Biologia (2019) 74:623–629
https://doi.org/10.2478/s11756-018-00186-8

ORIGINAL ARTICLE

Identifying knowledge gaps in the research and management of invasive species in India

Ninad Avinash Mungi[1] · Monica Kaushik[1] · Nitya Prakash Mohanty[2] · Rajat Rastogi[1] · J. Antony Johnson[1] · Qamar Qureshi[1]

Received: 5 July 2018 / Accepted: 13 December 2018 / Published online: 8 January 2019

Abstract
India, a megadiverse tropical country is grappling with the issue of biological invasions. As a signatory to the Convention on Biological Diversity, India is committed for managing its major biological invasions by 2020. Lack of prioritization of invasive species for control and management is the biggest hurdle for achieving this commitment. We reviewed 21 High Concern Invasive Species (HiCIS) across four major ecosystems (terrestrial mainland, island, freshwater, and marine) in India, utilizing the prioritization framework for understanding the existing knowledge and gaps. We reviewed the existing peer-reviewed and grey literature on HiCIS for information on their ecology, impacts, and management. Prioritization framework provided "priority scores" and "confidence scores" to each HiCIS, where priority score comprised of the species' ecology and its management lacunae. Confidence score represented the reliability of the priority score. We found that invasions on terrestrial mainland ecosystem in India are the most studied invasions followed by freshwater, island, and marine ecosystem. Priority score of a given HiCIS was positively correlated with its impacts on biodiversity ($R = 0.63$), physical environment ($R = 0.70$), and ecosystem services ($R = 0.60$). This correlation supports scientific focus on deleterious species. The study also indicates policies and guidelines in place for management of invasions as a part of a larger scheme or Legal Act, resulting in their obscurity to the managers, and hindering management of HiCIS. This quantitative synthesis provides a model framework for countries struggling with channelizing management efforts to an overwhelmingly large number of invasive species.

Keywords Conservation policy · India · Invasive species · Prioritization

Introduction

Human-induced biological invasions have homogenized the global biota and irreversibly modified many native ecosystems (Ellis 2011; Simberloff et al. 2013). It has threatened the ecological integrity of landscapes by affecting key processes, leading to local extinction of native species in some instances (Sax et al. 2002; Clavero and Garcia-Berthou 2006). Economic sectors like agriculture, timber industry, irrigation, and human healthcare are also affected due to biological invasions worldwide (Pimentel et al. 2001). Such impacts on varied sectors have severe consequences for the livelihood, ecological

Electronic supplementary material The online version of this article (https://doi.org/10.2478/s11756-018-00186-8) contains supplementary material, which is available to authorized users.

✉ Ninad Avinash Mungi
shastri.ninad@gmail.com

Monica Kaushik
monikakaushik05@gmail.com

Nitya Prakash Mohanty
nitya.mohanty@gmail.com

Rajat Rastogi
rajat.rastogi0648@gmail.com

J. Antony Johnson
jaj@wii.gov.in

Qamar Qureshi
qnq@wii.gov.in

[1] Wildlife Institute of India, Dehradun, Uttarakhand 248001, India

[2] Centre for Invasion Biology (CIB), Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, Stellenbosch 7602, South Africa

security, and economic growth of developing or under-developed countries (Early et al. 2016), where the knowledge on this subject is often fragmented (McGeoch et al. 2010). Managers dealing with invasive species in such countries often have limited resources to deal with multiple invasion events. Such challenges demand a logical and evidence-based framework for management of concerned species.

India is one such developing country, where invasive species pose a severe ecological threat but their management and control is limited due to lack and unequal research across diverse ecosystems. Native ecosystems in India are under a gamut of anthropogenic influences, which might facilitate invasive species (e.g. Mungi et al. 2018) and affect already threatened native species (Theoharides and Dukes 2007). The total cost of environmental and agricultural losses caused by the invasive species in India is speculated to be around 116 billion USD per year (Pimentel et al. 2001). As a result, of increasing concern on biological invasions, India included identifying and managing invasive species and their pathways as its fourth national biodiversity target (Pande and Arora 2015), in alignment with the ninth Aichi target. Non-native species in India are represented by approximately 18,000 plants, 30 mammals, 4 birds, 300 freshwater fishes, 1100 arthropods, and 18 marine species that could be potentially invasive (Ali and Pelkey 2013). However, managing all non-native species by 2020 is not practically possible. Successful invasive species management elsewhere has demonstrated the importance of species prioritization, leading to the effective allocation of resources (Lowe et al. 2000; Koehn 2004; Nel et al. 2004). Hence, selected few High Concern Invasive Species (HiCIS) with known negative impacts were focused for management through an expert panel comprising of stakeholders involved in research and management of invasive species in India (Kaushik and Mungi 2015; Mathur et al. 2015).

Prioritization based on experience or solely on expert knowledge could be biased and demands for scientific validity. This in-turn demands for systematic prioritization using available information on the ecology of invasive species and their management aspects. Prioritization is usually conducted using two frameworks 1) Evidence-Based Analytical Protocols (Morse et al. 2004; Randall et al. 2008; Brunel et al. 2010): an induction-based identification of a high concern invasive species, based on long-term observations and experiments. The major drawback of this approach is its time and resource exhaustive nature and 2) Expert-Based Evaluation Protocol (Robertson et al. 2003; Liu et al. 2010; Forsyth et al. 2012): a knowledge-based review of existing information by interviewing the experts involved in studying and managing invasive species. The major limitation of this approach is its value-driven nature and subjectivity regarding the ranking system. However, both approaches can be used in combination to overcome the limitations and improve the timely decisions and its effective outreach. Moreover, in case of India, few invasive species have been studied and managed in almost all the landscapes and the major ecosystems (Bhagwat et al. 2012); but their results are not published or are restricted to the regional reports and practice guidelines (e.g. forest management plans). Hence, it is essential to consider this experience and grey literature in addition to peer-reviewed publications for filling the knowledge gap for robust prioritization. This process also helps to bridge the gap between managers and scientists by bringing them on the common platform for the assessment (Kumschick et al. 2012; Lach et al. 2003; Marris 2006; Mungi and Qureshi 2018). Present study relies on this combination of above-mentioned two methods. We prepared a list of HiCIS through consultation with experts and later reviewed existing knowledge (ecology, impacts, and management) on the HiCIS in India by using a prioritization framework to identify the knowledge gaps.

Method

Expert-based selection of species and criteria

We reviewed information for 21 HiCIS species shortlisted by the expert panel (Mathur et al. 2015). These species belonged to one of the four major ecosystems viz. terrestrial, freshwater, marine, and island. For each species, we reviewed published information under three modules - ecology, impacts, and management, for assigning the priority scores using the Delphi method (Robertson et al. 2003). These modules were selected to understand the invasive potential of species, magnitude of its impacts and type of management intervention used for either control or containment. Each module had multiple criteria developed by the experts involved in studying and managing invasive plants (Kaushik and Mungi 2015), which can be scored quantitatively. The ecology module had criteria evaluating species distribution, density, dispersal, dispersal agents, invasiveness, and recolonization potential. The impact module had criteria regarding species' impact on biodiversity, physical parameters, ecosystem services, and economics. The management module had criteria for controlling techniques, restoration, legislation, stakeholders, and conflict involved. In total, 21 species were evaluated for 17 criteria under three modules (Table S1).

Evidence-based review and scoring

To score the criteria, we conducted a literature search using ISI Web of Knowledge database and Google Scholar. The publication period, journal categories, and languages were not restricted. We used species name and generic synonyms (e.g., *Cassia tora* OR *Senna tora*) as the search string for finding relevant information on every species. Our study focused on

Table 1 Priority scores of High Concern Invasive Species (HiCIS) under different priority models based on their ecology, impacts, and management. Priority is depicted from red to blue (higher priority to lower priority). Confidence score represent the quality of existing scientific knowledge for every species

Species name	Neutral model	Management model	Impact model	Ecology model	Confidence score
Prosopis juliflora	15.0	9.8	10.2	10.1	2.7
Chromolaena odoratum	12.7	8.5	8.4	8.8	2.8
Mikania micrantha	12.1	7.8	8.3	8.5	2.7
Parthenium hysteroporus	12.1	8.0	8.0	8.6	2.9
Mimosa diplotricha	12.1	8.1	7.9	8.5	2.8
Lantana camara	11.7	7.4	7.7	8.5	2.7
Eichhornia crassipes	11.0	7.0	7.4	7.8	2.7
Clarias gariepinus	10.4	7.3	6.7	7.1	2.2
Kappaphycus alvarezii	10.1	7.6	6.2	6.9	2.4
Salmo trutta fario	9.8	6.8	6.0	6.8	2.0
Senna tora	9.5	6.4	5.6	7.1	2.4
Oreochromis mossambicus	9.2	6.5	5.7	6.4	2.1
Ageratina adenophora	9.0	6.2	5.7	6.5	2.4
Ipomoea carnea	8.6	6.2	5.5	5.9	2.1
Cyprinus carpio	8.2	5.7	5.2	5.7	1.7
Hyptis suvavolence	8.2	5.8	5.0	5.9	2.2
Axis axis	7.5	6.0	4.9	5.0	2.0
Achatina fulica	6.9	6.3	4.4	4.5	2.4
Ageratum conyzoides	6.7	5.4	4.1	4.6	2.1
Xanthium strumarium	6.5	5.6	3.7	4.6	2.2
Hoplobatrachus tigerinus	4.7	3.9	3.0	3.1	1.5

the criteria provided in Table S1, and hence, we avoided any literature regarding phytochemical analysis, behavior, animal husbandry, disease pathology, and any study outside the political boundary of India. The criteria under the ecology and impact modules of species are usually published. However, except for a few popular invasive species, we had limited number of studies regarding their management. Hence, we collected information from managers and other practitioners in the workshop (mentioned in the acknowledgments) regarding different management techniques used across the country and the associated economics, legislation, and stakeholders involved in the process. Scoring for each criterion was either binary or ordinal (Table S1). Each criterion was scored (henceforth, 'priority score') using the degree of precise scientific knowledge or replicable and logic-based expert opinion. As a result, the priority score was higher for species with established impacts, higher distributional magnitude, inadequate information on management and policies; and vice-versa. To scale the confidence of information obtained from varying sources, we included an associated 'confidence score'. If the priority score was based on published evidence, the confidence score was 1; if based on unpublished data (i.e. grey literature) or experience, it was 0.5; and if based on extrapolative interpretation of studies, it was 0.25. Confidence scores not only represent the precision of criterion scores but also indicate the state of knowledge about each species on every aspect.

Priority models

To make all the criteria comparable after evaluating priority and confidence scores for each species, we standardized the summed priority score for each criterion by dividing it with the maximum possible score for each criterion. Based on the three modules of the criteria we developed four 'priority models' viz. neutral, management, impact, and invasiveness potential by assigning different weights to every module. Neutral model: assigning equal weight to all module; whereas, in other models, higher weight was given to the module of interest while assigning equal weight to rest of the modules. We calculated the model confidence score by summing the confidence score and dividing it by the total number of criteria in a model. The final priority score of a model was obtained by summing the weighed priority scores and its confidence for each species. This weighing scheme provides flexibility and control to the decision maker to choose priority based invasive species as per their focus and demand. In case, the stakeholders are interested in managing the invasive species with existing guidelines on management techniques and policies, management model can be used to identify such HiCIS. In another case, if decision-makers are concerned about the high impact on native species due to an invasive species, they can use the impact model.

Evaluating ecosystem priority and reasons

To identify an ecosystem that has relatively higher priority, we compared different ecosystems for the difference in priority and confidence score using Mann–Whitney *U* test. For this, we used the average priority and confidence scores for all the species selected under each ecosystem. Subsequently, for understanding the reasons for high priority perception, we investigated the correlation in the priority of a species and its economic and ecological aspects. For this, we correlated the overall priority score generated by the neutral model with a standardized score of all criteria (e.g. the effect on biodiversity, availability of policy for management or control, etc.) for every species using Pearson correlation and assessed its statistical significance.

Result

Out of 14 HiCIS plants, one was algae, and 13 belonged to the dicotyledonous class of angiosperm. Of the seven HiCIS animals, one was mollusc, four were fishes, one was amphibian, and one mammal. Overall, the priority score of the freshwater ecosystem was insignificantly higher ($p < 0.50$) compared to the terrestrial ecosystem (Fig. 1). However, confidence scores for the terrestrial ecosystem were significantly higher ($p < 0.004$) to the freshwater ecosystem. When assessed between terrestrial and island ecosystems, the terrestrial ecosystem had insignificantly higher priority ($p < 0.11$) and

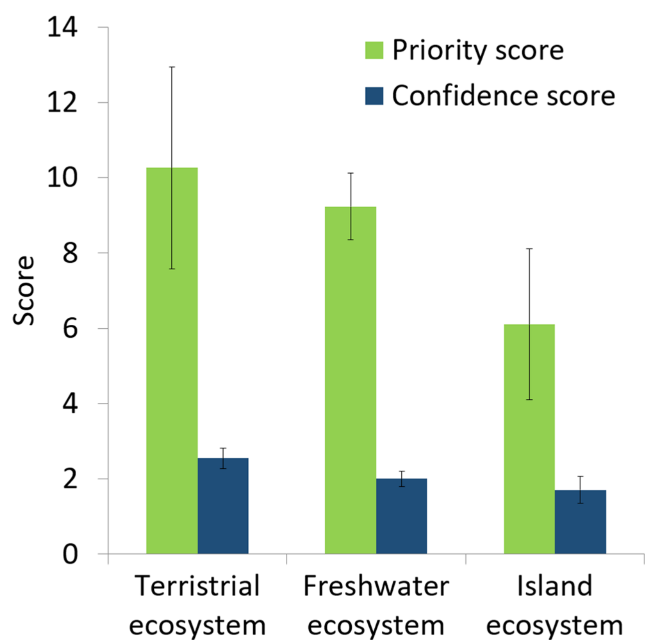

Fig. 1 Average priority and confidence scores (mean ± SE) for High Concern Invasive Species across different ecosystems (Marine ecosystem was excluded as it had only one High Concern Invasive Species, which cannot be compared using present statistics)

significantly higher confidence score ($p < 0.03$) (Fig. 1). Out of all the criteria, a significantly positive correlation with the neutral priority model was observed for criteria on impact on biodiversity ($R = 0.63$, $p < 0.005$), impact on physical environment ($R = 0.70$, $p < 0.005$), and impact on ecosystem services ($R = 0.60$, $p < 0.01$); while significantly negative relation ($R = -0.46$, $p < 0.05$) was observed with availability of legal instruments. A positive correlation was also observed in the neutral priority score and the criteria of spatial distribution ($R = 0.42$, $p < 0.08$).

Terrestrial mainland ecosystem

Terrestrial ecosystem had 11 plants and one animal identified as high concern by the experts during the workshop. Prioritization framework identified *Prosopis juliflora* as the top HiCIS priority followed by *Chromolaena odorata;* whereas, *Xanthium strumarium* and *Ageratum conyzoides* gained the least priority across all priority models (Table 1). *Parthenium hysterophorus* was the species with highest confidence score across the ecosystems; while, *Xanthium strumarium*, *Ageratum conyzoides*, and *Hyptis suaveolens* were the species with least confidence in the terrestrial ecosystem (Table 1) (Fig. 2). The Giant African land snail (*Achatina fulica*) received higher priority in management weighed model and had moderate confidence score (Table 1).

Island ecosystem

Populations of the Spotted deer (*Axis axis*) and the Indian bullfrog (*Hoplobatrachus tigerinus*), occurring on the Andaman Islands, received high priority. The Spotted deer received a higher priority (Fig. 2) and confidence score than the Indian bullfrog (Table 1), and had a higher criterion and confidence score across all priority models (Table 1). Management model for the Spotted deer received a higher score as compared to ecology and impact models. The Indian bullfrog was ranked the lowest among all species.

Freshwater ecosystem

This ecosystem had the second highest number of priority species after the terrestrial ecosystem. Four fishes and two plants were identified as HiCIS in the freshwater ecosystem. Prioritization framework assigned highest priority and confidence score to *Eichhornia crassipes* followed by *Clarias gariepinus* in this ecosystem. Interestingly*, Eichhornia crassipes* received lower priority in the management model, where *Clarias gariepinus* received the highest priority (Table 1). *Cyprinus carpio* had the least priority and confidence score across the models in the ecosystem followed by *Ipomoea carnea*, both with a moderate confidence score. *Oreochromis mossambicus* was a species with moderate priority and confidence score (Fig. 2).

Marine ecosystem

The sea algae *Kappaphycus alvarezii* was the sole nominated marine invasive species by the experts attending the workshop. The algae ranked seventh in the management model; else, it ranked at the ninth amongst all the HiCIS (Table 1) (Fig. 2).

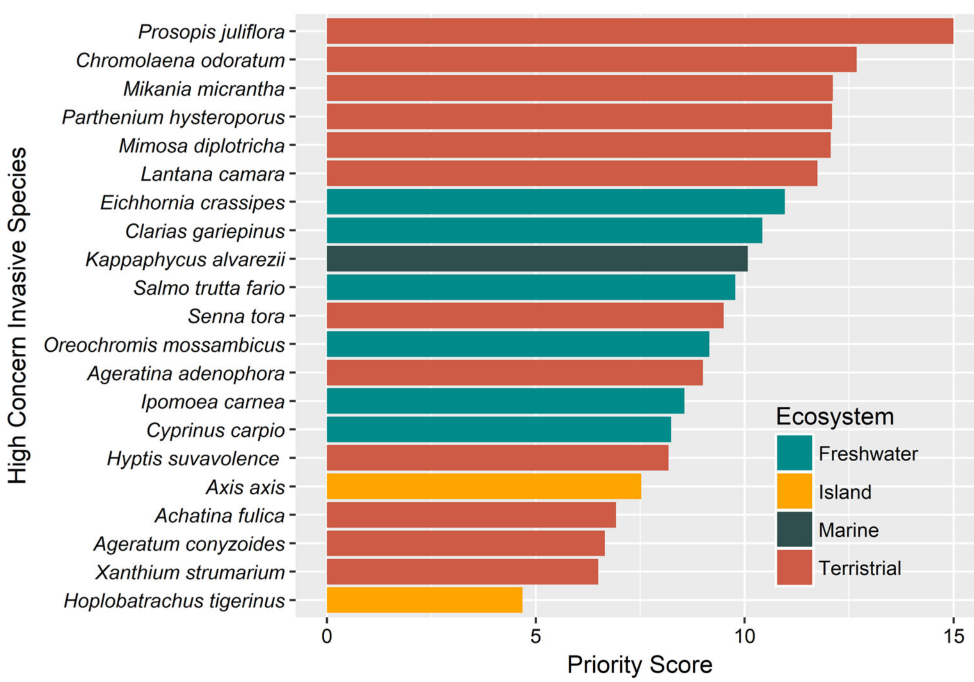

Fig. 2 Priority score of High Concern Invasive Species (HiCIS) in terrestrial, freshwater, marine and island ecosystem of India

Discussion

Present study evaluated the research and management priorities for the 21 HiCIS within four major ecosystems of India. The significant relationship between priority scores and impacts of the HiCIS on native biodiversity, environment, and ecosystem services explains the importance of the impacts on biotic components for the designation of a species as HiCIS. Secondly, the negative relationship between priority scores and lacuna in legal instruments for management indicates a lack of legal policies and management guidelines for the less popular species with lower priority.

Across all the ecosystems in India, freshwater and island ecosystems received a lower confidence score reflecting the research and information gap for these ecosystems. This gap in information might be due to the limited research in these ecosystems, amidst the repeated invasion, particularly through aquaculture. Since only mechanical removal of these species is practiced in pockets of its invasion range, the priority score of these species in the management model was higher than other models. The mainland terrestrial ecosystem plant species had the highest priority scores representing significant ecological evidence, yet, paucity in their management. However, high confidence score point towards a higher degree of scientific consideration for the terrestrial ecosystem. This can also be suggestive of the bias in the conduct of research across ecosystems, since most of the conservation research is carried out for flagship species on terrestrial mainland. Island ecosystem had invasive species that are protected by the law in India. However, their presence on the islands, where they are non-native, imparts their adverse effects on the ecosystem. Although their management is perceived as a conflict with the existing law, our study revealed the presence of all amendments for managing these species, once their impacts are documented. Nomination of a single species in the marine ecosystem, although, reflects scantiness in research about marine ecosystem, but it might also be a product of under-representation of experts in the panel identifying the HiCIS (Mathur et al. 2015).

Similarly, previous studies have also expressed the paucity of information regarding the invasive status of fungi, bacteria, and other micro-organisms (Bebber and Gurr 2015; Mallon et al. 2015; Walsh et al. 2016). Though impacts of microscopic invasive species on the agricultural crops, pisciculture, and animal husbandry are established (Pimentel et al. 2001) but information about their status and control mechanism is either limited or unknown to many stakeholders. Due to the difference in the conservation priorities and ecological settings of these species and ecosystems, we discuss each ecosystem in detail in the supplementary information 1.

As India plans to manage the priority species by 2020, it is crucial to focus on management-based research, as invasiveness and impacts on the ecosystem are already documented. The spatial distribution of invasive species often represents invasiveness and provides an opportunity for prioritizing management. However, we observed that the information on spatial distribution for all HiCIS at optimal scale, which is important for management or understanding the spread of the species, is unavailable but crucial for prioritizing management effort. Notably, we found existing legal instruments through which a species could be declared as invasive for managing it inside/outside protected areas. However, these legal instruments and guidelines for invasive species management were part of larger legal schemes (e.g. National Forest Policy 1988, National Working Plan Code 2014, Marine Product Export Development Authority) and wildlife laws for protected area management (e.g. Wildlife (Protection) Act 1972). Given that, the lack of explicit legal scheme and guidelines for invasive species management might bring subjectivity due to differing interpretation of a given scheme by the park managers. It would be particularly true for managing invasions inside Protected Areas that are governed by strict national laws.

Nevertheless, our synthesis revealed that in certain cases, invasive species were managed under existing umbrella policies and Acts (e.g. forest policies by the state of Madhya Pradesh-2005, Maharashtra-2008, and Assam-2004). However, prior managing a species within protected area, it is mandatory to prove a species to be invasive and detrimental for the ecosystem, which in turn demands scientific research and experimentation. Hence, we disagree with the previous study (Kannan et al. 2013) that believed legal unawareness to be responsible for poor management of invasive species in India; but simultaneously, we voice our concerns regarding the lacuna of explicit schemes for declaring and managing invasive species. Amidst the limited information for evidence-based policies, present review of published records and expert knowledge can help prioritize and channelize the limited resources for imminent threats brought by the invasive species.

Acknowledgments Present study is based on the workshop on 'Management of Human – Wildlife negative interactions and Invasive species', funded by the Ministry of Environment, Forestry and Climate Change (MoEF&CC) and organized by the Wildlife Institute of India (WII). We thank Dr. V.B. Mathur (WII), Dr. G.S. Rawat (WII), Dr. B.C. Sinha (WII), Dr. Y.V. Jhala (WII), Dr. S. Sathyakumar (WII), Dr. K. Sankar, and Shri. S.S. Bist for facilitating the study and participants of the workshop for giving field inputs. We thank Dr. Hukum Singh (Forest Research Institute) and the anonymous reviewers for improving the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Ali R, Pelkey N (2013) Satellite images indicate vegetation degradation due to invasive herbivores in the Andaman Islands. Curr Sci 105: 209–214

Bebber DP, Gurr SJ (2015) Crop-destroying fungal and oomycete pathogens challenge food security. Fungal Genet Biol 74:62–64. https://doi.org/10.1016/j.fgb.2014.10.012

Bhagwat SA, Breman E, Thekaekara T et al (2012) A battle lost? Report on two centuries of invasion and management of *Lantana camara* L. in Australia, India and South Africa. PLoS One 7:e32407. https://doi.org/10.1371/journal.pone.0032407

Brunel S, Branquart E, Fried G et al (2010) The EPPO prioritization process for invasive alien plants. EPPO Bull 40:407–422. https://doi.org/10.1111/j.1365-2338.2010.02423.x

Clavero M, Garcia-Berthou E (2006) Homogenization dynamics and introduction routes of invasive freshwater fish in the Iberian Peninsula. Ecol Appl 16:2313–2324. https://doi.org/10.1890/1051-0761(2006)016[2313:HDAIRO]2.0.CO;2

Early R, Bradley BA, Dukes JS et al (2016) (2016) global threats from invasive alien species in the twenty-first century and national response capacities. Nat Commun 7:1–9. https://doi.org/10.1038/ncomms12485

Ellis EC (2011) Anthropogenic transformation of the terrestrial biosphere. Philos Trans R Soc Lond Math Phys Eng Sci 369:1010–1035. https://doi.org/10.1098/rsta.2010.0331

Forsyth GG, Le Maitre DC, O'farrell PJ, Van Wilgen BW (2012) The prioritisation of invasive alien plant control projects using a multicriteria decision model informed by stakeholder input and spatial data. J Environ Manag 103:51–57. https://doi.org/10.1016/j.jenvman.2012.01.034

Kannan R, Shackleton CM, Uma Shaanker R (2013) Playing with the forest: invasive alien plants, policy and protected areas in India. Curr Sci 104:1159–1165

Kaushik M, Mungi NA (2015) Human–wildlife interactions and management of invasive alien species. Curr Sci 108:1039

Koehn JD (2004) Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. Freshw Biol 49:882–894. https://doi.org/10.1111/j.1365-2427.2004.01232.x

Kumschick S, Bacher S, Dawson W et al (2012) A conceptual framework for prioritization of invasive alien species for management according to their impact. NeoBiota 15:69. https://doi.org/10.3897/neobiota.15.3323

Lach D, List P, Steel B, Shindler B (2003) Advocacy and credibility of ecological scientists in resource decisionmaking: a regional study. BioScience 53:170–178. https://doi.org/10.1641/0006-3568(2003)053[0170:AACOES]2.0.CO;2

Liu S, Proctor W, Cook D (2010) Using an integrated fuzzy set and deliberative multi-criteria evaluation approach to facilitate decision-making in invasive species management. Ecol Econ 69: 2374–2382. https://doi.org/10.1016/j.ecolecon.2010.07.004

Lowe S, Browne M, Boudjelas S, De Poorter M (2000) 100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database. The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), New Zealand, 12pp

Mallon CA, Poly F, Le Roux X et al (2015) Resource pulses can alleviate the biodiversity–invasion relationship in soil microbial communities. Ecology 96:915–926. https://doi.org/10.1890/14-1001.1

Marris E (2006) Should conservation biologists push policies? Nature 442:13. https://doi.org/10.1038/442013a

Mathur VB, Kaushik M, Bist SS, et al (2015) Management of human-wildlife interaction and invasive alien species in India. Report no. TR 2015/004, Wildlife Institute of India, Dehradun

McGeoch MA, Butchart SHM, Spear D et al (2010) Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Divers Distrib 16:95–108. https://doi.org/10.1111/j.1472-4642.2009.00633.x

Morse LE, Randall JM, Benton N et al (2004) An invasive species assessment protocol: evaluating non-native plants for their impact on biodiversity, version. NatureServe, Arlington, Virginia, p 1

Mungi NA, Qureshi Q (2018) On the history, politics and science of invasion ecology. DIALOGUE: science, scientists, and Society 1: 1–16. https://doi.org/10.29195/DSSS.01.01.0009

Mungi NA, Coops NC, Ramesh K, Rawat GS (2018) How global climate change and regional disturbance can expand the invasion risk? Case study of *Lantana camara* invasion in the Himalaya. Biol Invasions 20:1849–1863. https://doi.org/10.1007/s10530-018-1666-7

Nel JL, Richardson DM, Rouget M et al (2004) A proposed classification of invasive alien plant species in South Africa: towards prioritizing species and areas for management action: working for water. South Afr J Sci 100:53–64

Pande HK, Arora S (2015) India fifth national report to convention on biological diversity. Ministry of Environment and Forests and climate change. Government of India, New Delhi

Pimentel D, McNair S, Janecka J et al (2001) Economic and environmental threats of alien plant, animal. and microbe invasions Agric Ecosyst Environ 84:1–20. https://doi.org/10.1016/S0167-8809(00)00178-X

Randall JM, Morse LE, Benton N et al (2008) The invasive species assessment protocol: a tool for creating regional and national lists of invasive nonnative plants that negatively impact biodiversity. Invasive Plant Sci Manag 1:36–49. https://doi.org/10.1614/IPSM-07-020.1

Robertson MP, Villet MH, Fairbanks DHK et al (2003) A proposed prioritization system for the management of invasive alien plants in South Africa: research in action. South Afr J Sci 99:37–43

Sax DF, Gaines SD, Brown JH (2002) Species invasions exceed extinctions on islands worldwide: a comparative study of plants and birds. Am Nat 160:766–766. https://doi.org/10.1086/343877

Simberloff D, Martin JL, Genovesi P et al (2013) Impacts of biological invasions: what's what and the way forward. Trends Ecol Evol 28: 58–66. https://doi.org/10.1016/j.tree.2012.07.013

Theoharides KA, Dukes JS (2007) Plant invasion across space and time: factors affecting nonindigenous species success during four stages of invasion. New Phytol 176:256–273. https://doi.org/10.1111/j.1469-8137.2007.02207.x

Walsh JR, Carpenter SR, Vander Zanden MJ (2016) Invasive species triggers a massive loss of ecosystem services through a trophic cascade. Proc Natl Acad Sci 113:4081–4085. https://doi.org/10.1073/pnas.1600366113