Indian Journal of Weed Science (2022) **54**(4): 360–369
http://dx.doi.org/10.5958/0974-8164.2022.00067.3

OPINION ARTICLE

Invasive alien weeds problem in South Asia: Challenges and prospects of their management

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Received: 15 October 2022 | Revised: 20 November 2022 | Accepted: 22 November 2022

ABSTRACT

South Asian region, like other regions of the world, is witnessing a rising problem of invasive alien weeds with wide ranging environmental and socio-economic impacts. Current policy and management responses, and national capacities of the South Asian countries are inadequate in slowing down the rate of invasion process, suggesting a need for new approaches to address the problem. Through narrative review of selected references and author's own experiences, several challenges of invasive weed management in South Asia have been identified, including inadequate policy responses, ineffective quarantine and biosecurity rules, low national capacity, knowledge gaps on key aspects, and a lack of common and agreed standards for species categorization. Future prospects identified for effective management of invasive weeds in South Asia include improving awareness of invasive weeds problem among policy makers and other stakeholders, regional networking for information exchange, regional collaboration for biological control program, and regional collaboration among researchers to generate policy relevant information. In a nutshell, formulation of the South Asian Regional Strategy for Invasive Alien Species and its proper implementation will prevent introduction of new invasive weed species and control of established invasive weed species for the benefit of imperiled biodiversity, ecosystems and billions of people inhabiting in this region.

Keywords: Biological invasions, Invasive weeds, Invasive plants, Management strategy, Regional collaboration

INTRODUCTION

Movement of organisms beyond their native distribution range crossing natural biogeographical barriers is a prominent ecological foot print of humanity in the era of Anthropocene (Kueffer 2017). Such organisms introduced by humans are often referred to as 'alien' or 'exotic' species in their new introduced range. Some of these alien species are the valuable sources of food, fiber and medicine while others are pests, pathogens and weeds. A subset of the alien species which spread rapidly in the introduced range with potentially negative impacts to native biodiversity, ecosystems, and human welfare are referred to as invasive alien species (IAS) (https://www.cbd.int/idb/2009/about/what/, accessed on 15 Nov 2022). Global agriculture production system has been also threatened by a large number of such IAS and many of them are invasive alien weeds (Paini *et al.* 2016). The invasive weeds and other IAS reduce agriculture production and increase crop protection cost, with ultimate negative impacts to global food security. To address this and other similar problems caused by the IAS, efforts have been made for their prevention and control by individual nations and global community (*e.g.* Aichi biodiversity target 9 of the Convention on Biological Diversity, https://www.cbd.int/sp/targets/rationale/target-9/). However, the past efforts remain inadequate as the number of IAS and the associated economic costs have increased continuously with their higher rate in more recent years (Seebens *et al.* 2017; Diagne *et al.* 2021). Additionally, the IAS interacts with other drivers of global environmental degradations such as the land use and climate changes, with their synergistic negative impacts to biodiversity, ecosystems and agricultural productions (Lopez *et al.* 2022; Ravi *et al.* 2022). Therefore, the management of IAS is becoming increasingly more challenging at all levels of management – national, regional and global.

South Asia constitutes eight countries (Afghanistan, Bangladesh, Bhutan, India, Myanmar, Nepal, Pakistan and Sri Lanka), which share similar climate, environment and socio-cultural features, and have high interconnectedness through trade and travel. There are three (of 35) global biodiversity hotspots (Himalaya, Indo-Burma, and Western Ghat-Sri Lanka) and one (of 17) mega-diverse country

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(India) in South Asia. The region is inhabited by nearly 1/4th of global human population and ranked first in population size among different sub-regions of Asia (https://www.worldometers.info/world-population/population-by-asia-subregion/, assessed on 15 Nov 2022). The agriculture is the mainstay of the national economy in most countries of this region, with half of the population directly dependent to agriculture for their livelihood. In recent decades, the agriculture sectors of this region have been threatened due to global environmental changes such as climate change and the biological invasions (Bang *et al.* 2022; Pathak 2023). Threats to agriculture due to the IAS is relatively high in this region with Nepal and Bangladesh ranked third and fourth most threatened countries globally (Paini *et al.* 2016). Additionally, Asia in general and the South Asia in particular are lagging behind the rest of the world in terms of IAS related researches, knowledge bases, and management activities (Shrestha *et al.* 2022). In this paradoxical context, major challenges of the invasive alien weed management in this region have been summarized and future prospects have been discussed based on a narrative review of selected references and author's own experiences. In absence of systematic regional assessment of the invasive species problem in South Asia, the regional patterns of their spread, impacts and appropriate management options at regional level remain elusive. However, the author hopes that this communication will encourage regional dialogue and networking among diverse stakeholders to understand and address the emerging problem of invasive weeds and other species at regional level in South Asia.

DIVERSITY

All countries of the region do not have a comprehensive list of invasive alien weeds and they have not followed the same standard for assigning the alien species to 'invasive' status. This situation has made comparing and collating the number of invasive weeds reported in each country challenging. Available literature clearly revealed a disparity on the number of invasive weeds reported in each country. For example, the number of invasive weeds reported in Bhutan is exceptionally high based on the normalized value of species number (#species/10^5 km^2) (**Table 1**). It is likely because of the differences in the definition used by the researchers of Bhutan (Dorjee *et al.* 2020) and other countries such as Nepal (Adhikari *et al.* 2022). It appears that in 'invasive' species of Bhutan, Dorjee *et al.* (2020) included all widely distributed naturalized species irrespective of their ecological and socio-economic impacts while in the 'invasive' species of Nepal, Adhikari *et al.* (2022) included those naturalized species which have reported negative impacts (ecological and/or socio-economic) in Nepal. For example, *Alternanthera pungens, Amaranthus viridis, Cannabis sativa* and *Crassocephalum crepidioides* are present both in Bhutan and Nepal but they have been considered as invasive by Dorjee *et al.* (2020) but not by Adhikari *et al.* (2022) because their negative impacts have not been reported though they are also widespread in Nepal. When information related to impact is unavailable, the number of invasive alien species reported is likely an underestimate of the real situation. For example, while the available literature reported >100 species to be invasive in India (Khuroo *et al.* 2021), Sandilyan *et al.* (2019) reported that 60 alien species are naturalized in terrestrial and inland freshwater ecosystems of India and met the criteria (with high weightage give to impacts on ecosystem, biodiversity and livelihood) adopted by the National Biodiversity Authority of India for invasive species.

Except Bhutan, the normalized species number is relatively high in island countries like Maldives and Sri Lanka (**Table 1**) which is quite expected because islands are highly vulnerable to plant invasions relative to the comparable areas in the mainland (Lonsdale

Table 1. Number of invasive alien weeds reported in eight countries of South Asia

Country	Area (Km^2)#	Number of invasive alien weeds (Reference)	Species/ 10^5 Km^2*	Number of globally worst invasive weeds**
Afghanistan	652,230	-	-	1
Bangladesh	147,570	46 (Mukul *et al.* 2020)	31	6
Bhutan	38,394	101 (Dorjee *et al.* 2020)	263	5
India	3,287,590	145 (Khuroo *et al.* 2021)	4	15
Maldives	300	9 (Sujanapal and Sankaran 2016)	3000	5
Nepal	147,181	28 (Adhikari *et al.* 2022, Shrestha *et al.* 2021)	19	7
Pakistan	881,912	73 (Qureshi *et al.* 2014)	8	6
Sri Lanka	65,610	39 (Bambaradeniya (2002)	59	13

#https://www.worldometers.info/geography/largest-countries-in-the-world/ (Accessed on 14 Nov 2022); *Species number normalized following Turbelin *et al.* (2017); **After Shrestha *et al.* (2022)

1999). The number of globally worst invasive alien weeds is the highest in India followed by Sri Lanka. Among them, *Lantana camara* has been reported from all countries in South Asia while other commonly reported species are *Leucaena leucocephala*, *Pontederia crassipes* and *Mikania micrantha* (Shrestha *et al.* 2022).

IMPACTS

A wide range of environmental and socio-economic impacts of invasive alien weeds have been reported in South Asia (**Table 2**). Commonly reported environmental impacts includes reduction in native species diversity, change in soil nutrient and chemical properties, negative effects on tree regeneration, and degradation of wildlife habitats. Similarly, the frequently reported socio-economic impacts include reduction in agriculture and livestock production, health hazards to human and livestock, and a decline in forest resources supply (*e.g.* forage, wild edible fruits). These environmental and socio-economic impacts of invasive weeds have been reported mostly from India, Nepal, Bhutan and Pakistan, suggesting that the study which assesses impacts of invasive weeds is virtually lacking in the remaining four countries (Afghanistan, Bangladesh, Maldives and Sri Lanka).

Impacts of invasive weeds have been assessed in terms of monetary values too but such studies are available only for a few species in South Asia. For example, total cost associated with damage and control of *Parthenium hysterophorus* in agroecosystems of India between 1955 and 2009 was estimated to be ₹ 2.067 trillion (equivalent to UD $ 24.8 billion as per the exchange rate of 17 November 2022) (Sushilkumar and Varshney 2010). In Punjab province of Pakistan, Bajwa *et al.* (2019) estimated annual cost of *P. hysterophorus* invasion associated

Table 2. Selected examples of environmental and socio-economic impacts of invasive alien weeds in South Asia

Invasive weed	Impacts	Countries	References
Environmental impacts			
Ageratina adenophora	Native plant species reduced	India (Uttrakhand)	Kumar *et al.* (2020)
Chromolaena odorata	Native species richness reduced	Nepal	Thapa *et al.* (2016)
	Tree (*Shorea robusta*) regeneration negatively affected	Nepal	Thapa *et al*. (2016)
Lantana camara	Native species richness and diversity reduced	India (Himachal Pradesh, Uttrakhand), Nepal	Singh *et al.* (2014); Bhatt *et al.* (2020); Kumar *et al.* (2020)
	Fire regimes altered	India	Hiremath and Sundaram (2005)
Leucanthemum vulgare	Species diversity reduced	India (Kashmir)	Khuroo *et al*. (2010), Ahmad *et al.* (2019a)
	Soil nutrient and chemical properties altered	India (Kashmir)	Ahmad *et al*. (2019b)
Mesosphaerum suaveolens	Native species richness declined	India (Chandigarh)	Sharma *et al.* (2017)
	Soil organic carbon and electrical conductivity increased	India (Chandigarh)	Sharma *et al.* (2017)
Mikania micrantha	Habitat of one-horned rhino degraded	Nepal	Murphy *et al.* (2013)
	Soil nutrient cycling enhanced	India (Meghalaya)	Swamy and Ramakrishnan (1987)
Parthenium hysterophorus	Native species richness and abundance reduced	India	Kaur *et al*. (2019); Sushilkumar (2014)
	Plant species (above ground + soil seed bank) composition modified	Nepal	Timsina *et al.* (2010), Rokaya *et al.* (2020), Khatri-Chettri *et al.* (2022)
	Nutrient concentration in soil changed	India (Chandigarh), Nepal	Kaur *et al.* (2019), Timsina *et al*. (2010)
Pontederia crassipes	Diversity and abundance of threatened birds reduced	Nepal	Basaula *et al.* (2021)
Prosopis juliflora	Nesting habitat of breeding bird degraded	India	Chandrasekaran *et al*. (2014)
Xanthium strumamrium	Species richness and diversity reduced	Pakistan (Punjab)	Qureshi *et al.* (2019)
Socio-economic impacts			
Ageratum houstonianum	Livestock toxicity and increased weed problem in agriculture	Nepal	Shrestha *et al.* (2019a)
Alternanthera philoxeroides, *Azolla filiculoides*	Fishing and availability of wild edible fruits affected negatively	India (Kashmir)	Keller *et al.* (2018)
Mikania micrantha	Fodder availability reduced in forests	Nepal	Rai and Scarborough (2015); Sushilkumar (2014)
Parthenium hysterophorus	Human skin disease (dermatitis), allergy	India, Nepal, Bhutan	Sharma and Verma (2012), Shrestha *et al.* (2015); Chhogyel *et al* (2021)
	Crop and livestock production as well as quality of human life negatively affected	Pakistan (Punjab), Bhutan	Bajwa *et al*. (2019); Chhogyel *et al.* (2021)

with crop and livestock production, health, and social well-being to be US $ 913 per household. Similar estimates are not available for other species and in other countries of this region. Bang *et al.* (2022) estimated economic cost of invasive alien species to Indian economy (US$ 127.3 to 182.6 billion for the period of 1960-2020) but they have not specified the cost associated with invasive alien weeds.

MANAGEMENT

Current management practices

Management of invasive weeds is complex, challenging and highly contextual. Suitable management approaches vary according to the invasion stage of invasive weeds, invaded ecosystems, socio-economic status of the people involved in management, and government policy. In general, prevention, early detection and rapid response (EDRR), control (physical, chemical and biological control), ecosystem based management, and community participation are common approaches of invasive weeds management in Asia including South Asian region (Shrestha *et al.* 2022). *Prevention* is the most effective and economic method of invasive weeds management, yet it is also the most challenging in South Asian region because of open (*e.g.* Nepal-India border) and porous international borders (*e.g.* India-Bhutan and India-Bangladesh borders) with very poor implementation of border quarantine rules. When prevention fails, the next option available is the Early Detection and Rapid Response (EDRR) which involved an early detection of founding populations of invasive weeds and subsequent eradication or containment through rapid responses before they become widespread (Reaser *et al.* 2020).

Once the invasive weeds are widespread, control measures such as physical, chemical and biological methods are implemented. *Physical control* including the use of mechanical tools has been routinely used in farm lands while it has been also implemented frequently in natural ecosystems such as the managed forests, plantations, and wetlands (Shabbir *et al.* 2019, Shrestha 2019). Physical control measures are mostly implemented by farmers, local people and community based organizations, and therefore these activities seldom appear in scientific literature. In chemical method, herbicides are used to control invasive and other weeds in farmlands but their use in natural ecosystems is not recommended due to their negative impacts to non-target organisms. Biological control using carefully selected natural enemies (*e.g.* arthropods, fungi) found in the invasive weeds' native range is considered the most effective, environment friendly, economic and sustainable for their long-term control (Day and Witt 2019). However, the biological control program has been implemented only in a few countries such as India (Rabindra and Bhumannavar 2009; Sushilkumar 2015) and Pakistan (Weyl *et al.* 2021) in South Asia, possibly because of a relatively high initial cost and a longer time period required for screening and subsequent release of the suitable biological control agents. Yet, some of the biological control agents have crossed the international border naturally and established in countries where they have not been released officially. For example, a leaf feeding beetle *Zygogramma bicolorata* was released in India during early 1984 to control *Parthenium hysterophorus* (Jayanth and Visalakshy 1994). The beetle has spread naturally and reached to Nepal (Shrestha *et al.* 2019b; Sushilkumar 2015), Bhutan (Dorji and Steve 2020) and Pakistan (Javaid and Shabbir 2006; Sushilkumar 2015) crossing international border where it has already established with partial control of *P. hysterophorus*. At least 18 biological control agents targeting 11 invasive weeds have established in one or more of five South Asian countries (Bhutan, India, Nepal, Pakistan and Sri Lanka) after deliberate and/or fortuitous introductions (**Table 3**). *Lantana camara* has the highest number of biological control agents (4 spp.) followed by *Pontederia crassipes* (3 spp.). Most of the biological control agents reported in South Asia have established in India with low to high impacts on the target invasive weeds. Only a few agents have established in the remaining four countries. The author is not aware of the presence of biological control agents against invasive weeds in Afghanistan, Bangladesh and Maldives.

Ecosystem based approach of invasive weeds management seems promising (Byun *et al.* 2018), yet its potential has not been adequately explored and documented in South Asian countries. A few studies have revealed that abundance of invasive weeds and their negative impacts can be reduced by restoring degraded forests (Khaniya and Shrestha 2020), and promoting native and other useful species in ecosystems (Khan *et al.* 2014; Thapa *et al.* 2017). It is highly likely that some of the invasive weeds might have been controlled when the indigenous people and local communities (IPLC) managed forests and other ecosystems. However, such benefits of ecosystem management have not been well recognized and documented in this region. Similarly, community participation through direct involvement of the IPLCs and various community based organizations for

Table 3. Established biological control agents with their targeted invasive alien weeds in South Asian countries (modified and updated from Shrestha *et al*. 2022)

Targeted weed [Family]	Biocontrol agents [Family]	Countries with established population	General impacts	References
Ageratina adenophora [Asteraceae]	*Procecidochares utilis* [Tephritidae]	Nepal, India	Low	Day *et al*. (2018); Sushilkumar (2015); Shrestha (2019)
Chromolaena odorata [Asteraceae]	*Cecidochares connexa* [Tephritidae]	India	Low	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
	Pareuchaetes pseudoinsulata [Arctiidae]	India	Low	Rabindra and Bhumannavar (2009) Sushilkumar (2015)
Mikania micrantha [Asteraceae]	*Puccinia spegazzinii* [Pucciniaceae]	India	Nil	Sreerama (2016)
Parthenium hysterophorus [Asteraceae]	*Puccinia abrupta* var. *partheniicola* [Pucciniaceae]	Bhutan, Nepal, Pakistan	Low	Dorji and Adkins (2020), Shrestha (2019), Iqbal *et al*. (2020)
	Zygogramma bicolorata [Chrysomelidae]	Bhutan, India, Nepal, Pakistan	Moderate	Dorji and Steve (2020); Shrestha *et al*. (2019b), Javaid and Shabbir (2006)
		India	High	Sushilkumar (2009, 2014, 2015
Xanthium strumarium [Asteraceae]	*Puccinia xanthii* [Pucciniaceae]	Sri Lanka	Moderate	Shen *et al*. (2018)
Opuntia stricta [Cactaceae]	*Dactylopius opuntiae* [Dactylopiidae]	India, Sri Lanka	High	Shen *et al*. (2018); Sushilkumar (2015)
Opuntia elatior [Cactaceae]	*Dactylopius opuntiae* [Dactylopiidae]	India	High	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
Opuntia monacantha [Cactaceae]	*Dactylopius ceylonicus* [Dactylopiidae]	India, Sri Lanka	High	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
Pontederia crassipes [Pontederiaceae]	*Neochetina bruchi* [Erirhinidae]	India	High	Sushilkumar (2015)
	Neochetina eichhorniae [Erirhinidae]	India	High	Sushilkumar (2015)
	Orthogalumna terebrantis [Galumnidae]	India	Moderate	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
Salvinia molesta [Salviniaceae]	*Cyrtobagous salviniae* [Curculionidae]	India	High	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
Lantana camara [Verbenaceae]	*Octotoma scabripennis* [Chrysomelidae]	India	Low	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
	Teleonemia scrupulosa [Tingidae]	India, Sri Lanka	Moderate	Shen *et al*. (2018); Sushilkumar (2015)
	Uroplata girardi [Chrysomelidae]	India	Low	Rabindra and Bhumannavar (2009); Sushilkumar (2015)
	Epinotia lantana [Tortricidae]	India	Low	Rabindra and Bhumannavar (2009); Sushilkumar (2015)

invasive weeds management have been reported in South Asian countries (Shrestha *et al*. 2022). Various efforts have been made to create awareness among communities about the problems of invasive species and increase their participation through organizing awareness campaigns (*e.g*. Parthenium awareness week, Varshney and Sushilkumar 2009, 2014) and publication of community education materials in local language (e.g. Adhikari *et al*. 2022). However, the current efforts remain inadequate because many of the IPLCs are still unaware of the invasive species problems and available management options (Shrestha *et al*. 2019a).

Policy responses

National biodiversity strategy and action plans (NBSAP) of all eight South Asian countries have recognized invasive species as an important threat to ecosystems, biodiversity and agriculture productions (all documents available at https://www.cbd.int/countries/?country). Assessment of invasive species problems in these countries and their future plans are largely guided Aichi Biodiversity Target 9 of the Convention on Biological Diversity (CBD) (https://www.cbd.int /sp/targets/ rationale/target-9). According to the national reports submitted to the CBD secretariat (available at https://www.cbd.int/countries/?country), progress towards meeting Aichi Biodiversity Target 9 is improving but at an insufficient rate in Bangladesh, Bhutan, India, Maldives, Nepal and Sri Lanka but there was little or no progress in Afghanistan and Pakistan (both these countries submitted the last report in 2014). Besides NBSAP, countries like India (Sandilyan 2019) and Sri

Lanka (Biodiversity Secretariat 2016) also have separate national strategy for the management of invasive species including invasive alien weeds. The author is not aware of such a separate national strategy for invasive species in the remaining six South Asian countries. In addition to the national policies, researchers have also proposed frameworks for weed risk assessment in Bhutan (Dorjee *et al*. 2021) and prevention and control of invasive species in India (Banerjee *et al*. 2021). Such scholarly exercises are lacking in other countries of the region.

Management challenges

A brief review of literature, as discussed above, reveals that the current management practices are insufficient to address the increasing problems of invasive weeds. There are various management challenges which need to be overcome before effective management of invasive weeds is anticipated. Major challenges among them are summarized below:

Inadequate policy responses: Appropriate national policies and strategies are crucial for the effective management of invasive weeds. However, most South Asian countries do not have such dedicated national policy and strategy. All countries of this region have performed poorly on the national targets set in the national biodiversity strategy and action plan to prevent and control the invasive species.

Ineffective quarantine and biosecurity rules: International borders are either porous or open and interconnectedness in trade and travel is high among countries in South Asia. This has made the implementation of quarantine and biosecurity rules highly challenging. However, prevention of invasive species is far more effective and economic than their control after invasion. Therefore, there is no alternative to strengthening quarantine and biosecurity rules by each country in South Asia to combat increasing problem of invasive species.

Low national capacity: Countries in South Asia have relatively low national capacities (both proactive and reactive) for invasive species management in terms of expertise and available resources (Early *et al.* 2016). While national expertise has been improving gradually in some countries (e.g. Bhutan, Nepal), helps from international experts can be solicited to fill the shortfalls of national expertise. Countries have to increase their spending on invasive species control programs because any delay on the control of invasive species will significantly increase their impacts and management cost in future.

Key knowledge gaps: Available data and knowledge on some of the key aspects such as dispersal (introduction) pathways, economic valuation of impacts, and cost-benefit analyses of various management options are insufficient for informed policy and management decisions. Interdisciplinary and transdisciplinary approaches as well as regional/ international collaboration in research can generate additional data to improve knowledge gaps on these key issues.

Lack of common and agreed standards for species categorization: Absence of common and agreed standard for species categorization among South Asian countries has led to a large difference in the number of invasive species reported for the same country by different researchers (e.g. India: 60 spp. by Sandilyan 2019 but 145 spp. by Khuroo *et al*. 2021). Similarly, there is a large difference in the number of invasive weeds reported by geographically, climatologically and socio-economically similar countries such as Nepal (28 spp.) and Bhutan (101 spp.) (**Table 1**).

Future prospects

In spite of several challenges for invasive weed management in South Asia, there are also some opportunities for better management outcomes through improved stakeholder awareness, regional collaboration for research and knowledge/data sharing, and formulation and proper implementation of regional strategy for invasive species management. These future prospects have been discussed briefly in the following section.

Improving awareness among stakeholders: Over the past few years, researchers have generated a wealth of data and knowledge revealing the severity of invasive species problems across various geographical, jurisdictional and governance scales in South Asia and beyond. Minimum data and knowledge required to initiate stringent prevention and control measures are available for most of the South Asian countries. In some countries, however, policy makers and practitioners appear not to be fully aware of the seriousness of the invasive species problems, available management options, and future consequences of the lack of timely intervention. Improved communication among various stakeholders including researchers, policy makers and practitioners will increase policy uptake of the research findings and effectiveness of management activities.

Regional network for information exchange: The problem of invasive species originates outside political border of any country. In other word, what is happening in the neighboring countries determine, to some degree, what would happen (*i.e.* the extent of invasive species problem) in a country. Therefore, the invasive species is clearly a transboundary and regional/international problem requiring effective communication and cooperation among countries for their long term management. The COVID19 pandemic has also reminded us the value of information sharing by countries for tackling such global problem (Jit *et al*. 2021). Therefore, establishment of a platform for invasive species information sharing and exchange will i.) provides opportunities for the prevention of additional invasive species by countries, ii.) increases probability of early detection of and rapid response to founding populations of invasive species, and iii.) provides avenue for up-scaling and out-scaling of appropriate management options.

Regional collaboration for biological control program: One major hindrance of biological control program of invasive species is the requirement of screening phylogenetically related native and useful species in standard quarantine facilities. Partly, because of this, most of the South Asian countries have not institutionalized biological control program and thus unable to get benefit from this environmentally friendly and sustainable measure of invasive species control. The South Asian countries not only share several invasive species, they also share several native and useful species which are phylogenetically closely related to the invasive species in question. If host range expansion of a biological control agent to a set of species is ruled out in a quarantine screening facility of a country, it is not necessary to repeat quarantine screening of the same set of species in another neighboring country with similar climatic condition. In such situation, quarantine screening of phylogenetically related additional species may be adequate for final decision of whether or not to release the agent. A great amount of resources and time can be saved when countries follow same protocol for quarantine screening and officially share their findings to other countries in the region. This will create a conducing technical and financial environment to initiate biological control program by countries which have not done it yet.

Regional collaboration for research: South Asian researchers collaborate extensively with researchers of Europe, America and Australia but they do less so with fellow researchers of other south Asian countries (Rana *et al*. 2022). However, collaboration among South Asian researchers working on invasive weed species provide opportunities for mutual learning of common regional problems such as the invasive weed species spread, reveal regional pattern of biological invasions, may increase success rate of international funding applications, and complement each-other's research findings for a broader understanding of the regional problems. Additionally, such collaboration may also help to fill data gap of countries with very low research efforts (e.g. Afghanistan, Maldives). In a situation when political relations between countries is contested, research collaboration can improve the state of science diplomacy which ensure joint efforts to tackle regional problems (Shrestha and Bhadra 2019). In specific, collaboration among researchers of different South Asian countries provide an avenue for the development of regional strategy for invasive species management.

Regional strategy for invasive species management: As discussed above, invasive weed species is trans-boundary and global problem, and therefore a regional strategy is needed in South Asia to manage invasive weed species and protect native biodiversity, ecosystems and improve people's livelihood. Researchers, policy makers, practitioners and representatives of indigenous and local communities, among others, can work together for the preparation of South Asian Regional Strategy for prevention and control of invasive weed species. Such strategy will encourage information sharing and technology transfer (e.g. biological control program) among South Asian countries. Additionally, the regional strategy will also help to i.) harmonize data standards (e.g. definition and thus the number of invasive species) of individual countries, ii.) improve national funding for invasive weed species research and management, iii.) prevent introduction of new invasive weed species to South Asia, iv.) encourage regional collaboration for research and innovation, v.) create enabling environment for the development of national strategy by individual countries, and vi.) meet global targets of the Contention on Biodiversity Diversity and the United Nations.

CONCLUSION

Hundreds of invasive alien weeds have invaded diverse natural habitats and agriculture lands in South Asian countries with wide ranging environmental and socio-economics impacts. Number of invasive weeds and their impacts are likely to increase further in future due increased international trade and travel globally as well as in South Asia, and inadequate management and policy responses. There are several shortfalls in data availability (*e.g.* no national list of invasive weeds in some countries), empirical evidences of ecological and economic impacts, national capacity in terms of expertise and available resources, and policy and management responses of the South Asian countries. Invasive weeds being a regional problem, improving awareness of invasive weed problems among policy makers and other stakeholders, regional networking for information exchange, regional collaboration for biological control program, and regional collaboration among researchers to generate policy relevant information will create enabling environment for effective management of invasive weeds at national and regional level. Overall, formulation of the South Asian Regional Strategy for Invasive Alien Species and its proper implementation will prevent introduction of new invasive weed species and control established invasive weed species for the benefit of imperiled biodiversity, ecosystems and billions of people living in this region.

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