

Article

## A framework for management of *Lantana camara* in India

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### Abstract

Invasive species are recognized as potential threats to ecosystem and this problem is exacerbated as global trade and travel accelerates and human-mediated disturbance increases. Synergies are lacking across management, research, policies and decision making as there are insufficient networking, coordination and collaboration across organizations and departments to manage invasion. Thus, sustainable management of invasive species is challenging but inevitable given the increasing range of alteration caused by invasion which has little prospect of irreversibility. To be sustainable, Invasive Species Management Framework (ISMF) strategies must include environmental, social, economic and political factors that influence the causes, impacts, and control of invasive species across spatio-temporal scales. Although these elemental management strategies are easy to document and comprehend but their implementation is often limited by insufficient control measures, funds, research, socio-economic pressures and political constraints. In this paper, specific objectives for sustainable management of invasive species, *Lantana camara* – notorious weed, is proposed for Indian settings. Even a few of the outlined ISMF strategies, if incorporated into a management plan, will lead to effective management through increased coordination, communication, transparency, accountability and help avert potential risks posed by accidental and/or intentional introduction of *L. camara*. Incorporating these management strategies in formulating plans will allow not only allow decision makers to respond quickly and effectively to invasions but will also enable to combat new invasion in a rapidly changing global environment.

**Keywords** invasive species; *Lantana camara*; sustainable management; management plan; framework.

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### 1 Introduction

According to the World Conservation Union, invasive species are generally considered to be the second greatest threat to biodiversity after habitat destruction (Wilson, 1992; Buckley et al., 2004; De Milliano et al., 2010; Zhang and Chen, 2011). In their new ecosystems, these become predators (Drenovsky et al., 2012),

competitors (DiVittorio et al., 2007), parasites (Holmes et al., 2009), hybridizers (Corbin and D'Antonio, 2004; Prentis et al., 2008; Cordell and Sandquist, 2008), and cause diseases to native and domesticated plants and animals (Ehrenfeld, 2006; Chambers et al., 2007; van Kleunen et al., 2010). Besides these, they create a host of harmful effects to native environs that include displacement of native species (Cohen and Carlton, 1998; Anderson, 2005), degradation or elimination of habitat (Rogers and Biggs, 1999; National Invasive Species Council, 2005), alteration in soil properties (Szaro et al., 1998; Nichols and Williams, 2006), degradation or elimination of wildlife forage (Williams, 2001), adversely alter fire regime (D'Antonio and Vitousek, 1992; Varner et al., 2009; Metz et al., 2011) and pose a considerable threat to endangered species (Wilcove et al., 1998; Moore and Conroy, 2006). Besides, these species impose enormous costs of invasion. Researchers have estimated the following annual environmental costs of invasion: Australia – US \$6.8 billion; Brazil – US\$ 6.7 billion; India – US\$ 25.0 billion; South Africa – US\$ 3.0 billion; United Kingdom – US\$ 6.6 billion; and the United States – US\$ 58.0 billion (Pimentel et al., 2000). The ecological, social and economic effects combined together alters native regimes beyond range of variation which has little prospect of reversal (Vila and Ibanez, 2011).

*Lantana camara* L., an invasive terrestrial weed of South and Central American origin, is one such species which has caused huge repercussions to the native composition of terrestrial ecosystem. It has now naturalized in approximately 60 countries or island groups ranging between 35°N and 35°S and is regarded as the world's 100 worst notorious weeds (Lowe, 2007; GISD, 2010; Lüi, 2011). It was introduced to India in 1809 by the British as an ornamental plant for the Calcutta Botanical Garden (Brandis, 1882; Kumar, 2001). Voyaging two centuries of its establishment in India, at present it is considered to be extremely adaptable and prolific. Thus, it has its indiscriminate spread and presence in almost all regions of India including farm (Bhatt et al., 1994; Saha, 2002), pasture (Hakimuddin, 1929; Batianoff and Butler, 2003), fallow land (Sharma and Raghubanshi, 2006) and forest (ISSG, 2008) except the Thar Desert and its surroundings (Dogra et al., 2009). Its invasion is implicated in widespread loss of native species diversity via recruitment, limitation, competition, and alteration of ecosystem structure and function (Bhatt et al., 1994; Fensham et al., 1994; Swarbrick et al., 1995; Gentle and Duggin, 1998; Sharma et al., 2005; Kohli et al., 2006; Dobhal et al., 2009). Not only is the geographic range of *Lantana camara* escalating in various regions, but the density of infestations within its range is mounting and has been acknowledged and recognized as a potential threat (Sharma and Raghubanshi, 2006; Kimothy et al., 2010; Lüi, 2011).

So far, various control measures have been employed to curb *Lantana camara* infestations in India, but none have been able to completely curtail its invasion. Control measure involving mechanical methods are coupled with certain drawbacks such as problem of re-growth which is imminent if the rootstock is not removed while weeding; suitability of such method is for smaller areas only and not recommended in areas susceptible to erosion. Various authors have proposed control of *Lantana camara* through application of chemicals such as glyphosate, fluroxypyr with aminopyralid, imazapyr and many more. However, these suggestions are still under testing stage and little has been done in this regard to serve as effective measure to combat species. In addition, there is likelihood of harm being caused by them to the ecosystem through affecting food chain, soil health, causing water pollution and/or giving genesis to ancillary problem. A number of biological control organisms have been studied for controlling *Lantana camara* spread. There are no effective agents available on an operational scale. Biological organisms for controlling *Lantana camara* include *Ophiomyia Lantanae* (fruit-mining fly), *Calycomyza Lantanae* (agromyzid seedfly), *Teleonemia elata* (leaf-sucking bug), *Teleonemia scrupulosa* (leaf-sucking bug) but most failed as it has several varieties or forms resulting in complicating the introduction and establishment of exotic insects. Several researches on other candidate agents undergoing host specificity and potential impact studies are underway (Rao et al., 1971;

Sankaran, 1971; Sen-Sharma and Mishra, 1986; Thakur et al., 1992; Sharma et al., 2005) and no concrete results have been reported despite the efforts of entomologists worldwide. The failure of biocontrol program directs to think that long-term management will rely on integrative management approach which not only involves control measures, instead strategies directed to intercept species at each stage of invasion should be adopted to combat invasive species.

India has several statutes addressing issues associated with invasive alien species. However, there is not a core policy and legislative framework of common elements, goals and definitions nor has a concerted attempt been made to harmonize the relevant laws and regulations to ensure uniform and consistent practice. There are gaps in addressing management and control of invasive species in legislation and policy. Relevant legislation and policies include, The Destructive Insects and Pests Act, 1914 and amendments; Indian Forest Act, 1927; Wildlife (Protection) Act, 1972; Forest (Conservation) Act, 1980; Environment Protection Act, 1986; The Plants, Fruits & Seeds (Regulation of Import into India) Order 1989 (PFS Order 1989); Livestock Importation Act, 1898 and the Livestock Importation (Amendment) Act, 2001; National Policy and Macrolevel Action Strategy on Biodiversity, 1999; The Biological Diversity Act, 2002; The Plant Quarantine (Regulation of Import into India) Order, 2003; National Environment Policy, 2004 The Prevention and Control of Infectious and Contagious Disease in Animals Act, 2009; but none is exclusively intended to deal with the invasive alien species framework for its control and management (FAO, 2003; CBD, 2005; CITES, 2005; MoEF, 2008; CIA, 2008; APFISN, 2009).

Presently there is no full proof system of reporting about the existence of IAS in India either through the government officials or the general public. Only when a species becomes invasive and starts affecting socio-economically, measures are taken for its eradication and control (APFISN, 2009). Several attempts to assess the risks posed to ecosystems, habitats and species by some invasive within India have been carried out. However, most assessments were done at the local level such as legislative and administrative measures adopted by states such as West Bengal and Tamil Nadu. Active cooperation among the concerned central and state government departments like agriculture, livestock, forests, water resources, tourism, commerce, shipping, environment and rural development involving lead institutions and NGOs are developed, but this is done on case-to-case basis. Thus, it is important to develop a management framework that focuses on strategies and actions which would be effective and less cost intensive for better and sustainable management especially *Lantana camara*.

## 2 Invasive Species Management Framework (ISMF)

The Invasive Species Management Framework (ISMF) is a systematic process intended for use by governments, private companies and individuals to identify the steps that need to be taken to minimize the harmful ecological, economic and human health impacts for efficient and effective management of invasive species (United States National Invasive Species Council Management Plan, 2001). A management framework should possess following characteristics:

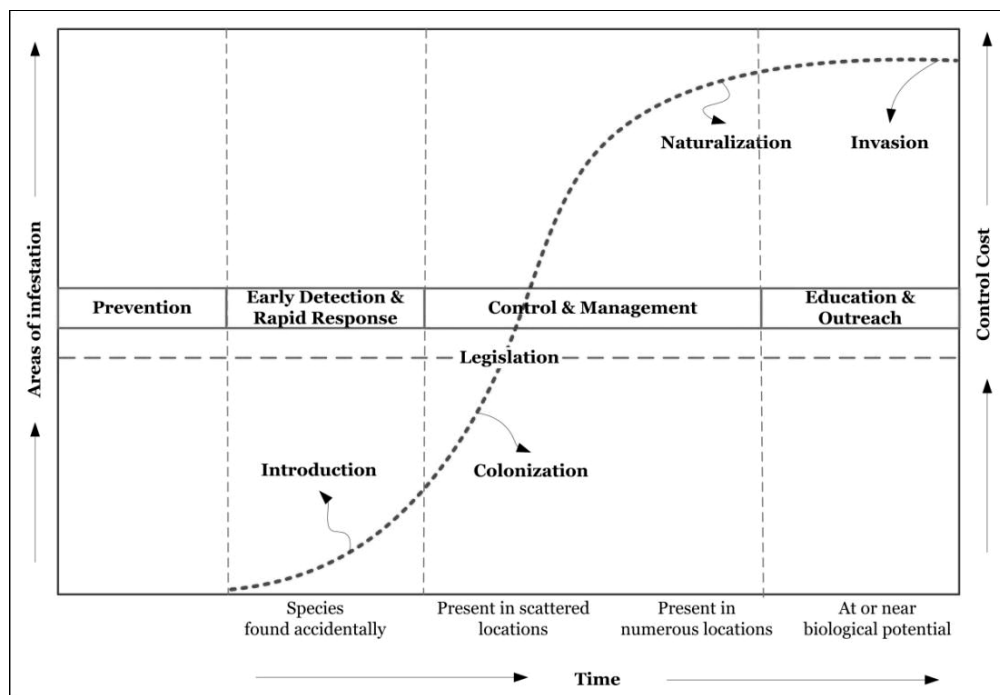
- a. Not a trial and error process but rather links management objectives with learning
- b. Incorporates qualitative, conceptual and highly detailed testable models
- c. Integrates monitoring for measuring progress toward management objectives
- d. Suited under substantial uncertainty regarding the most appropriate strategy of managing
- e. Requires interventions of institutions, government, and stakeholders and their agreement, commitment, and support for monitoring and assessment

ISMF includes various strategies to mitigate the effect of invasion. There are five elemental strategies which forms the baseline for any management framework. These include - prevention, early detection & rapid

response, control & manage, legislation, and education & outreach which are directly or indirectly linked to curtail invasive at varied stages of invasion process (Fig. 1).

**2.1 Prevention**

It is considered to be the most cost-effective and environmentally desirable approach to stop the introduction of new high risk invasive species (introduction phase of invasion process – Fig. 1). In reality, complete prevention is often impossible, and a risk management approach is needed to identify and assess risks, and the feasibility of managing the species after introduction. Monitoring and surveillance to confirm absence, risk and pathway analysis, education and awareness, lists of high risk species and border controls are important tools to ensure that no new high risk invasive species are introduced.



**Fig. 1** Management strategies to curtail invasive at different stages of invasion process.

**2.2 Early detection and response**

When invasive species circumvent prevention measures and enter, it is essential to detect, identify and respond to them before - or immediately after - they become established i.e. when a species voyaging through introduction to colonization phase of invasion process (Fig. 1). Site-specific and general monitoring around critical points of entry, protected areas, urban and agricultural ecosystems is important. Taxonomic expertise and innovative taxonomic research are critical to properly identify invaders once they are detected. Integrated rapid response networks are required and contingency plans and emergency funds for quarantine measures are essential immediately upon detection before they can establish and spread.

**2.3 Control and manage**

The strategy prevents the spread of established species to new areas i.e. a species at naturalization phase of invasion process (Fig. 1). This can be done by containing its distribution and/or by limiting the density of invasive species. The prime focus is on use of control tool such as mechanical, chemical, biological, cultural and many more to contain distribution and abundance of the species.

## 2.4 Legislation

This strategy aims at formulation of legal and regulatory roles and responsibilities through the development of a coordinated legislative ‘road map’ that incorporates all relevant legislation and linkages needs. As appropriate, and where feasible, development of legal and regulatory tools and amendments in existing legislation and regulations to strengthen measures to prevent, detect, respond, and manage invasive alien species needs to be carried out across departments and agencies and their counterparts. This strategy is critical and is of utmost value in managing invasive species at all stages of invasion process.

## 2.5 Education and outreach

The strategy aims to minimize the overall adverse impacts of widespread and abundant invasive species throughout their potential range rather than attempting to manage the invasive species population itself i.e. a species at invasive stage of invasion process. Asset-based approaches are commonly adopted to deal it. Focused efforts complemented by broader outreach efforts, including the development of education curricula, raising awareness on the need to prevent future introductions are implemented at this stage. Education and outreach initiatives facilitating on-the-ground action through stewardship programs that involve communities are part of this management strategy and is sensitive to scale of management

## 3 Success Stories

Most of the invasive species framework revolves around these five elemental strategies and have been incorporated in management plan of various countries to mitigate widespread effect of invasive. Invasive species have posed significant threat to the mission of the USDA (US Department of Agriculture) Forest Service, the health of America’s ecosystems and the security of the nation (USDA, 2003). Framework for the National Invasive Species Management Strategy for the USDA Forest Service was developed to guide invasive species management operations and improve the agency’s effectiveness against this threat. The framework incorporate science-based *prioritization* of invasive species problems, better *collaboration* on the solutions to those problems, and an improved system of *accountability* that ensures the most efficient use of limited resources. The adoption of framework has resulted in increasing effectiveness in invasive species management operations. Further, in Canada, invasive alien species have resulted in significant social costs, especially to rural Canadian and Aboriginals which are dependent upon natural resources. To mitigate this, federal, provincial, and territorial ministers for wildlife, forests, fisheries and aquaculture drafted strategies to address the threats. The management strategies established a framework to address invasive through four strategic challenges, including, *integrating environmental considerations* into decision-making with economic and social factors; *enhancing co-ordination* and *co-operation* to respond more rapidly to invasions and its pathways, *strengthening programs* to protect natural resources under pressure from increased global trade and travel; and *maximizing collaboration* between adhoc and regional/issue specific efforts to ensure the limited resources are used on highest priority issues Thus, approved ‘*framework blueprint*’ have resulted in better response to challenges posed by invasive. Californians have benefited from the introduction of various fish, plants and other species necessary for food or other human pursuits; however, there are many other introduced species that have wreaked havoc on the state’s environment and economy. Thus to combat this effect, a management framework addressing California Aquatic Invasive Species, was developed (State of California Resources Agency Department of Fish and Game, 2008). The framework included five basic management strategies, often in combination for managing invasive species. These included, prevention; early detection and monitoring; rapid response and eradication; long-term control and management; and education and outreach. This proposed framework enabled in reducing both cost and effort of management. In yet another attempt to develop management framework, Australian Pest Animal Strategy (Natural Resource Management Ministerial

Council) and the Australian Weed Strategy (Natural Resource Management Ministerial Council), adopted hierarchical intervention framework for new, emerging and widespread invasive species in their key national invasive species strategies (De Milliano et al., 2010). Thus, the adopted management strategy helped in stopping, eradicating and protecting ecosystem assets at varied stages of invasion. Secretariat of the Pacific Community (SPC) and Secretariat of the Pacific Regional Environment Programme (SPREP) developed a comprehensive management framework for managing pests, weeds and other invasive species (Tye, 2009) in response to growing invasive species menace in the Pacific. The management framework drafted herein focused around nine themes which included information, awareness, infrastructure, protocols, legislation, funding, linkages and others into a logical structure. The management framework provides a comprehensive strategy for invasive species management in the Pacific for the foreseeable future and also provides guideline for its replication by regional and international agencies for developing their management framework. Further, management framework developed for Alberta Invasive Alien Species (2010), laid emphasis on increasing coordination and communications and henceforth increasing transparency and accountability. Thus, through this enhanced communication, collaboration, and coordination risk of invasive species have declined in recent past and have also improved preparedness and awareness among people of Alberta (Invasive Alien Species Working Group, 2009). Thus, literature is full of such success stories and reveals that overall goal of management framework is to protect the integrity and health of native ecosystem from degradation caused by invasive species. This can be achieved by maximizing prevention of new invasions, enabling early detection and rapid response and ensuring that the response to new or existing invasions includes science-based approaches to contain, reduce or eradicate populations.

Based on lessons learnt from review of various frameworks proposed for invasive species management, a framework for *Lantana camara* invasion management is proposed in this research study to achieve several outcomes. This include decreasing the risk of invasion, improving preparedness and awareness, enhancing communication, collaboration, and coordination among agencies, and more effectively allocating resources for better planning and management. Formulating objectives, strategies, and action items for containment and controlling existing infestations and protecting non-infested regions in India, an integrated management approach is proposed based on best management practices adopted from various invasive species management plans. This framework can be replicated to assist identification of threat and management of further potential invasive alien species.

#### **4 Framework for *Lantana camara***

The primary purpose for development of this management framework and its addenda is to provide strategies to coordinate and guide efforts to prevent the introduction, to eradicate, to control the spread, and to promote appropriate management of *Lantana camara* populations.

The framework proposes to enhance coordination and collaboration from central, state, and local government bodies, as well as the research institutions and private sector. The benefit of implementing this framework will be to minimize the negative impacts caused to native plants, animals, natural ecosystems, recreation, tourism, agriculture, businesses, and human health. The framework further provides inputs on making people aware of the harmful effects of this invasive plant/species and how to utilize materials derived from them for livelihood generations. To develop this, six interrelated and equally important strategies addressing *Lantana camara* problems is targeted. The strategies included in framework are prevention, early detection & rapid response, control & manage, research, education & outreach and legislation (Fig. 2).

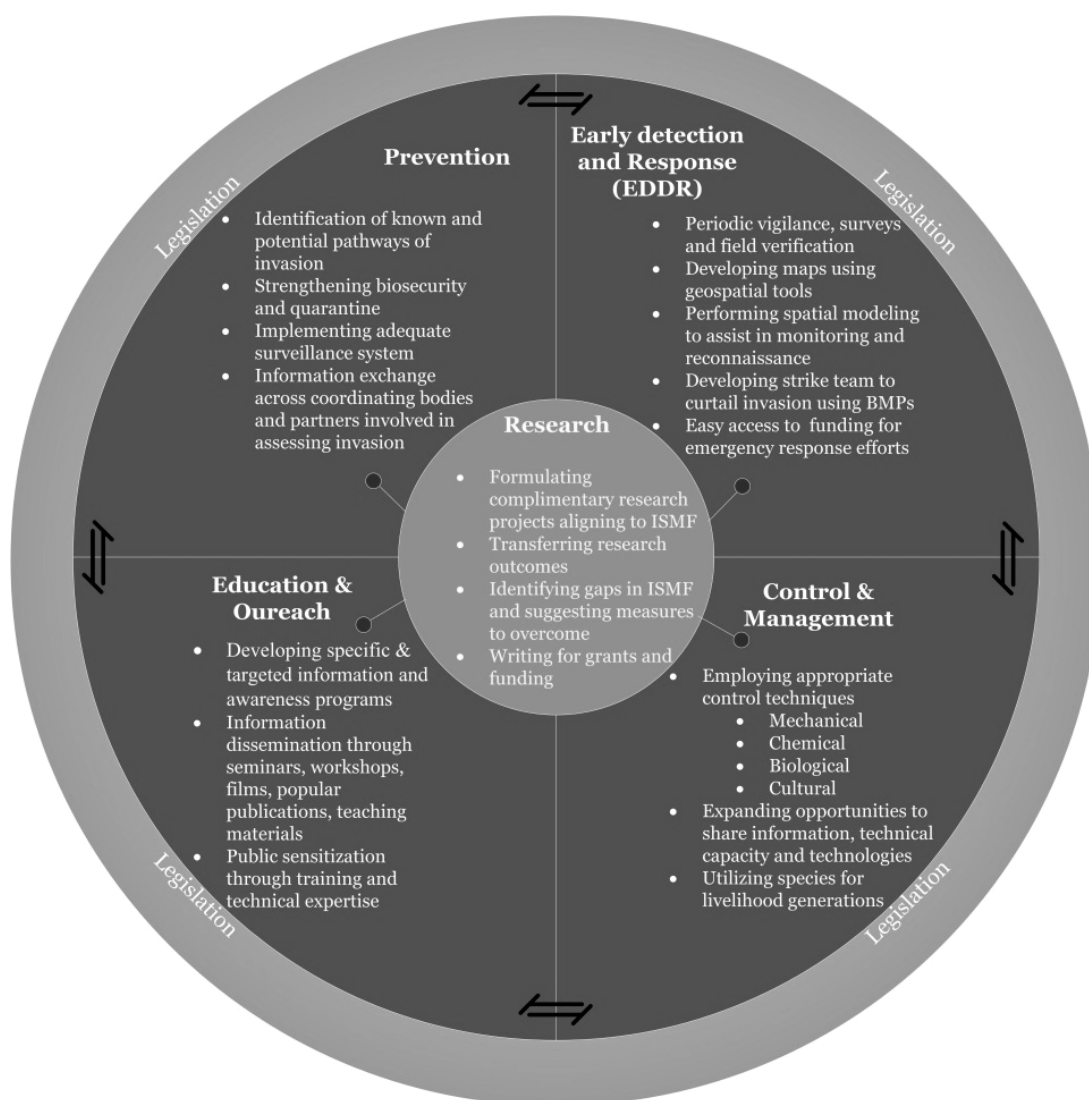


Fig. 2 Management framework proposed for managing *Lantana camara*.

#### 4.1 Prevention

It is generally a cost effective method of managing invasive species as it seeks to ensure that establishment of species do not occur and cause harm to the environment, the society, or to the economy. Prevention efforts eliminate the accidental or intentional introduction threat posed by the invasive species. The most efficient method of preventing invasive species entering assessment area unintentionally is to identify the pathways by which they are introduced and to develop methods to thwart introductions. This allows efforts to focus on intercepting an invasive species at the point of entry/release or altering the behaviors, attitudes, or awareness that supports the movement and introduction of invasive species.

Key actions that can be undertaken to achieve prevention for *Lantana camara* include:

- a. Promoting greater communication and collaboration amongst agencies that are responsible for issuance of certificate for export/import of bioresources such as Plant Quarantine Division, NBPGR; The Plant

Protection Adviser; Department of Animal Husbandry and Dairying; Directorate General of Foreign Trade; The Ministry of Environment & Forests; and The National Biodiversity Authority

- b. Strengthening enforcement of biosecurity, Sanitary-Phytosanitary import permits and quarantine at entry points and/or collaboration with cross border authorities as well
- c. Identifying invasion pathways and targeting specific programs or efforts to address them
- d. Promoting development and implementation of stronger international standards governing control of species at export, with particular attention to the main trading partners of countries
- e. Establishing and implementing national risk and impact assessment for proposed deliberate movements and for the movement of goods that may accidentally carry *Lantana camara*
- f. Reviewing existing border controls, transport controls and quarantine systems to identify gaps in country or pathway coverage (movement of ships, planes, people, other organisms, goods etc.) and technical or resource constraints and taxonomic gaps
- g. Providing all agencies involved in invasive species management with quarterly summary information on issues so that each agency is fully aware and adequately informed. This exchange of information should occur more frequently when threat arises
- h. Collaborating with the government departments to develop road maintenance plans that reduce the introduction and spread of *Lantana camara*

#### **4.2 Early Detection and Rapid Response (EDDR)**

EDDR involves scanning the landscape for existing, new and potential invasive species. Community groups, non-government organizations, private land owners, academics and general public are all valuable resources when it comes to the discovery and information gathering of invasive species. It is important for such groups to know who to contact with information concerning invasive species. Communication, collaboration, and coordination between different management authorities and between management authorities and other groups will ensure more complete scanning and reporting early detection of invasive species and streamline rapid response processes.

Key actions that can be undertaken to achieve EDDR for *Lantana camara* include:

- a. Expanding vigilance, surveys and field verifications
- b. Developing a local information centre for reporting *Lantana camara* presence and make its status and distribution updates available at appropriate websites
- c. Performing periodic inspections of managed area and surrounding landscape which has potential for invasion by species
- d. Utilizing technical experts to verify *Lantana camara* sightings
- e. Using geospatial tools to develop and maintain database that contain detailed information about *Lantana camara* (including its origin, habitat, pathways of dispersal, photographs, impacts and many more) as information repository for enhancing knowledge
- f. Developing maps at national, regional, and local levels using aerial photography, satellite data and videography to assist in target centric eradication measures
- g. Using spatial modeling to predict *Lantana camara* invasion potential for frequent monitoring as undetected plant propagules may exist in the area. This can be achieved through making use remotely sensed and GIS data, GPS/GNSS techniques with knowledge of species ecology. These geospatial tools enable large area evaluations, is cost-effective and incorporates potential time lags
- h. Identifying, monitoring, and preventing existing and potential vectors through partnerships with local government, and resource agencies



- i. Working with government departments, private agencies, research institutions and community to streamline immediate reporting of *Lantana camara* presence in an area
- j. Compiling an on-call list of experts for the species identification, management and rapid response expertise
- k. Development of a strike team that has expertise in protocol, procedures, planning, quarantine, monitoring, research and development and controlling *Lantana camara* using best available technology and practices
- l. Developing Best Management Practices (BMPs) for managing different variants of *Lantana camara* and carry out field trials to identify measures to combat *Lantana camara*. These practices should include proper equipment cleaning, appropriate weed and seed disposal, material inspection, herbicide use, minimizing soil disturbance and the retention, recycling, or re-establishment of native vegetation
- m. Quick access to stable funding for emergency response efforts and a separate funding for early detection and eradication efforts

#### 4.3 Control and management

Strategies to control and manage established populations of *Lantana camara* is determined based on size of the infestation, merits of management techniques, and economic, environmental, and technical constraints. Till date, there are no adequate control and management methods available to completely eradicate *Lantana camara*. This is because its populations are too widespread and it is a hard weed to deal with incredible rebound capabilities. Thus, control and management efforts are directed only when the species have established and no other management strategy is effective. This is because these measures do not completely remove species instead it suppresses the population, limit dispersal or lessen the effects of infestations by making use of the species.

Key actions that can be undertaken to achieve control and management of *Lantana camara* include:

- a. Monitoring species populations records in order to establish thresholds (such as population size, economic, etc.) for implementing control measures
- b. Implementing control measures when thresholds indicate control is needed and assesses their effectiveness. The control measures include:
  - i. Designing and implementing cultural practices especially to evade infestation by *Lantana camara* such as Crop rotation; Re-vegetation of a treated site by planting trees or encouraging naturally occurring seedlings that give priority to native plants and are compatible with the local vegetation; Sowing a pasture that outcompetes with and smother *Lantana camara*; Preventing grazing to hinder growth of the species (not operational on large scales) and applying physical restraints such as fences, equipment sanitation.
  - ii. Designing and implementing effective physical/chemical control techniques especially when high-value sites have been invaded by *Lantana camara*. The physical/chemical control methods include: Mechanical removal practices include involving stick raking, bull dozing, ploughing, grubbing, hand cutting using brush cutters, hand pulling, chain pulling and flame weeding; Chemical control using appropriate chemical and/or pesticides when there is good soil moisture and the species is in active growing period. Use of fluroxypyr, glyphosate, triclopyr and Grazon DS is recommended. Post emergence application of glyphosate is assumed to provide good control (Achhireddy et al., 1985; Sharma 1988)
  - iii. Carrying out research programs directed to identify the potential biocontrol agents. . The same can be first subjected to field trials and then released to actual site of invasion. Once identified, biological control techniques should be implemented when it is difficult to manage by other means and area has exceptional conservation value
  - iv. Keeping records of all pertinent control data and their results for information dissemination

- c. Initiating, facilitating, and supporting small-scale research projects on utilization of *Lantana camara* biomass into products of commercial importance such as furniture products, baskets, mulch, compost, drugs and other biologically active agents. Some of these research activities are already put into conservation practices. These include
- i. Herbal Medicine: Various researchers have documented *Lantana camara* as potential source of source for herbal medicine because of its several therapeutic uses (Sharma et al., 1988; Sharma and Sharma, 1989; Ghisalberti, 2000; Day et al., 2003). This include making use of leaves extracts as it exhibit antimicrobial, fungicidal, insecticidal, nematicidal, biocidal activity (Chavan and Nikam, 1982; Sharma and Sharma, 1989; Begum et al., 2000; Saxena, 2000; Day et al., 2003). Ghisalberti (2000) have reported oil extracted from leaves can be externally used for curing leprosy and scabies. Use of plant extracts have been reported in treatment of cancers, chicken pox, measles, asthma, ulcers, swellings, eczema, tumors, high blood pressure, bilious fevers, catarrhal infections, tetanus, rheumatism, malaria and atoxy of abdominal viscera (Kirtikar and Basu, 1981; Sharma and Sharma, 1989; Begum et al., 2000; Day et al., 2003). However, the research is still at its nascent stage and more information is required to put this to practical use.
  - ii. Goods and utilities: Soligas, the tribal artisans of South India in Male Madeshwara Hills (Karnataka), and villagers of Lachhiwala (Dehradun) are ingeniously utilizing the invasive weed *Lantana camara*. The project to control *Lantana camara* is an interesting mix of community involvement into conservation practices with payoffs for both. *Lantana camara* parts are being used effectively in making furniture, trays and baskets, which is cheaper than cane and equally sturdy. The pungent *Lantana* leaves have been used to make excellent mosquito repellents and incense sticks. Bangalore based institutions Ashoka Trust for Research in Ecology and the Environment (ATREE) and Dehradun-based NGO Himalayan Environmental Studies and Conservation Organisation (HESCO) are helping the tribal and village communities respectively in logistic, certification and marketing support for *Lantana camara* products. Experiments like this showcase innovation that can generate livelihood options and perk up a weak economy.
  - iii. BioFuel: Use of *Lantana camara* for fuel ethanol production is recommended in various research findings (Sharma et al., 1988; Inada et al., 1997; Varshney et al., 2006). Biofuels obtained from twigs and stems serve useful fuel for cooking and heating in many regions of India.
  - iv. Kraft Pulping: Researches by Khullar et al. (2004), Ray et al. (2006), Naithani and Pande (2009), Bhatt et al. (2011) and many others have demonstrated *Lantana camara* as potential source of raw material for paper making and henceforth likelihood of replacing traditional forest based species like wood and bamboo.

#### 4.4 Research

Research supports varied aspects of the management framework ranging from assisting policy makers in assessing gaps in invasive management, supporting invasive species resource optimization, improve the ability to identify potential threats, assess the potential effects, prioritize the risks of invasive species and public outreach efforts. Besides these, it increases the effectiveness of a wide range of efforts carried out by central, state, local governments and the private sector to combat invasive species. Although progress continues, the ability to support effective research is continually being challenged by the ever expanding number of invasive species issues and the myriad of potential authorities and supporting agencies. It is important that management authorities communicate and connect across jurisdictions and administrative boundaries to ensure efforts are not duplicated.

Key actions that can be undertaken to achieve research of *Lantana camara* include:

- a. Formulation of complementary research projects ranging from basic investigations (such as gaining thorough understanding of invasion processes, species dispersal pathways, and drivers promoting invasion processes) with broad application (such as consequences of invasions on ecological, agricultural, economic,

animal health, human health, and social systems; predicting new or expanding pathways of invasion) for highly invaded areas

- b. Development of applied research including developing and testing control and restoration methods; developing better methods and technologies for managing invasion pathways; improving the ability to assess and monitor invasive population parameters on appropriate spatial and temporal scales; and developing enhanced means to collect and more fully utilize data obtained and improve research support for cooperative efforts.
- c. Identifying data, information and communication gaps
- d. Increasing trained personnel, such as taxonomists who can help identify, research, provide solution to combat species
- e. Transferring research outcomes to national, state, local, tribal and private sector stakeholders for their utilization
- f. Identification of constraints that may obstruct implementation of prevention and monitoring programs (government policies, regulations, or conflicting mandates) and containment and control programs (insufficient research to guide management decisions based on species varieties and/or site conditions)
- g. Funding long-term and core research programs focused upon priorities identified by government and private sector stakeholders
- h. Writing grants to secure outside funds for program implementation and expansion
- i. Developing a research compendium on effects of management techniques
- j. Facilitating collaboration among research scientists and stakeholders to advance knowledge, refine research, and guide long-term management

#### **4.5 Education and outreach**

Effective education or outreach programs are key components of any management framework. Early detection and treatment of invasive and an effective prevention program is dependent on education. Many people are unaware that their actions can result in the introduction and spread of *Lantana*. Thus, making people aware of their actions and having their stake in reducing the effects can inadvertently curtail spreading of species. Over time, this may prove more effective at controlling invasive species than other management strategy. Effective education and outreach programs should be considered by management authorities and other groups involved with invasive species management.

Key actions that can be undertaken to achieve education and outreach of *Lantana camara* include:

- a. Supporting/encouraging government agencies to develop mandatory policies to prevent, detect, control and manage *Lantana camara*
- b. Coordinating nationwide campaign message with regional and local efforts to eliminate *Lantana camara*
- c. Identifying training needs and conducting periodic training and providing technical expertise with a focus on species identification, reporting procedures, and monitoring of high risk sites for governmental agencies and non-governmental organizations
- d. Utilizing field testing pre-and post-survey results to assist in refining message to be conveyed to general public
- e. Organizing workshops, conferences and symposia on relevant topics relating to *Lantana camara* management to bring together major stakeholders and key players to facilitate communication, public input, and information exchange
- f. Production and dissemination of films, audio-visual and popular publications, educational materials to expand knowledge

- g. Setting up of eco-clubs in schools to communicate how prevention of an invasive species will affect quality of life, biodiversity conservation, and other human values
- h. Institution of awards and fellowships on providing inputs and suggestions for managing the species
- i. Holding public listening sessions to receive public input on management options
- j. Promoting stakeholder communication and coordination. This is the most important action as stakeholders transfer critical information between the management authority and the public and thus ensures that all key players understand and retain the invasive species management messages

#### 4.6 Legislation

Targets for drafting legislation and policies aimed at curbing *Lantana camara* directly or indirectly in most of the relevant national plans, programmes and strategies should be aimed under this management strategy.

Key actions that can be undertaken to achieve legislation of *Lantana camara* include:

- a. Participating in a coordinated (inter-agency) review of legislation, regulations and policy directions (including connections with central statutes) relevant to the prevention and control of alien species invasions, to establish an efficient and effective framework for coordinated management
- b. Examining need for appropriate amendments to legislation and/or regulations under the various Ministries (such as Ministry of Environment and Forests, Trade and Travel and many more) to enable appropriate and coordinated actions to identify, prevent, eradicate and/or control invasive species
- c. Participating in targeted groups tasked with the development and/or implementation of coordinated invasive alien species legislation and policy (e.g., prevention network, risk assessment protocols and decision-making, rapid response measures)
- d. Formulating nationwide risk assessment protocols for determining degree of invasiveness and strategizing actions to combat accordingly
- e. Setting up of an approachable National Invasive Species Advisory Committee for addressing concerns related invasive species
- f. Driving specific programmes for species management for developing species centric network project with information collated across departments, agencies, private, players, NGOs should be formulated
- g. Developing public-private partnerships that support national systems for effective management of *Lantana camara*

Thus, this sustainable invasive species management framework will enable broadening scope beyond short-term control methods and hence will enable in addressing root causes of invasion, spread, and its likely impacts. This approach will enable response from every sections of the society and hence management will be quicker and effective.

#### 5 Conclusion

Invasive species when established in an ecosystem interferes with ecosystem structure and functions. They develop equilibrium with native environment to which they invade and disturb homeostasis of ecosystem and weaken it. Thus, its removal through single management measure in isolation can have striking negative impact on various ecosystem components. So, strategic and sustainable approach incorporating holistic process of control and management of invasive species is required. This can be achieved through use of various tools and techniques at varied levels of management processes and help safeguard against accidental, adverse effects on native ecosystems.

Management of invasive species is formidable task that require integrated effort, cost, and planning to curb invasive species at all stages of invasion process. Furthermore, as the global trade, travel and tourism accelerates, globalization increases, climate change mediated shifts take place, invasive species will begin to

exert more profound effects on natural ecosystem thus having little prospect of reversing. This wide amplitude of impacts together will require even greater coordination, collaboration and investments to control manage and conserve invasion. With this purview of global climate change and anthropogenic influences, management strategies must incorporate precautionary principles of sustainability into invasive species management framework.

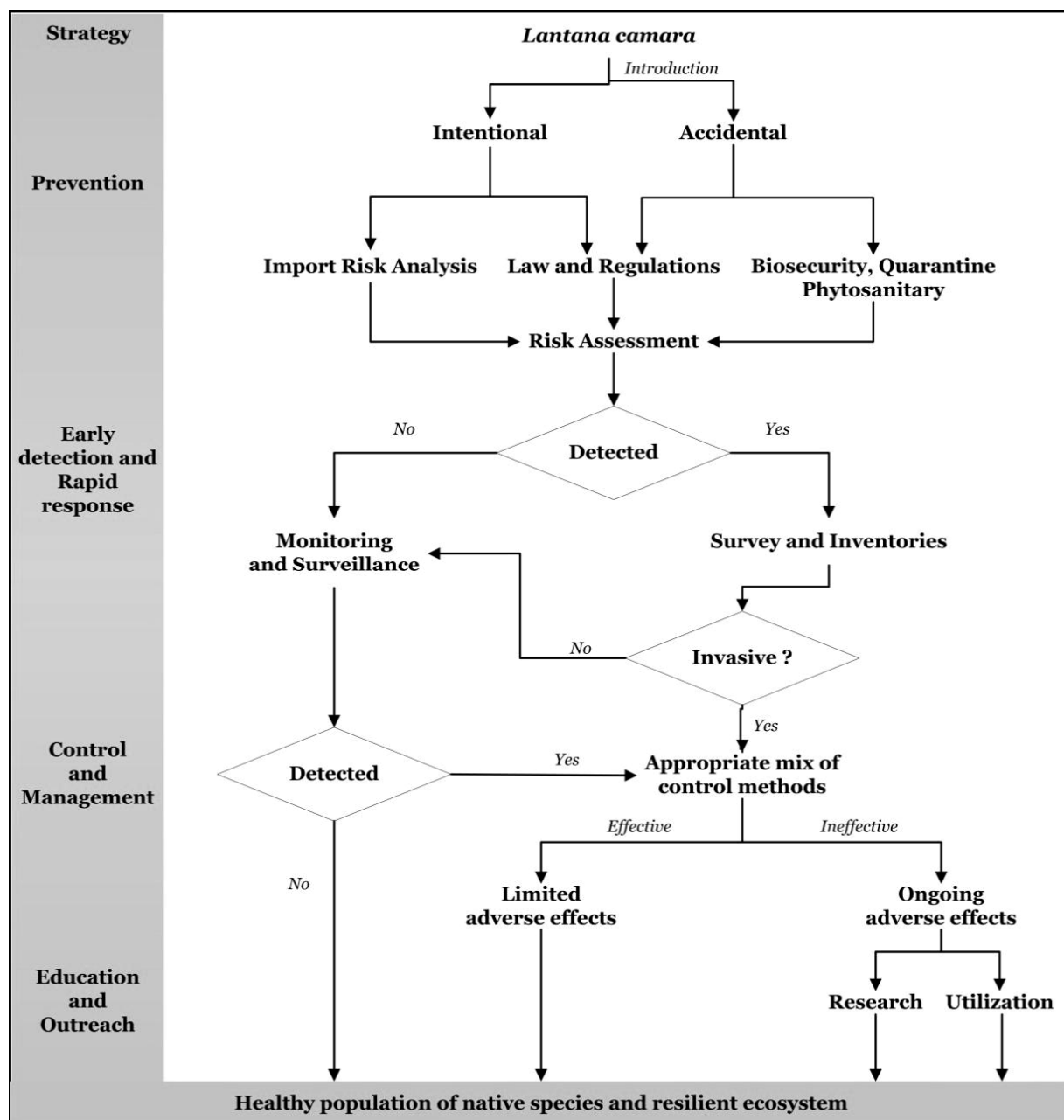


Fig. 3 Proposed management strategies and actions to control *Lantana camara*.

Various management frameworks grossly adopt five basic strategies for managing invasive: prevention, early detection & rapid response, control & manage, legislation and education & outreach formed on the environmental, social, and economic management objectives. The frameworks however differed from one another based on scale and management objectives formulated within basic strategy. This enabled frameworks

to formulate and adopt ecologically-based, species centric prevention and control measures. Thus, with this backdrop, actions and their outcomes from various management frameworks were reviewed and best management practices are incorporated to develop framework to the seemingly intractable problem of restoration opportunities for *Lantana camara*.

For management of *Lantana camara*, basic strategy of prevention, eradication and control at measures at varied level of infestation should be adopted. Introduction, be it intentional or accidental, is difficult to check but both should be subjected to stringent quarantine and biosecurity measures so that they may not harm the ecological integrity of an ecosystem. The approaches for application of control measures such as cultural, mechanical, chemical, biological controls is proposed to be the adopted as last resort for containing and managing *Lantana camara*. While opting for drafting legislation, formulating research projects and developing education and outreach programmes, community participation is of utmost importance as this could result in managing invasion and overcoming problem without much cost and efforts. This strategy is crucial for success of management framework in the long run (Fig. 3). Although it may not be feasible to incorporate all of suggested measures into individual management plan, even a subset of these framework can increase the sustainability *Lantana camara* management programs. However, decision makers would benefit from this framework as this approach illustrates strategies and actions that can be realized at all levels viz. government, research institutions, stakeholders, agencies and communities and many more to curtail *Lantana camara* invasion. Implementation of education and outreach strategy in the framework open up avenues to help reduce spread of invasive without much efforts and costs. Incorporating strategies and actions proposed in framework will allow decision makers to respond quickly and effectively in incorporate management actions in an adaptive management feedback loop.

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