended exploring the utilization value of the invasive species. Results of some studies in the utilization aspect established that it is one of the good options to control the invasion in the near future (Tessema 2012; Sandilyan and Charlet 2016).

Besides, studies from different parts of the world have established that *P. juliflora* would not be controlled by engaging a single generic management approach. Though integrated approaches are warranted to minimize the invasion by combining more than one option (Samuel *et al*., 2013; Abdulahi *et al*., 2017), the option could also be site/area specific and also have other regional concerns. For instance, researchers from Australia recommend an integrated management approach which combines mechanical control with the use of herbicides and fire. They explained that spraying herbicides produces dead wood that will ignite and support a sustained fire with more likelihood of killing the remaining trees. Besides, they advised to read the contents of the label and follow all instructions and safety requirements (Fact sheets on *Prosopis*) and also take care of the native species that are prone to the particular herbicides and fire.

Based on the aforesaid, CEBPOL, NBA collected and analysed the available control methods practised in several countries for the containment of *P. juliflora*. Based on the collected literatures, CEBPOL, NBA developed a knowledge database. The main aim of the database is to provide the available control methods/strategies for the managers/policy makers and other associated authorities. Obviously, the choice of selection is highly site, area and habitat specific.

a. Mechanical control methods

In mechanical control, the plants are removed from the invaded site with the help of humans and machine. The common mechanical methods include pulling and digging, cutting and uprooting, bulldozer pushing and blade ploughing. Besides, stick raking (if the soil is dry enough the root system can easily desiccate) and chain pulling are also exercised in several countries including Australia, Yemen and Ethiopia. Obviously the mechanical control methods often culminate with burning of the cleared biomass (Van wilgen *et al*., 2001; Geesing *et al*. 2004). In general, mechanical methods are labour intensive; however, it is highly effective and economic in some regions where the manual labour is readily available and can be hired cheaply (Abdulahi *et al*., 2017).

Researchers and managers opined that manual control has certain specific benefits, especially the targeted species alone is eradicated from the site; however, for the expected results continuous monitoring and repeated operations are needed. In most of the management operations, manual control alone is seldom entirely successful against large-scale invasions. However, periodical hand clearing/picking/uprooting of newly growing seedlings from the cleared site is very important (Abdulahi *et al*., 2017).

b. Biological Control

In recent decades biological control (biocontrol) has gained considerable attention for invasive management, and many countries have found that biological control is one of the best cost-effective ways to manage invasive problems. In general, organisms such as insects, mites, pathogens (mostly fungi) are used as biocontrol agents. Obviously the biocontrol agent(s) is (are) collected from the original home range of the invasive species. Before introduction, host specificity should be studied properly to avoid unwanted consequences (Gordon and Arne, 2013). For a better result, introduction of more than one biocontrol agent is advisable and the organism is selected based on the parts they damage (*e.g*. leaf, flower, fruit, seed, wood). In most of the cases the biocontrol agent does not completely eradicate the invasive species from the habitat; however, it weakens the competitive ability of the invasive species, eventually suppressing the biomass and diminishing the impacts caused by the invasive species in that habitat and provides chances for the recovery of native vegetation (Gordon and Arne, 2013). Globally, a largenumber of biocontrol agents have been used to control *P. juliflora* invasion. For instance, four insect species (*Algarobius bottimeri, Algarrobo prosopis , Prosopidopsylla flava, Evippe* sp.) have been introduced in Australia to halt the spread of *P. juliflora*. The larvae of *A. bottimeri* and *A. prosopis* systematically damage the seeds in the mature pods. Whereas *P. flava* is a sap-sucking insect and the Evippespp. is a leaf defoliator (DAFF Queensland, 2013; Abdulahi *et al*., 2017). However Evippe species has had significant impacts on *P. juliflora* by decreasing the long-term growth rates (Abdulahi *et al*., 2017). However, researchers recommend the introduction of more biocontrol agents in Australia for the containment of *P. juliflora* (van Klinken *et al*., 2003). South Africa introduced three biocontrol insects (*A. prosopis, A. bottimeri, Neltumius arizonensis*) in the 1980s and they mainly targeted to denature the seeds of *P. juliflora*. However, South Africa government failed to achieve the desired results; consequently researchers were requested to explore the possibilities of biocontrol agents which might prevent flower and seed-pod production altogether (Zachariades *et al*. 2011). Pertaining to India, no such attempt has been made so far.

c. Chemical Control

Chemical controls of invasive species involve the use of legally approved/permitted herbicides to eradicate/ control the invasive species from a habitat. In some cases, the chemicals are also used to improve the efficacy of manual and mechanical clearing activities as a follow-up activity.

In the chemical control method, the herbicides are sprayed to cut tree-stumps/incisions made in the bark of the individuals and the chemicals are directly applied/injectedthrough aerial application. A number of herbicides are non-selective in their action, so most of the time during aerial spraying the non-targeted species are also destroyed. On the other hand, direct application and injection of chemicals eventually kill the targeted species/individuals. Besides, the success rate of chemical control methods depends on several factors including the size of the tree, age and chemical uptake efficiency of the individuals (Gordon and Arne, 2013; Shanwad *et al*. 2015).

In Australia, managers cut the stems of *P. juliflora* trees and shrubs near ground surface and apply (spraying or painting) herbicides; sometimes they also using kerosene and diesel for this purpose (Fact sheets on *Prosopis*). However, triclopyr + picloram at 1 L/60 L diesel has been identified as an effective treatment for *P. juliflora* individuals which grow up to 5 cm in diameter. On the other hand triclopyr + picloram is used as an aerial spray for the trees taller than 1.5 m (DAFF Queensland, 2013).

Pertaining to India, chemicals such as Mera-71, paraqua, ammonium sulphamate, Diuron (Klass), glyphosate mixtures are used to control P. juliflora (Shanwad *et al*. 2015). A number of studies in India have established the effectiveness of chemicals on controlling *P. juliflora*. For instance, Panchal and Shetty (1977) established the efficiency of ammonium sulphamate in killing the matured *P. juliflora* trees. On the other hand, foliar herbicides are more efficient on controlling 1.5 m tall seedlings (Geesing *et al*. 2004). However, researchers recommend a combination of herbicides (*e.g*. Mera 71 + 2, 4-D; Mera-71 + paraquat) for better results (Shanwad *et al.* 2015).

Besides, studies also established that, using the approved herbicides for the basal bark and cut-stump techniques for the individuals matured trees (750 mm above the ground) during the growing season (October to April [varies on location]) is highly effective in India (Shanwad *et al* 2015).

However, in Indian conditions, application of chemicals at the early stages and applying mixture of chemicals and double application are very effective on *P. juliflora* management. Studies also recommend to use the locally available chemicals such as glyphosate and 2, 4-D ester for better results (Shanwad *et al.* 2015).

d. Control by Utilization

In most of the developing countries, the conventional *P. juliflora* control methods have been ineffective, expensive and with unwanted results (Abdulahi *et al*., 2017). Apparently, it is necessary to think about the alternative ways to control the invasion of Prosopis. In this connection researchers and managers also mentioned the commercial importance of *P. juliflora* and stated that it is an indirect viable alternate option to control the invasion (Tessema, 2012; Wakie *et al*., 2012). Researchers pointed out that exploitation of invasive species for their economic value will be used to halt the further expansion of the species (Tessema, 2012).

Pertaining to *P. juliflora*, managers already identified its commercial importance and large-scale utilization values (*e.g*. timber value, fuel value as charcoal). Besides, it is a very good source of honey and gum and the bark and root are the storehouse of natural tannin (Sai Bhaskar and Reddy 2009). Further, popularizing the commercial importance of the species may provide new income opportunities for the affected local people (Abdulahi *et al*., 2017).

Products like charcoal and flour produced from seeds are commonly available in all major city markets of Ethiopia. Most of the time, the flour is used as an animal feed by the locals (Abdulahi *et al*., 2017). Studies established that the pods of *P. juliflora* contain 20–30% sucrose and about 15% crude protein (Del Valle *et al*., 1983), which can be used as a supplementary nutrient mixture in animal feed (Prasad and Tewari, 2016). In India, supplementing 15–30% pods in the diet of Indian sheep under a feedlot system was reported to lower the feeding costs considerably, and it is a good money saving option for the formers (Prasad and Tewari, 2016). However, it is also advised that feeding of pods to cattle as the only diet should be avoided (Rawat *et al*., 1992). Obviously making flour from the seeds can prevent the formation of soil seed banks and apparently destroy the viable seeds and prevent future invasion (Abdulahi *et al*., 2017). Interestingly in Kenya, the antiemetic drugs are being mixed with the seed flour and converted into blocks and sold as animal feeds. Most of the time they are used to control worms in cattle and also increasing the livestock productivity (Syomiti *et al*., 2015).

Since 1983, the usefulness of the species has been well recognized in India. Further, it was strengthened after a small study carried out at the Central Arid Zone Research Institute, under National Agricultural Innovation Project during 2008–09. They investigated the value chain on value-added products derived from *P. juliflora* (Tewari *et al*., 2013). Under the project they developed different products including edible products for cattle and man (Table 1 and 2) (Tewari *et al*., 2013).

Table 1. Edible products derived from *Prosopis juliflora*

S. No	Product name and Users	Composition of the product
1.	Cheaper concentrate feed for livestock	*P. juliflora* pods + *Citrullus colocynthis* seed cake + *Cyamopsis tetragonoloba* seed cake + *Sesamum indicum* seed cake + wheat bran, maize grain, common salt and mineral mixture
2.	*P. juliflora* seed meal/multinutrient feed block for livestock	*P. juliflora* seed + *Cyamopsis tetragonoloba* seed cake + *Citrullus colocynthis* seed cake +molasses, urea, common salt, dolomite and vitamin–mineral mixture
3.	*Prosopis* coffee (Juli coffee)	Roasting *P. juliflora* pod flour at different temperatures and mixing chicory (*Cichorium intybus*) with raw coffee powder.
		The prepared coffee contained 70% *P. juliflora* pod powder and 30% chicory mixture (containing 20% raw coffee powder + 10% chicory powder)
4.	*Prosopis juliflora* syrup	One litter water + 350 g ripened pods boiled for two hours – thick liquid yellowish brown in colour. Used as a nutraceutical in beverage. Generally added with milk and fruit juices

Source: Tewari *et al*., 2013.

Table 2. Some of the well-known useful products derived from *Prosopis juliflora*

S. No	Used as	Description	Sources
1.	Fuel	70% of the firewood requirements of rural Indians in the tropical arid and semi-arid regions are fulfilled by *P. juliflora*	Harsh and Tewari 1998
2.	Furniture	The matured tree trunks of the plant possess a high-quality timber and it is good enough to Indian rosewood and other commercial hardwoods. The shrinkage is less when compared to other common trees used to make furniture in India. Furniture made from this plant has little or no cracking.	Singh, 2008; Tewari *et al*., 2013
3.	Papers, textile fibres, tyre cord and cellophane	The wood is soluble to varying degrees in water, sodium hydroxide, alcohol and benzene. Due to this nature it can be easily pulped and used to make printing papers, textile fibres, tyre cord or cellophane	Madan and Tandon, 1991
4.	Gum	Matured plants can exude significant quantity of gum (40 g – 1–2 kg depending on various factors including the climate). Every year the gum production and marketing is spiralling up. The gum is also used as an emulsifying agent. The adhesive strength is highly preferred and used for paper, brown paper and wall paper adhesive	Tewari, 1998; Vimal and Tyagi, 1986
5.	Medicine	Wood chips and the bark extract is used as an antiseptic on wounds and also recognized for its antifungal and antibacterial impacts Gum is used to treat eye infections. Plant parts are also used to cure catarrh, cold, diarrhoea, dysentery, excrescences, flu, hoarseness, inflammation, measles, sore throat and healing of wounds	Vimal and Tyagi, 1986; Rastogi and Mehrotra, 1993

e. Legislation

Apart from the control methods a robust legal framework is needed to halt the further expansion of the species. Formulation of new legislation with special reference to access and use and ban on domesticated herbivore grazing in the invaded areas are needed(National Strategy 2017). Besides some of the countries like Kenya declared *P. juliflora* a noxious weed under the Suppression of Noxious Weeds Act (CAP 325). Based on this act authorities can compel landowners to remove the species from their farmlands (Fact sheets on Prosopis).

In India, in response to a public interest litigation petition, the High Court of Chennai directed 13 district collectors to weed out *P. juliflora* from water bodies, river courses and all other sensitive habitats (Anon. 2016). Based on the court orders, all the village panchayats instructed the landowners to clear the plant from their land and the panchayat and municipality started to remove the plant from the government lands. However, in

response to another petition, the High Court stayed the removal process (Anon. 2017), with a special mention that, wherever the tree posed a problem, they could be removed, otherwise there was no need to clear the species (Oppili 2018). Apparently, this kind of court interventions will highly help to control a weed in a short time; however, unscientific way of invasive species eradication will change the habitat, making it highly vulnerable to multispecies invasion. Considering the experts' view is more useful with legal measures.

f. Recommendation

For an effective management of *P. juliflora* in India, it is better to organize series of regional multistakeholder workshops and ensure the participation of researchers, managers and policy makers to select the control methods which are appropriate for their region.

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Management and control of *Parthenium hysterophorus* L.

1. Introduction

Parthenium hysterophorus L. is an erect and much branched annual herbaceous plant, native to the area surrounding the Gulf of Mexico, Central America, southern North America, West Indies and central South America. The weed *P. hysterophorus* is responsible for causing several human and animal diseases and alters the soil chemistry, thereby diminishing the agriculture productivity and regional biodiversity on a large scale. Besides, the weed is considered as the seventh most devastating weed in Africa, Asia and Australia (Rollins 1950; Sushilkumar 2009; Kaur *et al*. 2014).

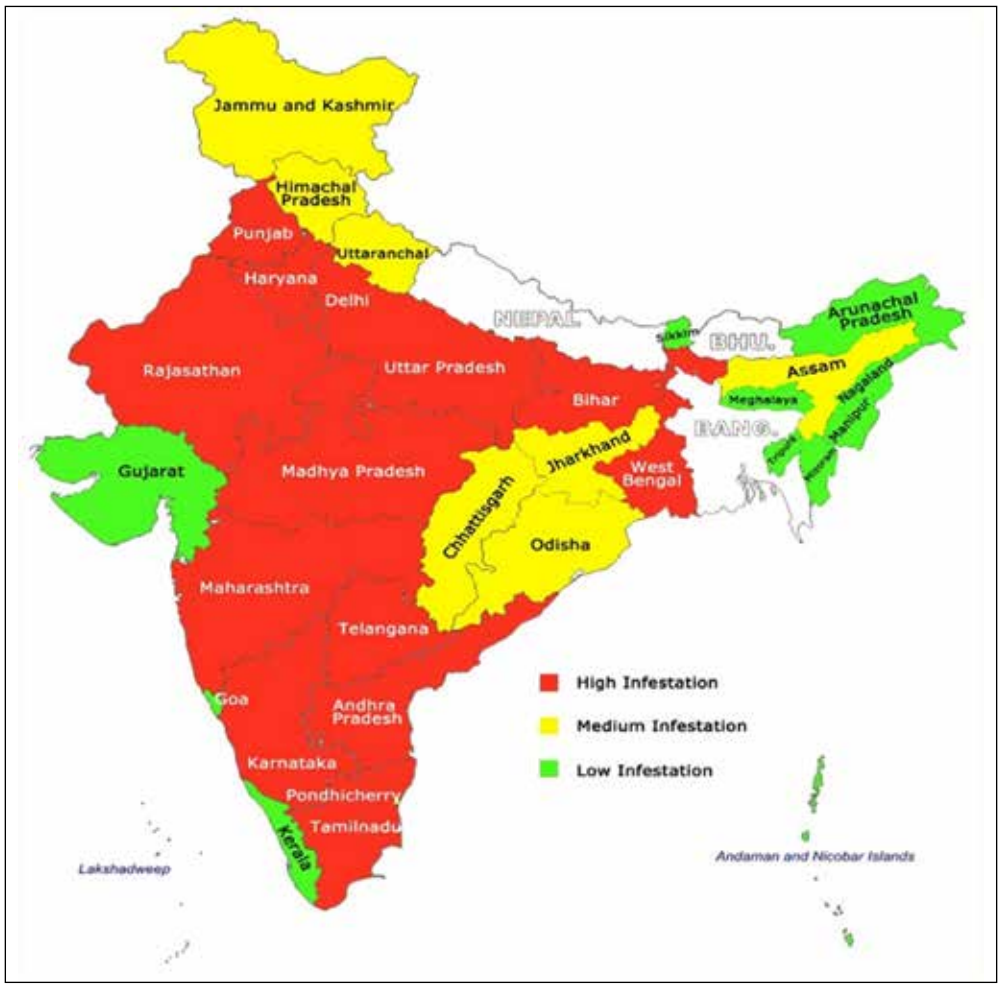
India and Australia are the countries that first recognized the invasion potential and deleterious impacts of *P. hysterophorus* (Rao 1956). In 1814, Roxburgh, father of Indian botanical research, first reported about the occurrence of the weed in India and he described about the plant in his book titled "Hortus Bengalensis". However, it is widely believed that the seeds of the weed entered into India during the 1950s along with the wheat grains received from the United States under the US PL 480 scheme. The scheme is also known as "Food for Peace" scheme (a scheme, which provided food grains to developing countries for the alleviation of starvation and malnutrition) (Roxburg, 1814; Rao 1956; Singh *et al*. 2008; Kaur *et al*. 2014).

Since its introduction, the weed has invaded different habitats in India including agricultural lands, bunds of wetland, watercourses, community land, urban areas, overgrazed pastures, industrial areas, playgrounds, sides of the road and railway tracks and the fringes of the reserve forests and other protected areas. The occurrence of the species in the wild was first reported from Pune, Maharashtra, in 1955. Surveys during 1975 revealed that the weed had invaded 5 million hectares. However, the recent estimations have exposed that *P. hysterophorus* invaded 35 million hectares in India (Sushilkumar 2009; 2012). The weed has been reported from almost all states and union territories of India. However, the highest density was reported from the states including Andhra Pradesh, Bihar, Chhattisgarh, Delhi, Haryana, Karnataka, Maharashtra, Madhya Pradesh,

Punjab, Tamil Nadu, and Uttar Pradesh (Sushilkumar 2012). The overall distribution patterns of the weed in India are provided in Figure 1.

Apart from India, the invasion of the weed was also reported from neighbouring Asian countries including Pakistan, Sri Lanka, Bangladesh, Nepal, Taiwan, China and Vietnam (see Strathie *et al*. 2011). So far, the weed has been reported from more than 20 countries across five different continents (Kaur *et al*. 2014).

Figure 1: Degree of infestation of *Parthenium hysterophorus* L. in different and Union territories of India



Source: Sushilkumar 2009, 2012

2. Biology of *Parthenium hysterophorus*

P. hysterophorus is an erect, much branched, fast-growing annual herbaceous plant belonging to the family Asteraceae (tribe: Heliantheae). The weed is known as bitter weed, carrot weed, broom bush and congress grass. Normally they grow up to 0.5–1.5 m; if the conditions are favourable, it will reach a height of 2 m and above (Kaur *et al*. 2014; Fact Sheet on *Parthenium*, 2018).

Within its short life span, the plant exhibits two distinct stages: (i) juvenile, rosette/vegetative stage and (ii) mature reproductive stage. During juvenile phase, it possesses a rosette with large, dark green, simple, radicle and pinnatisect small leaves without flowers, whereas in the adult stage, it develops more branches with matured leaves, flowers and strong root system (Kaur *et al*. 2014; Fact Sheet on P*arthenium*, 2018).

The leaves in the plants are simple, alternate, pinnately or bipinnately dissected with stalks and arranged in an alternative way. The lower leaves are relatively large (3–30 cm long and 2–12 cm wide) and are deeply divided (bi-pinnatifid or bi-pinnatisect), whereas the upper branches' leaves are smaller in size and less divided than the lower leaves (Kaur *et al*. 2014; Fact Sheet on *Parthenium*, 2018).

A single plant can produce numerous creamy white flowers (flower heads), and they are located in the tip and form a cluster with five tiny petals (Figure 2). Each flower head is borne on a stalk 1–8 mm long. Normally the flowering can occur at any time of the year, but it is most common during the rainy period. In a season, a plant can produce 624 million pollen grains and they are pollinated by wind (anemophilous) (Kaur *et al*. 2014;Fact Sheet on *Parthenium*, 2018).

Flowers produce 4–5 wedge-shaped black seeds that are 2 mm long with thin white scales and are hard to see by the naked eye (Figure 3). A single plant can produce nearly 25,000+seeds which are deposited in the ground (seed bank) (Javaid and Adrees, 2009; Kaur *et al*. 2014; Fact Sheet on *Parthenium*, 2018). In a highly infested area more than 340 million seeds per hectare can be collected from the soil surface. Interestingly, there is no dormancy period for the seeds and they can germinate any time depending on the availability of the soil moisture (APFSIN2018). The seeds on the soil surface can survive up to 6 months; under the soil (below 5 cm) they can survive for nearly 2 years. In contrast, some of the seeds are also reported to have the viability even after 15 years (APFSIN2018). The mature seeds can spread in many different ways; however, wind, animals, movement of vehicles, earth moving machinery, water flows over the soil surface during rain and flood are the predominant ways. This weed has two kinds of roots, one is the main branched taproot and the other one is finer root (Monaco *et al*. 2001; APFSIN2018).

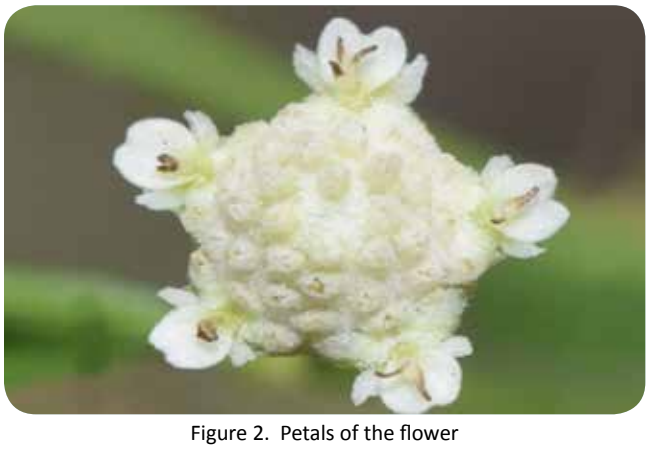


Figure 2. Petals of the flower

Figure 3. Seeds of Parthenium

3. Impacts of *Parthenium hysterophorus*

Due to its harmful effects on humans, livestock and to biodiversity, *P. hysterophorusis* declared as the most dangerous terrestrial weeds of our times (Kaur *et al*. 2014). The deleterious impacts of this specieshave been well documented in several countries including India, Australia and Ethiopia (Evans, 1997; Fact Sheet on *Parthenium* 2018).

Parthenium has been reported to convert the habitat and alter the natural distribution pattern of indigenous flora. In general, the grasslands, open woodlands, flood plains, agriculture land, riverbanks and associated watercourses, fringes of the forest and road are highly prone to *Parthenium* invasion (Javaid and Adrees 2009). A study disclosed that within a short span of 6 years *Parthenium* invaded 14.25 million hectares of farmland in Australia (Kaur *et al*. 2014), whereas in India, within 57 years, it spread over 35 million hectares (Sushilkumar 2009; 2012).

This weed contains unique chemicals (e.g. parthenin, hysterin, hymenin, ambrosin) during the invasion process, which continuously liberate the chemicals into the surrounding soil and alter the natural chemical composition of the soil. Besides the chemicals are also used to suppress and eliminate the growth of crop plants and other native plants (Gunaseelan, 1998). Further, the aforesaid chemicals also affect nitrogen-fixing microbes such as *Rhizobium, Actinomycetes, Azotobacter* and *Azospirillum*, which will ultimately affect the productivity of the leguminous crop plants in the agriculture system (Kaur *et al*. 2014).

The enormous amount of *Parthenium* pollens near the agriculture habitats can easily settle on the stigmatic surface of the crop plants such as tomato, brinjal, beans, capsicum, rice and maize during high wind. This process will significantly reduce the productivity of these crops. Besides, it was also reported that there was 40% yield decline in different agricultural crops in India due *Parthenium* invasion (Khosla and Sobti 1981; Kaur *et al*. 2014). Apart from flora species, *P. hysterophorus* weed also causes numerous problems to humans and livestock. The impacts of the weed on humans and animals are provided in Table 1.

Table 1. Impacts of *P. hysterophorus* on humans and animals

Sl. No.	Kind of Impacts	Reference
Humans		
1.	Asthma and bronchitis and other respiratory issues	Wiesner *et al.* 2007; Fact Sheet on Parthenium 2018
2.	Dermatitis, skin inflammation and eczema	Wiesner *et al.* 2007; Maishi et al 1998
3.	Diarrhoea	Maishi *et al.* 1998
4.	Hay fever	Wiesner *et al.* 2007
5.	Regular coughing	Fact Sheet on Parthenium 2018
6.	Swelling	Fact Sheet on Parthenium 2018
7.	Watery eyes	Fact Sheet on Parthenium 2018
8.	Black spots, blisters around eyes	Patel, 2011
9.	Burning rings	Patel, 2011

Animals		
1.	Alopecia	Aneja, 1991
2.	Anorexia	Aneja, 1991
3.	Dermatitis	Rajkumar *et al.* 1988
4.	Diarrhoea	Aneja, 1991
5.	Eye irritation and poor WBC count	Aneja, 1991; Yadav *et al.*, 2010
6.	Loss of skin pigmentation	Rajkumar *et al.* 1988
7.	Malfunction of liver and kidneys	Rajkumar *et al.* 1988
8.	Mortality	Narasimhan *et al.*, 1977
9.	Mouth ulcers with excessive salivation	Narasimhan *et al.*, 1977
10.	Pruritus	Aneja, 1991

4. Management of *P. hysterophorus*

Globally several researchers have suggested a number of control methods; however, most of them are regional and habitat specific (see Kaur *et al*. 2014). Besides, practicing more than one method (integrated approach) at a single stretch is a better option for an effective result (Samuel *et al*., 2013; Abdulahi *et al*., 2017). However, globally, a number of studies underscore the efficiency of biocontrol agents on controlling *P. hysterophorus*. For instance, the use of biocontrol agents such as insects and fungal pathogens and other competitive native and alien plants is a most economic and feasible method to control *Parthenium* (Kaur *et al*. 2014). On the other hand, some of the herbicides and physical methods also have commendable results on controlling this weed in different habitats (Dhanraj and Mitra 1976; Gaurav *et al*., 2017).

Based on the aforesaid, the Centre for Biodiversity Policy and Law (CEBPOL), National Biodiversity Authority (NBA), has collected and analysed the available control methods practiced in several countries for the containment of *P. hysterophorus*. Based on the collected literatures, CEBPOL, NBA has developed a knowledge database. The main aim of the database is to provide available control method/strategies for the managers/policymakers and other associated authorities. Obviously, the choice of selection is highly site, area and habitat specific.

a. Mechanical Control Methods

Mechanical control is one of the cost effective control methods which includes hand weeding, ploughing and keeping the farm equipment, livestock, human and vehicles clean and free from *Parthenium* seeds (Kaur *et al*. 2014; Gaurav *et al*., 2017).

Manual uprooting of the weed from the field before the flowering season will help to reduce the invasion intensity and it can be easily done when the soil is wet. However, manual uprooting is a time-consuming process and sometime causes certain health problems. On the other hand, ploughing is highly effective when the weed is in rosette stage (Kaur *et al*. 2014; APFISN 2018).

However, after the removal of the weeds through mechanical control, it is advised to cultivate the naive variety to avoid further new invasion (Kaur *et al*. 2014).

b. Chemical Control

Chemical control has been identified as one of the effective options where the natural enemies and other biocontrol methods are not applicable/feasible in a habitat (Kaur *et al*. 2014). Chemicals such as atrazine, ametryn, bromoxynil, chlorimuron ethyl, glyphosate, metsulfuron, 2,4-D ethyl ester (0.2%) and metribuzin (0.25 and 0.50%) are known to be very effective in controlling *Parthenium* (Kaur *et al*. 2014). However, the age and invaded habitat of the weed should be taken into account before going for chemical application.

Studies have established that at the rosette stage the weed can be effectively controlled inwastelands, non-cropped areas and roadsides. However, different chemicals showed various controlling rate among the weed population (Kaur *et al*. 2014). Some of the important chemicals and its effectiveness on the weed are provided in Table 2. Interestingly, spraying of sodium chloride (common salt) at 15–20% concentration has been found very effective on open wasteland and roadside (APFISN 2018). Obviously, application of sodium chloride solution in and around the cultivable land will increase the salinity level in the soil. Besides, Diquat 0.5 kg/ha in 500 litre spray effectively suppressed the growth of the weed in all growth stages (Dhanraj and Mitra 1976).

Table 2: Control efficiency of different chemicals/herbicides on *P. hysterophorus*

Sl. No.	Herbicides	Mortality % at rosette stage	Mortality % at bolted stage
1.	Glyphosate	96	91
2.	Metribuzin	87	75
3.	2,4-D	71–80	43
4.	Bromoxynil + MCPA	57–79	50–61.5
5.	Atrazine	56.5	36.5
6.	S-metolachlor	57.5	41
7.	Pendimethalin	42.5	30

Source: Kaur *et al*., 2014.

Overall, the effectiveness of herbicides was promising on rosette stage of the plants than the bolted stage of the plants (Kaur *et al*., 2014). It was also suggested that a continuous long-term follow-up action is needed for a complete eradication (Goodall *et al*. 2010). However, through chemicals we can clear the existing population but cannot prevent the entry of the seeds and its propagation in a habitat (Strathie *et al*., 2011).

On the other hand, most of the chemicals used for *Parthenium* eradication programmes are not species specific and are also highly toxic in nature. Further, most of them are highly persistent in the ambient environment and consequently cause some unwanted impacts on biodiversity and human health. Besides, considerable financial constraints are also present if it is in a larger land area (Kaur *et al*., 2014).

c. Control by Utilization

Obviously increasing market demands for a plant can lead to rapid decline of the species in the wild. For instance, some of the plant species which were reported to occur abundantly in India half a century ago are becoming rare nowadays mainly due to their commercial importance (Mishra 2000; Giri *et al*. 2015; Sandilyan and Vant Klooster 2016). Recent studies also disclosed the commercial values of the weed *P. hysterophorus* (Table 3). Apparently, screening and advertising the utilization property of the weed is a cost-effective alternative way for controlling the invasion.

Table 3: Identified commercial values of the weed *P. hysterophorus*.

Sl. No.	Uses
1.	Animal feed
2.	As analgesic in muscular rheumatism and vermifuge to eliminate helminthes and exhibit significant anticancer property
3.	As compost; green manure for maize and mung bean production
4.	Carbonized *Parthenium* can be used for removal of dyes, heavy metals, nitrates and phenols
5.	Eradication of *Salvinia* and water hyacinth from water bodies
6.	Flea repellent for ridding dogs of fleas
7.	Folk remedy against skin diseases, ulcerated sores, facial neuralgia, fever and anaemia
8.	Increasing crop productivity
9.	Removal of heavy metals from environment to sequester Cd(II) ions from soil
10.	Sequestration of Ni(II) from aqueous solution onto activated carbon
11.	Silver nanoparticle formation for biomedical uses
12.	Substrate for enzyme production
13.	Treat fever, diarrhoea, neurologic disorders, urinary infections, dysentery, malaria and as emmenagogue, eczema, skin rashes, herpes, rheumatic pain, cold, heart trouble

Source: Patel 2011.

d. Biological Control

Globally, several countries have accepted that biological control is one of the cost-effective and viable methods to control *Parthenium* invasion. Biological control of *Parthenium* can be achieved through the introduction of native and alien competitive plants, pathogens, and insects (Maheswari 1966; Sushilkumar 2009; Kaur *et al*., 2014). However, controlling a weed through another plant (competitive replacement) gained wide acceptance and was tagged as a safer method especially in agro ecosystem (Aneja 2009).

d1. Competitive replacement

Replacing or suppressing the invasion of a weed by another native or alien plant is called competitive replacement. Globally, a number of studies have identified such an effective plant against *Parthenium* (e.g. *Amaranthus spinosus, Cassia sericea, C. tora, C. auriculata, Croton bonplandianum, Hyptis suaveolens, Mirabilis jalapa, Sida spinosa* (Wahab 2005).

Pertaining to India, *C. sericea, C. tora, Desmostachya bipinnata, Imperata cylindrica, Kochia indica, Otcantium annulatum, Sorghum halepense, Cenchrus* hybrid, *Vetiveria zijanioichrus, Pinus* species and *Xanthium strumarium* are recognized for their commendable result on controlling the weed (Maheswari 1966; Singh and Kaur 1997; Sushilkumar and Bhan 1997; Javaid *et al*. 2005). For instance, sowing of *C. tora* in the invaded area before monsoon can help to reduce *Parthenium* intensity by 95% (Tiwari *et al*. 1997).

However, selection of a competitive plant should be habitat specific. Studies are also advocated that cultivation of marigold (*Tagetes* spp) in the protected areas and agriculture land can effectively control the *Parthenium* (Kauraw *et al*. 1997; Kaur *et al*., 2014). Besides, a study in Hubli city of Karnataka established that *Parthenium* did not establish in the area where natural vegetation was not uprooted (Mamtha and Mahadevappa 1988).

Apart from the competitive replacement technique, some of the plant extracts also have negative impacts on *Parthenium* invasion. For instance, the root and shoot extracts of the grasses such as *Dichanthium annulatum, Cenchrus pennisetiformis* and *Sorghum halepense* effectively controlled the seed germination and sapling survival (see Kaur *et al*., 2014). Likewise the application of the leaf extracts of *Azadirachta indica, Aegle marmelos* and *Eucalyptus tereticornis* on the infected field effectively inhibited seed germination (see Kaur *et al*., 2014).

d2. Bio-herbicidal Approach

Several plant pathogenic fungi are effectively used to control *Parthenium* weed. In general, the fungi are applied in a manner similar to the chemical herbicide application so it is also called as bioherbicides (Kaur *et al*., 2014). Globally numerous fungal pathogens are reported to infect *Parthenium*. However, some of the fungi expressed predominant suppression on *Parthenium* in the lab as well as field conditions (*e.g*. *Alternaria alternata, Cercospora parthenophilia, Fusarium pallidoroseum*) (Kaur *et al*., 2014). In India some of the studies have well established the *Parthenium* control efficiency of fungi. For example, a report from Andhra Pradesh stated that *A. alternata* effectively suppressed the growth of seedlings (Despandey *et al*. 1982). Studies from Tamil Nadu established the impacts of *Rhizoctonia solani, Lasiodiplodia theobromae* and *Odium parthenium on Parthenium* control (Kumar *et al*. 1979; Manickam *et al*. 1997; Jeyalakshmi *et al*. 2005). Especially *L. theobromae*, a host-specific blight causing fungus, was reported to cause severe damage to *Parthenium* within 15–30 days (Jeyalakshmi *et al*. 2005).

d3. Biological Control through Insects

Like fungi, a big list of insects have been tried to control *Parthenium* weed in different countries and a small list of such insects is provided in Table 4. Among the vast groups of insects the leaf-feeding beetle *Zygogramma* bicolorata and the stem-galling moth *Epiblema strenuana* caused more damages to *Parthenium* (Kaur *et al*., 2014).

Table 4: Insect biocontrol agents used to control *Parthenium* in different countries

Biological Control Agent	Feeding Habits	Native Country	Released Country
Bucculatrix parthenica	Leaf mining moth	Mexico	Australia
Epiblema strenuana	Leaf mining moth	Mexico	Australia
Platphalonidia mystica	Leaf mining moth	Argentina	Sri Lanka
Listronotus setosipennis	Stem-galling weevil	Argentina and Brazil	Australia
Conotrachelus albocinereus	Stem-galling weevil	Mexico	Australia
Smicronyx lutulentus	Stem-galling weevil	Mexico	Pakistan, Australia
Stobaera concinna	Parthenium sap feeder	Mexico	Australia
Zygogramma bicolorata	Leaf-feeding beetle	Mexico	Australia, India

Source; Kaur *et al.*, 2014.

Pertaining to India, many native insects have been documented to cause damage to *Parthenium* (e.g. *Aphis fabae, Ferrisia virgata, Hypothenemus eruditus, Leptocentrus taurus*). However, *H. eruditus* caused widespread damage to *Parthenium* (Sushilkumar, 2009). But, there are no further studies or eradication attempts carried out on the aforesaid species in India. In the meantime, Australia has successfully used *Z. bicolorata* and *E. strenuana* to control the weed. India also introduced these two species from 1983 to 1985 (Sushilkumar, 2009).

The larvae and adult *Z. bicolorata* enormously feed on the leaves of the weed. During larva stage, they used to consume terminal and auxiliary buds, and in the adult state, they consume leaf blades. Within 4–8 weeks period a single individual can cause skeletonization of leaves (see Kaur *et al*., 2014). However, after some time *Z. bicolorata* wasfound feeding on an important cash crop *Helianthus annuus* (sunflower) and caused considerable loss to the farmers (Sridhar, 1991; Kumar 1992; Sushilkumar, 2009). In the same way, *E. strenuana* lays eggs and causes damages to some cash crops (Kaur *et al*., 2014).

Based on the unexpected results, the Indian Council of Agricultural Research constituted a Fact Finding Committee to investigate the field reality and based on the result of the committee the release of the beetle was banned after 1992. However, in 1999, the Government of India lifted the ban on releasing the beetle in the wild for control of *Parthenium* (Sushilkumar, 2009). After this, a good density of the beetle was introduced into a number of *Parthenium*-infested areas in the country. A large-scale decline of the weed in many parts was reported after the reintroduction. For instance, 98% flower reduction was reported in Bengaluru (Jayanth and Bali, 1994; Sushilkumar, 2009).

However, researchers also emphasized that *Parthenium* weed management through biocontrolled agents is not as simple as in some other successful cases in several countries on other weed species. In the case of *Parthenium*, it is known for its high regeneration potential, seed production ability and germination ability in different ecosystems. In this scenario, researchers such as Bhan *et al*. (1997) suggested some future strategies and have stressed the need of integrated management with biointensive approach. Some of the important suggestions given by the researchers are given below without any modifications:

i) Efforts are required to look into the case of failure of past efforts in establishing seed feeding weevil *Smicronyx lutulentus*. The establishment of this insect alongwith *Z. bicolorata* may be helpful to manage *Parthenium* more effectively.

ii) So far only *Z. bicolorata* has been proved to be a successful bioagent, but this bioagent alone is not sufficient to manage *Parthenium* because of the reason that this beetle is able to make sufficient population buildup only during July to September in the area where monsoon rains are received. But, *Parthenium* is able to germinate throughout the year. The idea of importation and colonization of additional natural enemies, such as the leaf mining moth *Bucculatrix parthenica*, the seed feeding weevil *S. lutulentus* and the fungal pathogen *Puccinia abrupta* var partheniicola, may complement *Z. bicolorata* for *P. hysterophorus* control throughout India.

iii) Augmentation of *Z. bicolorata* can be achieved through mass multiplication. More concentrated efforts are needed to mass multiply *Z. bicolorata* throughout the season (Sushilkumar 2005).

iv) So far, only countable efforts have been made in India to make effective mycoherbicides. More concentrated research in this direction is imperative in the development of mycoherbicides for effective *Parthenium* management. It has been reported that integration of bioherbicides with reduced rate of herbicides can successfully improve the activity of mycoherbicides towards weed. It has also been suggested that bioherbicides comprised of native pathogens may be more effective than those comprised of introduced pathogens because of more ready adaptability.

v) The role of marigold should be encouraged in integrated *Parthenium* management in residential colonies, office premises and farmhouses with the help of people's participation. Using marigold, *Parthenium* suppression can be achievedon the one hand while aesthetic value can be maintained on the other hand.

vi) The competitive and harmless plants like *C. sericea* and, *C. tora* should be used in an integrated fashion to manage the weed biologically.

vii) Safe herbicides can also be integrated with bioagents.

e. Legislation

Australia declared the weed as noxious and requested their citizens to control the spread of the species from their land. Landowners must report the presence of *Parthenium* weed to the concerned control authority within 3 days and seek their professional advice to control and eradicate the weed from their respective land. Further, legislation introduced in Queensland insisted that the suppliers of stock, machinery, soil, water and other agriculture products should submit a declaration stating whether the material is clean from all forms of *Parthenium* weed (CRC Weed management, 2003).

Pertaining to India, the Government of Karnataka issued a notification on 23rd October 1975 declaring *Parthenium* a noxious weed in terms of Section 3 read with Subsection 7 of Section 2 of the Karnataka Agricultural Pests and Disease Act, 1968. By this act, the Bangalore Municipal Corporation issued notice to the public and asked them to remove the weed from their farm and garden. Unfortunately, the attempt failed to receive adequate public attention (Bhan *et al*. 1975).

After several years, in 2013 *Parthenium* awareness week was conducted in Jabalpur Agriculture University in collaboration with the Directorate of Weed Science Research. In this programme, awareness was created among students and staff of schools and colleges of Bengaluru and other rural districts. A documentary video on the impacts of *Parthenium* was projected and followed by an open discussion. Further, an exhibition was also organized to create awareness among public in the city (Rohith, BR. 2013). However, there are no further details available about the regularity of the celebration as well as the enforcement of Agricultural Pests and Disease Act, 1968.

Since *Parthenium* invasion has been reported in several parts of India, central and state governments should declared the weed as noxious in their appropriate act and should create awareness among the public and different research groups about the species as well as about the act. Strict implementation of law will highly be helpful to control the intensification of this weed.

f. Recommendation

For an effective management of *Parthenium* in India, it is better to organize a series of regional multi-stakeholder workshops and ensure the participation of researchers, managers and policymakers to select the control methods whichare appropriate for their region.

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Managementand control of *Mikania micrantha*

1. Introduction

Mikania micrantha, widely known as "mile-a-minute", is a terrestrial, perennial herbaceous climbing twining creeper, native to Mexico, Central America, the Caribbean and tropical South America and now with pan-tropical distribution. Like most of the other invasive plants, it causes huge damage to the native diversity and regional economy. Especially, *M. micrantha* apparently kills the native and cultivated plants by smothering them. This weed poses serious threat to commercial crops, changes the natural zonation pattern of the forest and soil chemistry, and alters the physiological traits. Based on the impact, the Invasive Species Specialist Group (ISSG) declared *Mikania* as one of the 100 worst invasive alien species and it was also considered to be one of the top ten worst weeds of the world. Besides, it is recognized as one of the most dangerous weeds of South and Southwest Asia (Huang *et al*.2000; Lowe *et al*.2001; Zhang *et al*. 2003; Shao et al 2005: Ellison *et al*., 2008; Day, 2012; Prabhu *et al*., 2014; Banerjee and Dewanji, 2012; Banerjee *et al*., 2017).

Asian countries such as India, China, Nepal, Indonesia and Malaysia highly suffer due to the invasion of *M. micrantha*. The creeper especially causes huge damage to the plantation crops such as coffee, cacao and tea and some tropical fruit trees including banana and other regional crops. The weed is also reported to invade mangrove forests in China and has also deteriorated the coastal microhabitat and changed the benthic community structure (Huang *et al*. 2000; Ye and Xia 2001; Sapkota 2007; Yu and Yang 2011; Banerjee and Dewanji, 2012; Chen and Ma, 2015).

In India, the weed was first reported from Bengal in 1918; however, studies also stated that the plant was introduced at the end of the Second World War. The weed was first reported in Assam during the 1950s and it was widely believed that it accidentally entered this region along with the fodder grass of mules and slowly caused huge problem in northeast and southwest parts of the country. The twining creeper was reported from Kerala in 1968, West Bengal in 1981, Karnataka in 1997 and was also widely reported from several parts of

Western Ghats around 1993. Recent studies from the Agricultural and Ecological Research Unit of the Indian Statistical Institute, Kolkata, disclosed that the species completed the lag phase in the southwestern and northwestern parts of the country and has now started to invade new terrains. Already the weed was reported from more than 15 states of India (Choudhury 1972; Parker 1972; see Banerjee and Dewanji, 2012). The invaded range and the projected distribution of *M. micrantha* in India are provided in Figures 1 and 2.

Invasion of *M. micrantha* in wetlands near Kolkata
(Photo by Achyut Kumar Banerjee)

Earlier studies clearly explain the introduction and establishment pattern of this weed. A number of studies have underscored that, urbanization process played a significant role on the introduction of this species into new habitats. Besides, the expansion of intra-city, intra-state and inter-state road transport schemes has

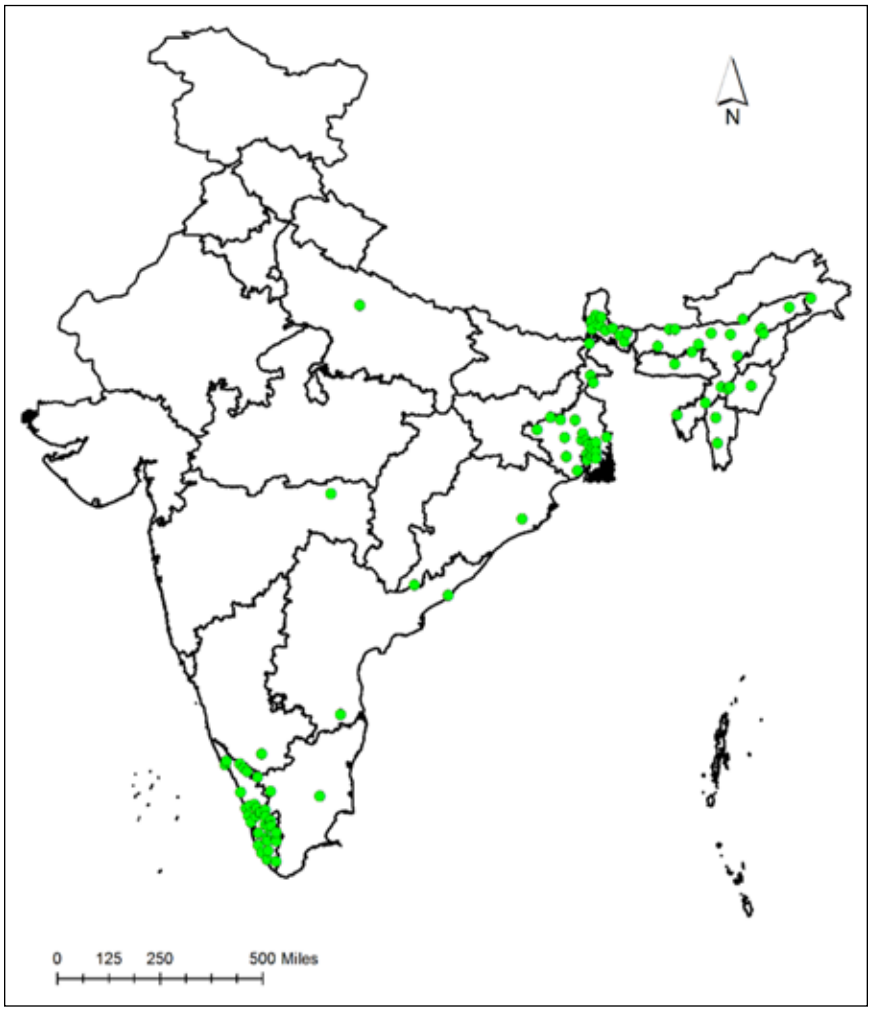

Figure 1:
Invaded range of *M. micrantha* in India

(Courtesy: Achyut Kumar Banerjee,Agricultural and Ecological Research Unit, Indian Statistical Institute, Kolkata.)

significantly facilitated the invasion. On the other hand, limited success was documented in controlling this species in India and researchers opined that biological control with integrated method is the viable option to control the weed (Ye and Xia 2001; see Banerjee and Dewanji, 2012: Anitha *et al*. 2017).

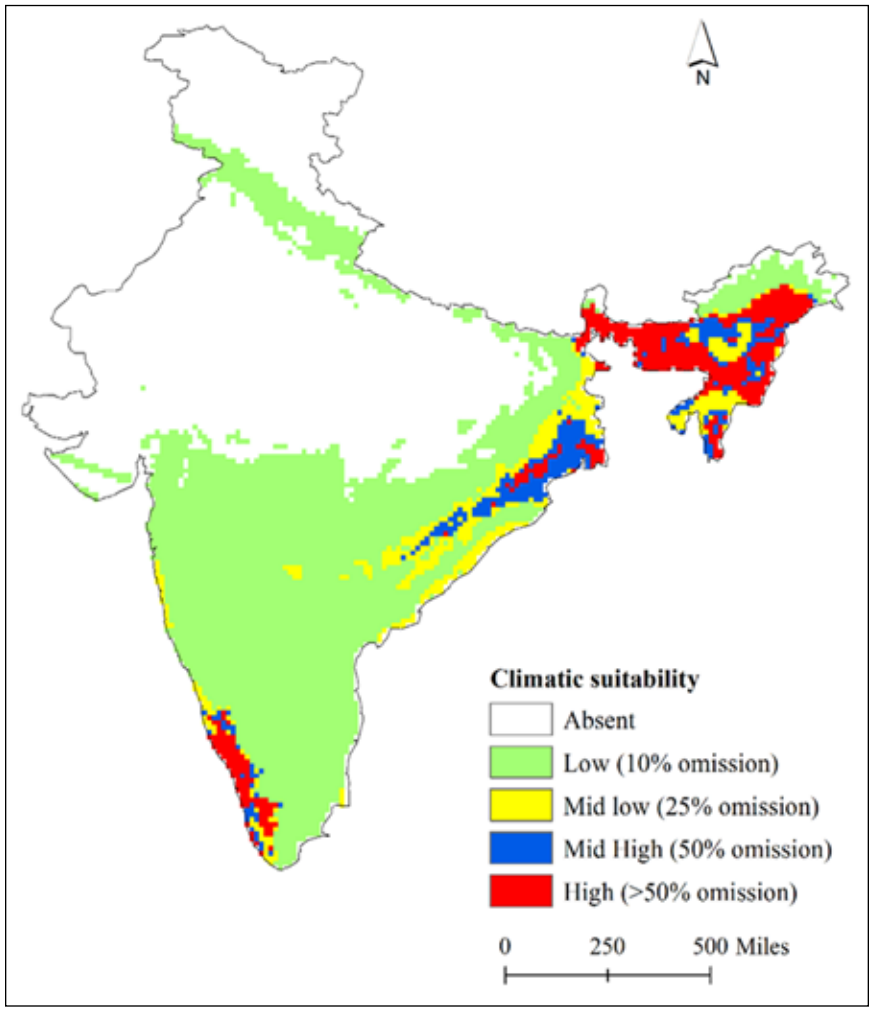

Figure 2:
Projected distribution in India. Figure legends depict four climate suitability classes based on thresholds calculated in terms of omission percentage of known native occurrences. (Inset) frequency histogram showing probabilities retrieved from Indian occurrence data.

(**Courtesy:** Achyut Kumar Banerjee, Agricultural and Ecological Research Unit, Indian Statistical Institute, Kolkata.)

2. Biology of *M. micrantha*

M. micrantha is a perennial climbing creeper of the family Asteraceae, with 5-ribbed branches with long stems, and can grow up to 6 m. The leaves grow up to 13 cm long, oppositely arranged and have a pointed apex and heart-shaped base (APFISN 2018).

The flowers of *Mikania* are white to greenish-white in colour and develop as clusters at the ends of stems. Each flower head is 4–6 mm long and contains four individual flowers. Normally the fruit setting occurs 17–21 days after flowering and a single stalk of *Mikania* can produce 20,000–40,000 black colour mature seeds/year. The tufted seeds (Fig 3) consist of 30 fine white hairs or bristles and grow 1.5–2 mm long and are highly equipped for wind dispersal; apart from that, animals and water current play a crucial role in dispersing the seed into

new areas. However, the germination ability of the seeds is very poor (8–12%). The abiotic factors such as light, water and soil moistures significantly affect the germination process. Obviously, vegetative propagation is highly helpful to the plant to disperse. Vegetative propagation occurs by the nodes and small fragments of the stems whenever they contact with wet soil and they quickly produce roots. The young plants can grow up to 8–9 cm within 24 hours under ideal conditions. The fast-growing character can help the plant in quick formation of dense cover (DAF 2016; APFISN 2018).

Figure 3. The tufted seed of *M. micrantha*

3. Impacts of *M. micrantha*

The major invasive attributes of *M. micrantha* include the rapid reproduction (sexual and vegetative) methods, ability to form dense thickest within a short period and high allelopathic capacity. Once it starts to establish in a habitat, it slowly kills the existing plant species in the habitat by smothering them, especially reducing light interception by covering the canopy of any natural and cultivated plant species. Further, it competes with native vegetation for soil nutrients and water and successfully drives them out from the race (Huang *et al*.2000; Sankaran *et al*. 2008; see Banerjee *et al*. 2017; APFISN 2018).

Globally *Mikania* was reported to cause more damages to forest and agriculture system. Especially the weed poses a serious threat to several cash crops such as oil palm, rubber, citrus, cassava, albizia, pineapple, coconut, teak, eucalyptus and acacia. *Mikania* also causes huge economic loss whenever it invaded into coffee, tea and coca plantation. Since the weed can easily smother young plants, 20% reduction in oil palm yield was reported in Malaysia. The government spends around 8–10 million dollars/year to rid this problem. Mikania also affects the young plantation crops such as rubber (55%), cocoa (53%) and coconut (61%). Besides, harvesting of any crop from the *Mikania*-infested area becomes difficult due to its creeping and twining nature (Sankaran *et al*. 2008, 2017; APFISN 2018).

In Nepal *Mikania* affects the regeneration potential of several valuable timber tree species such as sal (*Shorea robusta*), rosewood (*Dalbergia sissoo*), and Indian rosewood (*Dalbergia latifolia*). Further, the invasion of this weed affected the community forest, riparian sites, forest edges, grassland and other buffer zones of Chitwan National Park. This kind of invasion in the forest habitats altered the food availability and foraging efficiency of endangered mammals such as one-horned rhinoceros (*Rhinoceros unicornis*) (Adhikari, 2004; Baral and Adikari 2017).

Besides, studies from Nepal also established the invasion ability of the species in wetland ecosystem. Koshi Tappu Wildlife Reserve, one of the important Ramsar sites and important bird areas of Nepal, was highly infested by *Mikania*. It was reported that the weed invaded all parts of the wetland including the open water areas. The plant used the wetland vegetation for support and invaded several parts. As a result, a number of submerged, emerged and other aquatic diversity are facing local extinction (Baral and Adikari. 2017).

Pertaining to India, most of the agriculture and forest ecosystems of northeastern region was highly affected by the infestation of *Mikania*. Especially in Assam, due to this, the tea plantation faces huge loss. The tea-plucking period (April–September) is also the peak period for *Mikania* infestation, which affects the plucking process (Sankaran *et al*. 2017; APFISN 2018), whereas in Kerala, 38% of eucalyptus and 78% of the teak plantation was affected by this weed. Especially teak seedlings face huge threat due to *Mikania* (Sankaran *et al*. 2017).

Besides, studies from India also established the poor species richness, denatured habitats and species monopolization in the infested areas. Moreover, it reduced the availability and collection of non-wood products from the forest habitats (Sankaran *et al*. 2017; APFISN 2018).

Globally, several studies have underscored the impacts of the species in unique habitats including the coastal and inland wetlands. However, there is no specific study about the impacts of the species in each trophic level. Apparently, more studies are needed in this aspect to know about the real invasion potential of this species.

Management

Studies from Southeast Asia clearly established the invasion potential and ecological and economic damages caused by *Mikania*. Most of the studies focused on the impacts of this species on plantation crops and forest ecosystem. Plenty of literatures have described the efficiency of mechanical/physical, chemical and biocontrol methods in controlling *Mikania*. In fact, some of the methods are applicable to specific habitats/region. However, till date, there are no generic control model/methods available to rid *Mikania* problem forever.

a. Mechanical Control

Mikania infestation can be cleared by several ways including manual slashing, sickle weeding, uprooting and digging, hoeing, shovelling, mowing and tilling, and in some parts the managers use brush cutter too. Obviously, clearing of the stems close to the ground is more effective. The aerial part (up to 3 m from the ground) should also be properly removed and disposed. Repeated clearing operations are suggested to avoid further invasion (NCPN, 2006; Sankaran *et al*. 2017; APFISN 2018).

Sickle weeding is recommended before flowering and seed setting, even though it is a temporary solution; a quick re-growth is often encountered from the cut stumps. Some of the studies highlighted that uprooting of the weed during younger stage or initial phase of invasion is more effective. In some of the habitats, slash and burn technique is an ideal but not safe option near the reserve forest. Besides, most of the time the weed stock may survive even after burning and produces young shoots within a short period (NCPN, 2006; APFISN 2018).

The notable advantage of mechanical control method is the reduction of vegetative propagation; however, this method is very labour intensive and uneconomical in several regions. For instance, studies from Indonesia underscored that the cost of mechanical control is 125–175% higher than herbicidal control. Besides, physical removal of this weed after seed formation will significantly facilitate intensive re-growth compared with natural spread (NCPN, 2006; Sankaran *et al*. 2017; APFISN 2018).

b. Chemical Control

Re-growth of *Mikania* is a common phenomenon in the areas where mechanical control is practiced. In such areas managers suggested the application of chemicals/herbicides to halt the reappearance of the weeds in such areas. Most of the recommended herbicides are more effective, kill the entire plants and halt the re-growth of the weed in a reasonable time.

The common herbicides used to eradicate *Mikania* are glyphosate, sulfometuron-methyl, diuron, oxyfluorfen, paraquat, grazon DS and garlon 600. Application of a single herbicide and sometimes mix of herbicides is also used to control the invasion. Some of the chemicals are used to control the post-emergence and some of them are used to control pre-emergence of the weeds. For instance, oxyfluorfen (0.06 kg - ha) and paraquat (0.24 kg ha) are used to control the re-emergence. Moreover, the dosage of chemicals significantly varies depending on the density of the infestation (NCPN, 2006; APFISN, 2018).

Further, some of the chemicals are more suitable for certain habitats alone (*e.g*. glyphosate is good in forest plantations and effectively affects the seed banks and suppresses the seed germination). In general, it is not advisable to use the herbicides in the sites that are near to water sources, active agricultural land, gardens and residential areas (NCPN, 2006; APFISN, 2018).

Studies from the forest plantation sites in Kerala have identified a unique combination of chemicals (triclopyr+picloram, triclopyr, glyphosate) to control the weeds and it has been reported as cheaper (Rs. 1150–2000/ha) and most effective than the available and applicable mechanical control methods. It was proved that the mixture of chemicals could keep the weed under control for more than 8 months. However, the research team suggested that repeated application for consecutive years will help to eradicate the weed permanently from the site (Sankaran *et al*., 2017).

Besides, for an effective result, herbicide application should be carried out before the flower and seed begin setting, because the seed of *Mikania* is light weight and can easily be dispersed by wind. Studies also highlighted that the application of chemicals may control the weed for a reasonable time; however, the seeds can again be

introduced into the area from the adjacent habitat through wind which takes place regularly during the onset of the monsoon. Obviously, regular chemical application only warrants complete eradication (NCPN, 2006; APFISN, 2018).

c. Control by Utilization

Like other invasive plants, *Mikania* also has some utility value. The leaf of the plants is widely used as a fodder in many countries, including India. The leaf of the plant has some antimicrobial property and is widely used by the ethnic people to cure their wounds. Besides, people use the juice of *Mikania* leaf as an antidote for insect bite, scorpion sting; to cure itches; and for treating stomach-ache. In some parts of Africa, people use the leaves to make soups. However, there are notmuch studies about its therapeutic evidence (APFISN, 2018). Once the medicinal properties of this weed are scientifically established, there may be more chance to procure the plant by the pharmaceutical industry which will help to control the plant to a certain extent.

d. Biological Control

Studies from several parts of the *Mikania*-infested countries listed out nearly 75+ arthropod species associated with this weed. Pertaining to India, 19 insects and one mite species are associated with this weed. Besides, nine pathogens were identified to cause various diseases due to *Mikania*. However, most of the insects and pathogens do not have the potential to be used as a biocontrol agent. Further, most of them are generalized feeders and have the chance to become a pest in the introduced habitat (see Sankaran *et al*., 2017).

Few biological control agents have been identified so far to control the weed *Mikania*; however, there is no report about the complete control of *Mikania* by the introduced biocontrol agents. For instance, *Liothrips mikaniae*, a thrips species,has been introduced in Malaysia and Solomon Islands. However, there was no satisfactory result obtained by the administrators (Banerjee and Dewanji, 2012; APFISN 2018).

Pertaining to India, the Kerala Forest Research Institute (KFRI) introduced a microcyclic rust fungus *Puccinia spegazzinii* in Assam and Kerala during 2005–2006 and the rust spread rapidly on the Mikania weed within a week. However, after 3–4 months *P. spegazzinii* failed to survive on *Mikania* due to the environmental conditionsthat prevailed in those habitats. It was stated that inappropriate time of release was the main reason for the failure. However, in the initial period of the introduction, the results were encouraging (Sankaran *et al*., 2017; APFISN 2018).

e. Integrated Management with Biological control

The KFRI suggested an integrated management plan to control *Mikania* with biocontrol agents. The institute suggested setting up *Mikania* weed control groups at village level and the groupswere to collect the weed from the highly infested areas. The collected biomass may be used to make fodder and simultaneously was also suggested for application of the rust fungus *P. spegazzinii* in the collected area. The groups could also encourage the people to find alternate fodder apart from the weed after some time (Anitha *et al*., 2017).

f. Legislation

Australia is one of the countries which have a legal framework to control the weed. The Biosecurity Act 2014 mentioned that *Mikania* is a restricted invasive plant. The act insisted the public to report about the occurrence of the species in their locality to Biosecurity Queensland authorities within 24 hours of the sighting. Further, as per the general biosecurity obligation, every Australian citizen should take all reasonable and practical steps to minimize the risk of spread of *Mikania*. The act also strongly mentioned that prior approval is needed to sell and release the weed and any form of violation is punishable (DAF 2016). However, this kind of legal measures are not reported from several countries, especially in South Asian region.

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Managementand control of *Lantana camara*

1. Introduction

Lantana camara, popularly known as wild sage, is a thorny and multi-stemmed deciduous shrub, native of South and Central America and the Caribbean islands. The plant has been known for its deleterious impacts on terrestrial ecosystems and native diversity. Further, the weed is reported to have been naturalized in nearly 60 countries and several island nations. Considering the vast impacts on the ecosystem, biodiversity and range extension ability, the Invasive Species Specialist Group (ISSG) has declared the weed as one among 100 of the world's worst invasive species. On the other hand, the Global Invasive Species Information Network has placed it among the top ten invasive species list (Lowe, 2003; Dobhal *et al*. 2011; Lüi, 2011; Bhagwat *et al*. 2012; Priyanka and Joshi, 2013; Priyank *et al*. 2013).

Around the 19th century, the weed was widely introduced in the tropical parts of Africa, Asia and Oceania as an ornamental and hedge plant. In due course of time, the noxious weed managed to escape from the introduced sites and invaded several hectares. For instance, studies around 2010 disclosed that *Lantana* invaded 2 million ha in South Africa, 5 million ha in Australia and 13 million ha in India (Love *et al*. 2009; Bhagwat *et al*., 2012).

Weed invasion pattern studies with the help of spatial maps clearly established that early invasion started from the metro cities and towns and subsequently moved to the semi-urban areas, countryside and protected areas. This movement pattern was well established from the studies carried out in Australia and South Africa, whereas in India, most of the earlier studies are from the Nilgiri Biosphere Reserve (see Bhagwat *et al*., 2012).

Besides, the need of *Lantana* management was first recognized in India followed by Australia around the 1920s (see Bhagwat et al, 2012). Pertaining to India, the weed *Lantana* was introduced as an ornamental plant around 1807 at Royal Botanical Garden, Kolkata (renamed as Acharya Jagadish Chandra Bose Indian Botanic Garden). Now the species has been reported in all the tropical and subtropical habitats of India. Since 1920, several methods have been attempted to control the weed in India, including the use of tamed elephants to uproot *Lantana*. However, there was not much success (Thakur *et al*., 1992; Love *et al*. 2009; Bhagwat *et al*. 2012).

Apart from the deleterious impacts, researchers also mentioned about the utility value of the species across countries. Especially a number of studies have underscored the ethno-medicinal property of this weed. In general, the leaves of the plants are used to control blood pressure, modify respiration rate and trigger bowel movement. The leaf extract is also used to cure boils, swellings and body pain and exhibit antimicrobial, fungicidal, insecticidal and nematicidal properties and is also used as mosquito repellents (APFISN; Chatterjee, 2015).

2. Biology of *L. camara*

L. camara is a much-branched, deciduous upright shrub belonging to the family Verbenaceae. It is usually 2–4 m tall and forms dense thickets. Sometimes it grows like a vine (climbing or trailing woody-stemmed plant), especially near the dense vegetative area, and it reaches up to 15 m height in this condition. The stems of the weed are square when young and become round when it matures. The outer surface of the stems is covered by bristly hairs with scattered small prickles (Priyanka and Joshi, 2013; Keys and Fact sheet 2018).

The weed has oppositely arranged leaves with 5–30 mm long leaf stalks along the stem. The leaves are serrated blade margin with broad end at base. The texture of the leaf is quite rough but the underside is soft. Besides, the leaves have a strong aroma (Priyanka and Joshi 2013; Keys and Fact sheet 2018).

Lantana produces multi-coloured (white, cream, yellow, orange, red, pink, purple) small tubular cluster flowers (9–14 mm long and 4–10 mm across). Researchers have documented over 100 different combinations of flowers in wild varieties and subsequently the colour of the flower changed as an initiate of the act of pollination. Obviously, the flowers acted as a visual cue for the pollinators. The pollinations of the flowers are carried out with the help of insects and some smaller animals, especially butterflies,thrips and honeybees. In particular, the flowers are highly adapted to butterfly pollination (Schemske, 1976; Priyanka and Joshi, 2013; Keys and Fact sheet 2018).

The flowers produce green colour fleshy berries (fruits) and turn purplish-black or bluish-black when mature

and grow 3–6 mm in diameter containing 1–2 seeds of 1.5 mm long. Round the year *Lantana* can produce flowers and fruits (12,000 fruits/year); however, a peak flowering period is highly correlated with rainy season (Priyanka and Joshi, 2013; Keys and Fact sheet 2018).

The propagation of *Lantana* is largely by seeds, and they are easily dispersed through bird and animal faeces. Besides, the colony also spreads laterally through branches; whenever a branch/stem meets the soil surface, subsequently they produce root and develop into a new plant. In addition, the fragmented/broken stem can also give rise to new plants. However, the propagation through the seeds plays a crucial role in the invasion process (Priyanka and Joshi, 2013; Keys and Fact sheet 2018). Approximately a plant can produce up to 12,000 fruits each year, and germination process is more successful once the seed travelled through the gut of a bird or mammal. Comparatively the seed germination is easier and faster in *L. camara* and the seed viability ranged between 2 and 5 years. Apparently, the exact time of seed viability is still unknown and is mostly dependent on plant varieties, soil types and moisture levels. Anthropogenic disturbances such as burning, slashing, clearing, construction activities accelerate the seed germination process, even though the peak germination process starts after summer rains. The open canopy and dryness prevailing in the habitat will facilitate fast germination. However, the plant has a shallow root system made up of a short taproot with lateral roots that form thick cover (Priyanka and Joshi, 2013; The *lantana* profile, 2018).

3. Impacts of *Lantana camara*

Global and regional studies have established the deleterious impacts of *Lantana* on the ecosystem and native diversity. Several studies have pinpointed the role of this weed in eliminating native diversity. *Lantana* has the potential to distract the natural succession cycle of the native vegetation and systematically alter the floral composition of native communities (Murali and Setty, 2001; Sharma and Raghubanshi, 2010). Besides, the invasion intensity significantly increases the allelopathic interactions with native community, which directly affect the native species' richness (Day *et al*., 2003). For example, studies from the Himalayan foothills clearly establish the reduction in species richness and native tree populations (Prasad 2007). Apart from wild flora, 14 major cash crops such as coffee, cotton, coconut, tea, rice, oil palm and sugarcane are also affected by the allelopathic properties of *Lantana* (Bhagwat *et al*. 2012).

Several studies also highlighted the occurrence of *Lantana* in protected areas such as biodiversity hotspots, national parks and sanctuaries. For instance, several world heritage sites and endangered ecological communities are under tremendous pressure due to *Lantana* invasion (e.g. rainforest of northern Queensland, Fraser Island and the Greater Blue Mountains). Likewise, the Fynbos of South Africa and several Indian biodiversity hotspots have also suffered by the invasion (Bhagwat *et al*. 2012).

Moreover, *Lantana* is home to malarial mosquitoes and tsetse flies and stands as a reason for causing lethal diseases (Hiremath and Sundaram, 2005). The summation of the impacts of the weed *Lantana* is provided in Table 1.

A number of studies have highlighted the impacts of *Lantana* on ecosystem and biodiversity; however, scanty evidence is available at present to validate these claims (Priyanka and Joshi, 2013).

Table 1. Important impacts of *Lantana*

S. No	Impacts
1.	Diminishes the succession rate and decreases native biodiversity
2.	Understory competitor for forestry
3.	Reduces the economic viability of the crops
4.	Allelopathic qualities reduces the vigour of native plant species and limits their productivity and interferes with harvesting
5.	Loss of pasture in grazing areas
6.	Poisoning of livestock by plants
7.	Seeds are poisonous if ingested
8.	Affects agriculture by outcompeting native pastures
9.	Handling plant may cause skin irritation or allergic reaction
10.	Interferes with the mustering of cattle, causing death of stock by poisoning
11.	Reduces overall productivity in orchards
12.	Harbours pests/vector

Source: Priyanka and Joshi, 2013.

4. Management

Since the 19th century, continuous attempts have been made by the administrators to control *Lantana*. Pertaining to India, a combination of mechanical, biological and chemical methods were attempted. However, most of the time, combination/integrated methods are more reliable and effective rather than a single method.

a. Chemical Control

A large number of chemicals are used to control *Lantana* (*e.g*. aminopyralid, glyphosate, fluroxypyr, grazon DS, triclopyr). However, the effectiveness of chemicals on *Lantana* varies considerably depending on the nature of the habitats and various growth stages. For instance glyphosate is marginally effective as a foliar spray and regrowth is common in the practised area. Likewise the application of a mixture of fluroxypyr and aminopyralid two times within 6 months is effective. However, the use of fluroxypyr @ 0.5 to 1 L/100 L water, glyphosate @ 1 L/100 L water, triclopyr @ 1 L/60 L water and razon DS (300 g/L triclopyr + 100 g/L picloram) @ 350 mL/100 L water per ha is recommended during the growth period of this weed (APFISN; Priyanka and Joshi, 2013).

On the other hand, the use of such chemicals always causes some undesirable impacts on the native taxa and soil and water chemistry. Besides, the chemical residues reach considerable distance via food chain and cause the aforesaid impacts on habitats, which is several kilometres away from the chemical application site (APFISN; Priyanka and Joshi, 2013).

b. Biological Control

Globally so far 40 bio-control agents have been released to control the weed *Lantana*; however, there is no detailed record about the complete eradication of *Lantana* through this method. The well-known bio-control

agents include *Calycomyza lantanae, Diastema tigris, Falconia intermedia, Ophiomyia lantanae, Teleonemia elata, Teleonemia scrupulosa*. Some of the insects like sap-sucking bug (*Teleonemia scrupulosa*), leaf mining beetles (*Octotoma scabripennis*), and seed feeding fly (*Ophiomyia lantanae*) have had some major impact on controlling the weed. Apart from the insects, one of the rust fungus, namely *Prospodium tuberculatum*,was used to control *Lantana* in Australia (APFISN; Priyanka and Joshi, 2013).

On the whole, the bio-control methods are not so effective due to extreme variability of *Lantana*, unique climatic condition of the introduced nation, high level of parasitism on bio-control agents and failure to maintain a sustainable population, that is, need for repeated introduction (APFISN; Priyanka and Joshi, 2013).

c. Control by Utilization

Given the limited success in conventional control methods, obviously, the administrators explored development strategies aimed at best utilization of the species. Apparently, there is more chance for providing livelihood opportunities to the local communities by educating them on craft making, developing herbal medicine and uses of biofuel. Researchers advocated that, through this method, we can simultaneously create awareness about the impacts of the species and pave way for eradication of the species (Priyanka and Joshi, 2013).

The stems of the weeds are widely used by the local and ethnic people to manufacture furniture, rubbish bins, baskets, flowerpots, chicken coops, toys, weaving hedges, thatching roofs and temporary shelters. The handicrafts made from *Lantana* are strong, free from termite infectionand also lasts long. ATREE of Bangalore is now exploring the way for developing unique products from *Lantana* in order to manage the invasion problems in protected areas (APFISN; Kannan *et al*. 2008; Bhagwat *et al*. 2012).

Besides, *Lantana*, with 75.03% holo-cellulose, 8.461% extractive, 18.21% lignin and 2.31% silica, can be aptly used by the paper industry as an alternate renewable raw material. Studies also proved that good quality writing and printing paper can be prepared if the stems are treated with sulphate. In addition, in due course of time, the exploitation of the traditional forest species such as bamboos will be minimized and conserved (APFISN; Singh *et al*. 1992; Ray *et al*. 2006).

The stems and twigs of this weed act as good firewood and can be widely used for heating and cooking. Besides, it is also used to produce ethanol and other biofuel, which can be used for heating (Sharma *et al*. 1988). Notably, control through utilization is an ideal option for controlling the weed and providing livelihood to rural and ethnic communities.

d. Control through Legislation

Countries like Australia and South Africa have some legislation, which restricts the import of *Lantana* and insists the need for eradication. In Australia, the New South Wales Noxious Weeds Act 1993 declared *Lantana* as a noxious weed. Furthermore, through the Pest and Stock Route Management Act 2002, it declared all the varieties of *Lantana* species as Class III plant. The Act prohibited the sales of the species and also explains

the landowners' responsibility on eradicating the species from their land (DPIF 2008; Bhagwat *et al*. 2012).

South Africa declared *Lantana* as a noxious weed under the Weeds Act (No 42, 1937). The Conservation of Agricultural Resources Act (1983) declared *Lantana* as Category I weed of South Africa. These two acts clearly indicated the responsibility of landowners on eradicating the weed (see Bhagwat *et al*. 2012).

Obviously, no such legislation exists in India on controlling *Lantana*. On the other hand, India has several acts addressing the issues associated with invasive species, but apparently there is no core policy and robust legislative framework on invasive issues (Priyanka and Joshi, 2013).

e. Mechanical Control

Mechanically or physically removing *Lantana* is a common practice adopted by several countries. The usual methods are hand cutting, hand and chain pulling, bulldozing, ploughing, stick raking, grubbing of the medium-sized plants and flame weeding. Every mechanical control method has its own limitation; for instance, several methods are highly suitable for smaller areas as well as not recommended in areas prone to soil erosion. Setting fire is also an effective option when it is practised under the right conditions. However, burning is not recommended in natural dense forest areas (APFISN).

Pertaining to India, the most common methods used to manage *Lantana* in forests are hand pulling, slashing/chopping of the stems, burning and manual grubbing with substantial removal of the root system. However, it was not so effective/applicable in all the areas. Some of the methods even accelerate the infestation and worsen the situation. For instance, burning of the weed has facilitated spread of the species into new areas as well as encouraging the new growth and multi-species invasion (Love *et al*. 2009).

In 2009, the Centre for Environmental Management of Degraded Ecosystems, School of Environmental Studies, University of Delhi, proposed a sustainable mechanical method called cut rootstock method to control *Lantana*. In this method, *Lantana* can be cleared by '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 the undulating terrain and hilly tracts, the operation should be taken up on the slopes first and then downwards to the valley. The crew recommended carrying out the operation before flowering and fruiting (Love *et al*. 2009). The detailed procedure of the methods is described in Love *et al*. (2009).

The cut rootstock method was practised in 5 hectares as a trail in Corbett Tiger Reserve; soon the weed-free areas were restored into luxuriant grasslands. After three years, the habitats attracted several native herbivore species such as deer, wild boars and elephants. Based on the result obtained in Corbett Tiger Reserve, cut rootstock method was practised in Kalesar National Park (Haryana) and Satpura Tiger Reserve (Madhya Pradesh) (Love *et al*. 2009).

However, all the conventional methods require extensive management and follow-ups. Besides, it is important to know when not to use all the conventional control measures. The managers should analyse which would be effective and less cost-intensive for better and sustainable management (Priyanka and Joshi, 2013). Some of the general information about this is provided in Table 2.

Table 2. Things to do and not to do for an effective control of *Lantana*

Control Method	When to Use	Restriction to Use
Biological control	Bio-control agents are available and not already present	If the bio-control agents affect native species.
Mechanical control	Area suitable for access by machinery without causing damage to the habitats Not leading to further damages such as land degradation	Near rivers, creeks and drainage and lines If not possible to follow-up with treatments such as chemical or manual removal.
Manual removal	Cheap and adequate labour availability Smaller area to clear Easy possibility of follow-up technique after fire or mechanical removal	Cost of labour outweighs land value
Fire control	Extensive area Little risk of fire spreading	Near/within the dense forest Not to be used unless treatment done with chemical

Source:Priyanka and Joshi, 2013.

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Management and control of Water hyacinth (*Eichhornia crassipes*)

1. Introduction

Water hyacinth *Eichhornia crassipes* (Mart.) is one of the deleterious floating aquatic invasive plant species native to Amazon basin ofBrazil, South America. This species has drastically invaded into many tropical and subtropical countries of Latin America, Caribbean, Africa and Southeast Asia. Invasion of this species causes huge loss to aquatic biodiversity and provides home to several disease-causing vectors such as mosquito and snail. Due to its vast impacts on the regional economy, biodiversity and human health, the weed has been recognized as one of the 100 most dangerous invasive species and the top ten worst weeds (Julien *et al*., 1999; Julien, 2001; Narayanan *et al*.; 2007; Patel, 2012).

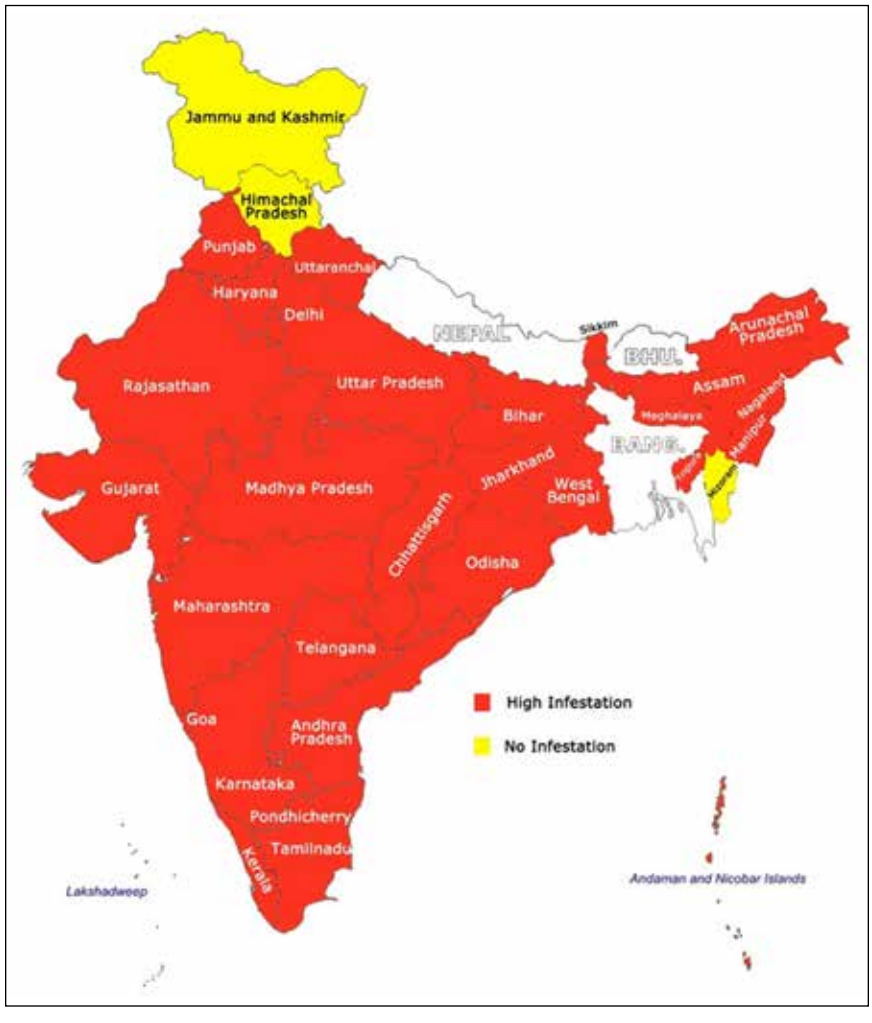
At the end of the nineteenth century, the plant was introduced into several parts of the world for ornamental purpose. In due course of time, water hyacinth found its way into natural inland water bodies such as lakes, rivers, reservoirs and rural ponds. In most of the wetlands of Africa and India, this species is still spreading even after a century of its initial introduction (Navarro and Phir, 2000; CABI, 2015).

Water hyacinth has been recognized for its rapid growth, dispersal capabilities and broad environmental

tolerance (Zhang *et al*., 2010). Within a short period, this weed can form dense impenetrable mats across the water surface, preventing the entry of sunlight and also limiting water access for human and wildlife. Further, the proliferation of the weed in the wetlands will slowly alter the density and diversity of the floating and submerged native aquatic plant species, ending in regional extinction. Besides, it will also choke the irrigation and the drainage systems, causing artificial flooding during rainy season (Julien *et al*., 1999; Narayanan *et al*.; 2007; Cherly, 2013). Despite the deleterious impacts, this weed has proved to have some ecological and economic benefits, which need to be explored further.

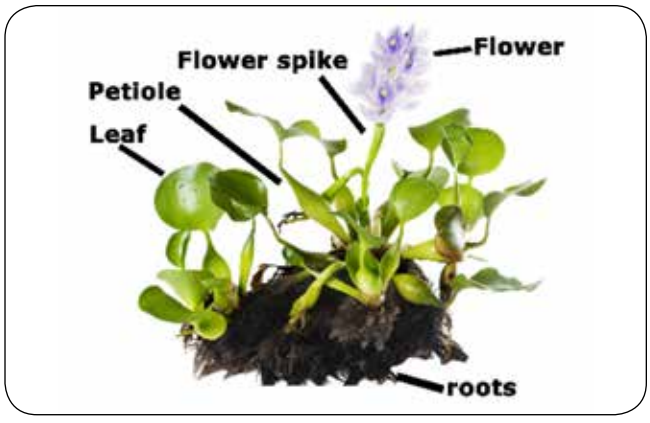
Pertaining to India, the weed was introduced during the colonial period as an ornamental plant in Calcutta Botanical Garden. Now the invasion of water hyacinth has been reported in almost all the inland wetlands of the country except the states of Himachal Pradesh, Jammu and Kashmir and Mizoram. Researchers stated that climate conditions in the aforesaid regions prevent the invasion very effectively. Besides, studies disclosed that all the major manmade and natural wetlands of India are continuously suffering by the invasion of this species for more than two centuries. Ironically, a large number of Indian Ramsar sites (e.g. Ashtamudi Wetland, Chilika Lake, Deepor Beel, Keoladeo National Park, Kolleru Lake, Loktak Lake, Ropar Wetland) have been facing huge socioeconomic and biodiversity problems due to this infestation (Narayanan *et al*., 2007).

Degree of infestation of Eichhornia crassipes in different States and Union territories of India



Source: Narayanan *et al.*; 2007

2. Biology of *E. crassipes*



Water hyacinth is a perennial, aquatic herbaceous plant belonging to the family Pontederiaceae. The plant can reach up to 65 cm in height and produce dark green rounded leaves with a diameter of 5–10 cm. The leaves comprise smooth, glossy, circular to kidney-shaped lamina and swollen spongy, bulbous structures when the plants are young. However, the matured plants have elongated leaf stalks (Gopal, 1987; Fact sheet 2016).

An erect stalk supports a single spike of 8 to 15 violet and yellow flowers; sometimes the flowers are light to darker blue-purple. The flowers can be self-fertilized and the inflorescence produces 3000–4500 egg-shaped seeds, which can reach a size up to 1.5 mm long and remain viable for 5–20 years. A single rosette can produce several inflorescences and several thousands of seeds in a season (Barrett, 1980; Gopal, 1987; Hill, 1999). Once the flowers of a plant withered, the stalk gradually bends into the water and releases the seeds after 18 days. The seeds reach new places by traveling through water movement and by attaching with aquatic vehicles such as boats. The changes in the water level highly influence the seed germination at various periods (Wright and Purcell, 1995; Julien *et al*., 2001; Fact sheet 2016). However, the seedlings develop into plants within 40 days after germination and get detached from the mud and become a free-floating plant (Barrett, 1980; Rao, 1988).

Vegetative reproduction is a common form of propagation rather than the sexual mode of reproduction. In fact, vegetative reproduction is largely responsible for the rapid increase of the biomass and facilitate establishing a colony in a new area (Barrett, 1980). Daughter plants are produced by vegetative methods; from the horizontal stolons they develop their own roots and later on separate from the mother plant. In warm climates, vegetative reproduction is rapid and enables the formation of large, dense mats within a short time. Besides, the young plants are detached from the mother plant during heavy wind, flood, fishing and other associated aquatic activities (Julien *et al*., 1999; Fact sheet 2016).

3. Impacts of Water hyacinth

Studies across the countries and continent evidently established the negative impacts of water hyacinth on biodiversity, environment and regional economy. The invasion affects the water transport, fishing, disruption of hydroelectric operations, blockage of the natural water tributaries and causes flooding and increase in the evapotranspiration rate. Besides, globally millions of people directly and indirectly suffer due to this weed in many forms (Howard and Matindi, 2003. Narayanan *et al*.; 2007).

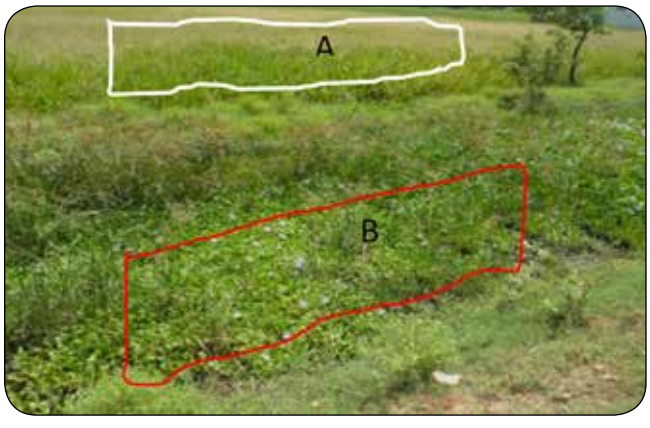
In general, the massive proliferation of the plant minimizes the availability and access of open water surface. Further, large-scale invasion prevents the entry of sunlight and significantly alters the air–water interface, which results in poor primary productivity. Researchers also found that massive invasion could significantly increase the sedimentation concentration. The combination of these phenomena results in de-oxygenation and poses

a serious threat to all aquatic organisms and leads to biodiversity loss. Moreover, the dense vegetation turns as a roosting and breeding ground for several vectors such as mosquitos, flies, and snails, which can transmit diseases like cholera, malaria, filariasis and schistosomiasis. Further, during water scarcity period, the weed starts to decompose with a distinctive smell and causes air pollution (Hailu et al., 2004; Kassahun *et al*. 2004; Narayanan *et al*.; 2007; Taye *et al*., 2009; Mujingni, 2012; CABI, 2015).

Also, the invasion highly affects the local fishing industry. For instance, fish catch rates on the Kenyan section of Lake Victoria decreased by 45% due to this weed invasion. Local community stated that the invasion prevents/ delays reaching fishing areas and also delays sending harvested fish to the market (Kateregga and Sterner, 2007). Further, the invasion also affects and reduces the natural water flow in the large lakes like Lake Victoria and causes several problems (Julien *et al*., 1999). For instance, in 1997, Kenyans were unable to operate the boats with capacities less than 700 tonnes in areas where water hyacinth had densely invaded; due to this Kenya Railway activities were closed in several areas such as Asembo, Homa Bay, Kendu Bay (Mailu, 2001). Apart from that, many large hydropower schemes also suffered because of the invasion (*e.g*. Owen Falls hydropower scheme at Jinja on Lake Victoria; Koka hydropower dam in Ethiopia) (see Gebregiorgis, 2017).

Moreover, most of the time, the small irrigational canals are choked by this weed, which affects agriculture productivity. It was also reported that the intrusion of the species in the paddy field directly suppresses the paddy germination and harvesting operations (EEA, 2012; Patel, 2012).

Whereas in India, Deepor Beel, a freshwater lake formed by the Brahmaputra River, was heavily infested by water hyacinth and it has been identified as causing heavy siltation in the wetlands. Navigation in the Brahmaputra river has been affected by water hyacinth, and it has also blocked irrigation channels and obstructed the flow of water to crop fields; slow water flow by 40 to 95% in irrigation channels was also reported in several parts of India (Jones, 2009; Patel 2012). In West Bengal, it causes huge annual loss of paddy by directly suppressing the crop, inhibiting rice germination and interfering with harvesting (Patel, 2012; EEA, 2012). Besides, the dense growth entangles with boat propellers, hampering fishing activity (Patel, 2012).



Invasion of E. crassipes in an irrigational canal obstructed the flow of water to paddy crop fields. (A) Paddy field, (B) Invasion in the canal. (Photo by Sandilyan.)

Water hyacinth clogging a canal in Chidambaram town, Cuddalore District of Tamil Nadu. (Photo by Sandilyan.)

4. Management

Globally, a number of effective control methods (physical, chemical and biological) have been adopted by the authorities to control the weed. However, every method has its own flaws. For instance, mechanical control is highly effective but is very expensive for developing and underdeveloped countries (see Rakotoarisoa 2017). Likewise, herbicides are so effective but not affordable by third world countries. Besides, it leads to environment pollution (Gnanavel and Kathiresan, 2007). Researchers recommended that prevention is the better option to escape from the deleterious impacts of water hyacinth. Especially colleting the weed from the larger areas before heavy rain and flood will help to halt further expansion and new invasion. In addition, removal of the plants before seed formation is a viable option (Fact sheet 2016). However, a number of studies advocated for integrated management.

a. Mechanical Control

Removal of water hyacinth by hand or machine is known as mechanical control. This method is more suitable if the infested area is small. However,if there is an urgent need to restore the functions and services of a large wetland with high infestation, mechanical harvesting is the suitable option. On the other hand, roughly 600–900 hours is needed to clear 1 hectare of dense infested area with some minimum device. For a better result, the removal process should start before flowering and seed formation. Further, to avoid the reoccurrence, the collected plants should be taken away from the cleared site and burnt (Australian Weeds Committee 2012;Cherly, 2013; Fact sheet 2016).

b. Chemical Control

Application (spraying) of chemicals has been identified as one of the effective management tools for controlling water hyacinth invasion in smaller areas. High-volume spraying with hose and handgun power sprays is the commonest mode of chemical application used to control water hyacinth. Application of chemicals can be easily carried out on the embankment of water body or using small boats. Some of the developed countries like Australia have opted for aerial spraying for large-scale invasion (Cherly, 2013; Australian Weeds Committee.2012; Fact sheet 2016).

In general, herbicides such as Amitrole, 2,4-D amine, Dalapon, Diquat are used by the managers to control the weed. However, researchers insisted that before the application of herbicide, it is essential to read the label and follow the instruction carefully. For instance, for application of herbicides where the water is used for irrigation and domestic use, the withholding period should be followed in accordance with the label. The details of some common chemicals recommended are provided in Table 1 (Cherly, 2013; Australian Weeds Committee 2012; Fact sheet 2016). After chemical application, decomposing vegetation will heavily affect the water quality, especially significantly altering the dissolved oxygen level. Obviously, oxygen level depletion will directly affect the productivity of the wetland. In order to avoid this phenomenon, simultaneously applying chemical on the one hand and going for physical removal on the other hand is the best available option. It is a fact that overapplication of chemicals in a wetland will denature/pollute the water quality and affect the aquatic diversity too (Cherly, 2013; Australian Weeds Committee.2012; Fact sheet 2016).

Table 1. Recommendation of herbicides for the control of water hyacinth in different situation

Situation	Herbicide	Rate	Suggestions
Waterways, nonpotable water, drains, dam margins, lakes and streams	2,4-D acid 300 g/L (e.g. Affray 300)	50 mL/10 L water or 500 mL/100 L water	Hand gun: 200 L spray solution/1000 m^2 Avoid causing submersion of sprayed plants
		1 L/20 L water	Sprinkler sprayer . Coverage 20 L spray solution/1000 m^2
		5 L/200 L water/ha	Boom application by helicopter. Raindrop D8 nozzles angled back at 45 degrees to minimize spray drift
Aquatic areas, channels, dams, bore drains and waterways	Amitrole 250 g/L + ammonium thiocyanate 220 g/L (e.g. Amitrol T®)	280 mL/100 L	Apply immediately prior to flowering. If infestation is large, treat in sections to avoid eutrophication of water
	Diquat 200 g/L (e.g. Diquat 200 (various brands) Reglone ®)	400 mL/100 L water + 150 mL Bonus wetting agent (permitted under Permit PER81236 APVMA; permit expires 30/06/2020)	Small areas. Thoroughly saturate. About 1 mL of product (250 mL of spray mix) should be sufficient to treat 1 m^2. Do not use water for 10 days after application
Pastures, rights-of-way and industrial	2,4-D amine 635 g/L (e.g. Crop Care Amine 625, Ken-Amine 635 and many other products) and other formulations where label includes water hyacinth	3.5–5.3 L/ha For other formulations consult label for correct rate	Apply to 2200–3300 L water/ha Refer to label for critical comments

Source: Fact sheet (2016).

c. Biological Control

Biological control is the cost-effective, eco-friendly and sustainable method to control water hyacinth. Further, it is a very good option for the places where the habitats are prone to repeated and large-scale invasion (Narayanan et al; 2007; Fact sheet 2016).

One of the most successful biological control methods is the introduction of insects on the infested areas. Globally, a number of insect species have the potential to control this aquatic weed (e.g. *Neochetina eichhorniae, Neochetina bruchi, Niphograpta albiguttalis, Xubida infusella*). However, the control efficiency of the agent is determined by several factors such as climate and water level. For instance, studies from Australia found that *N. eichhorniae* was more effective in Queensland; on the other hand, its efficiency in subtropics and cold areas is not up to the mark (Fact sheet 2016).

Apparently the success of the biological control agents depends considerably on the continuous availability of the weed in a wetland. In Indian condition, most of the water bodies are constrained with seasonal water flow and are mostly dry in summer. Therefore, the application of bio-control agents along with other methods is more effective in India (Gnanavel and Kathiresan. 2007).

Besides, a study by Kathiresan (2000) established the efficiency of an Indian medicinal herb *Coleus aromaticus/ amboinicus* in controlling water hyacinth. The application of powdered dry leaf of the plant in water bodies at 30 g/L showed a complete weed mortality within 24 hours and 100-biomass reduction within 9 days. Further, the application of the natural herbicide will be effective when it is absorbed through the root system. However, it is ineffective when it is applied on the foliage of the plant due to the lack of absorption through foliage surface.

d. Control by Utilization

Apart from the detrimental effects of weed infestation, the plant has several economic uses that indirectly help us to control the infestation. The rapid growth and biomass are helpful to produce briquettes, biogas (methane), fertilizers, fodder (for ruminants, pigs and ducks), furniture, handicrafts and to clean waste water through phytoremediation processes (Teherruzan and Kushani, 1989; Mehra et al.,1999; Jafari 2010; Ndimele et al 2011; Patel 2012). However, special technical skill is required to obtain biogas and briquettes from water hyacinth (see Rakotoarisoa, 2017). In the same way, manufacturing furniture and handicrafts from this weed is a viable option but it requires adequate market outlets (Patel, 2012). Further, recently researchers have derived sugar molecules like lignin, cellulose and hemicellulose from the weed and have converted it to polyhydroxybutyrate, which is a raw material to prepare biodegradable plastic (see Cherly, 2013).

Pertaining to India, a number of products have been derived from water hyacinth. In Andhra Pradesh, Allika, a social enterprise, is effectively manufacturing several products with the help of rural women and successfully marketing it in several parts of the country. Their products range from handbags, sling bags, laptop bags, to bowls, hats, trays, cups, lampshades and clutches and wallets. The pictures of the products are placed in the Annexure for reference (see: https://www.youtube.com/watch?v=P9MXAWz6V1s). Obviously, it will give livelihood to rural community. Exploring and encouraging this kind of studies will help to halt the invasion in a sustainable way.

e. Recommendation

Even though many management and control measures are available, the researchers underscored that, for an effective result integrated control method is the best. For instance, in Australia, the managers adopted the integrated approach by using mechanical removal followed by chemical application in highly infested areas. In this process, first they removed huge biomass with the help of specialized machines followed by spraying chemicals to eradicate the remaining and re-emerging plants. According to the authorities, the method has been successfully used to restore several floodplain wetlands and creek in Queensland (Australian Weeds Committee 2012). However, consider the local situation, habitat type and nature of water utilization (domestic, irrigation, recreation) before going for any control method (Australian Weeds Committee 2012).

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Some of the products from Allika, a social enterprise

About CEBPOL

Government of India in collaboration with the Norwegian Government has established "Centre for Biodiversity Policy and Law (CEBPOL)" at the National Biodiversity Authority (NBA), an autonomous and statutory body of the Ministry of Environment Forest and Climate Change towards strengthening of expertise in Biodiversity Policy and Law in India. This programme is executed by the NBA in collaboration with Norwegian Environment Agency through the Royal Norwegian Embassy, New Delhi, India.

The Centre aims to provide advice and support to the Government of India and Norway on Biodiversity Policy and Law related issues including complex negotiations on Access and Benefit Sharing and Traditional knowledge as well as governance issues relating to biodiversity at the National and International level. The Centre proposes to help NBA in the effective implementation of International agreements on conservation, sustainable use and the associated access and benefit sharing components of it.

CEBPOL is set up as a specialized Centre of Excellence in Biodiversity Policy and Law to network, organize and consolidate expertise on issues of Biodiversity Policy and Law in India and Norway. The Centre, located at NBA, would function as an independent think tank on Biodiversity Policy and Law. In addition, CEBPOL aims to contribute to the effective implementation of the Biological Diversity Act 2002 and Rules 2004.

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