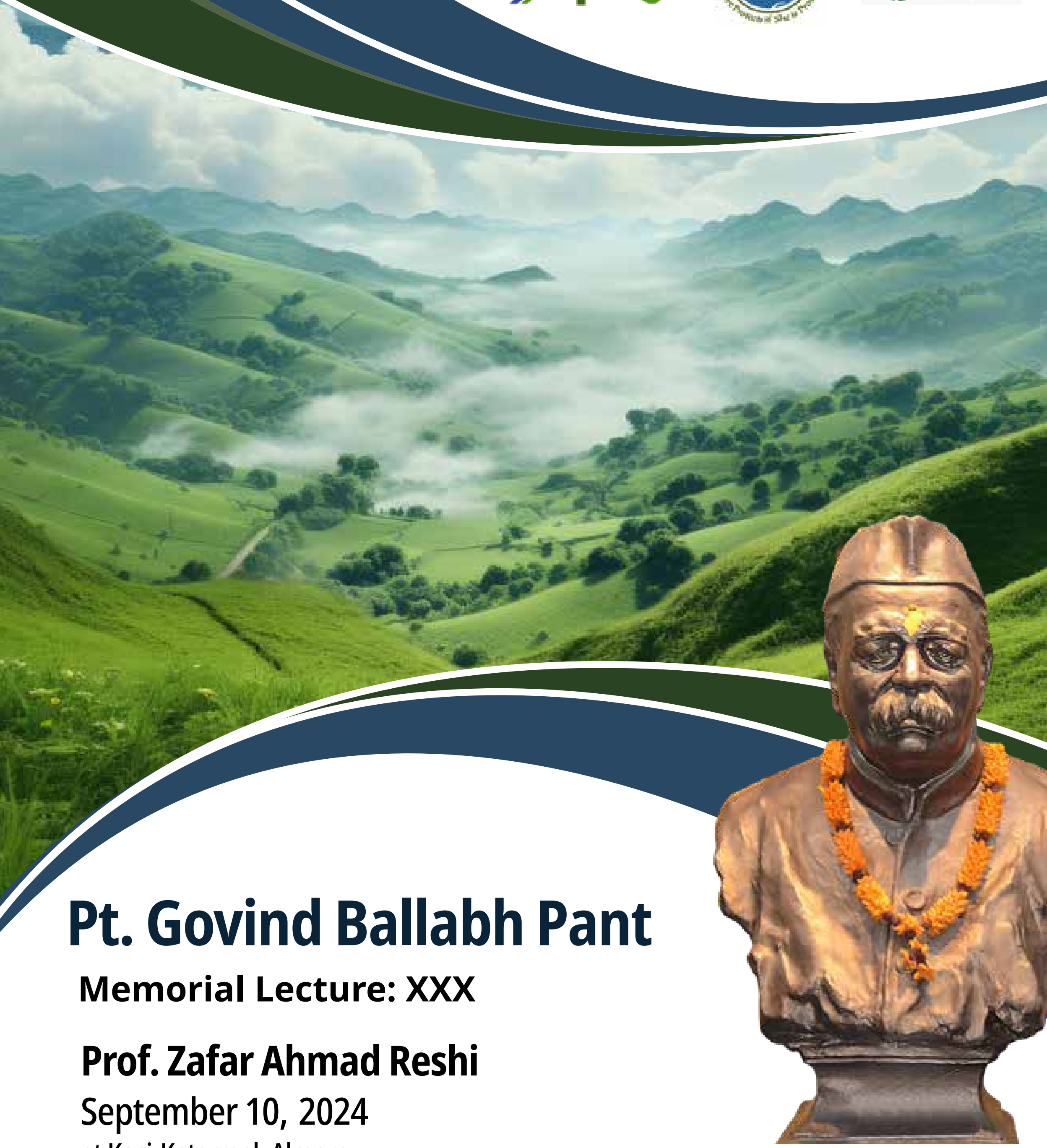


Pt. Govind Ballabh Pant

Memorial Lecture: XXX

Prof. Zafar Ahmad Reshi

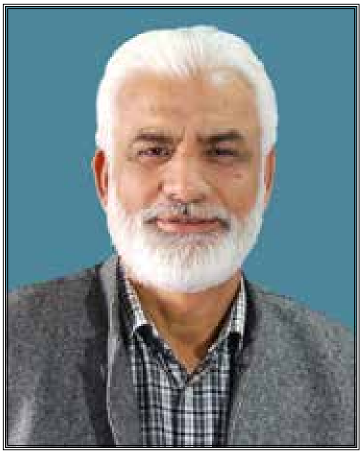
September 10, 2024

at Kosi-Katarmal, Almora

G.B. Pant National Institute of Himalayan Environment (NIHE)

(An Autonomous Institute of Ministry of Environment, Forest and Climate Change, Govt. of India)

Kosi-Katarmal, Almora, 263 643, Uttarakhand, India



Prof. Zafar Ahmad Reshi

Professor Reshi is a distinguished Professor in the Department of Botany at the University of Kashmir, Srinagar, in the Union Territory of Jammu & Kashmir. Renowned for his research and teaching, he possesses extensive experience and expertise in ecology, biodiversity, invasion biology, and microbial ecology. Over his illustrious career, he has guided more than 50 students for their Ph.D. and M.Phil. research programs and has authored about 230 research publications, including papers in prestigious international journals, book chapters, and two books on various aspects of Himalayan ecology and the environment.

Professor Reshi has successfully completed 29 research and consultancy projects, and was a collaborator in Indo-US, Indo-French, and Indo-German research projects. At the University of Kashmir, he has held several key academic and administrative positions, such as Head of the Department of Botany, Dean of the School of Biological Sciences, Dean of Research, Registrar, and Chief Coordinator of the Centre with Potential for Excellence in 'Kashmir Himalayan Biodiversity: Documentation, Bio-prospection, and Conservation'. He is an elected fellow of the National Institute of Ecology and holds memberships in several national and international professional organizations.

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Guardians of the Peaks: Confronting the Green Invaders of the Himalayan Highlands

Honourable Dignitaries, Director of the Institute, Respected Guests, entire NIHE family and media persons

It is a great honour and privilege to be invited to deliver this lecture on the occasion of the Annual day of **G.B. Pant National Institute of Himalayan Environment, Almora, Uttarakhand, India.** Today, I will be discussing a critical and pressing issue that affects the very heart of our majestic Himalayan region: the invasion of alien plant species. The title of my lecture, **"Guardians of the Peaks: Confronting the Green Invaders of the Himalayan Highlands"** reflects the urgent need to address the challenges posed by these invasive species to our unique and fragile ecosystems.

Introduction

The Himalaya, often referred to as the "water tower of Asia" due to its extensive glacial coverage, is not only a vital source of water for millions of people but also is a biodiversity hotspot and home to countless endemic species. However, this pristine environment is under threat from a wave of green invaders. Alien plant species, introduced intentionally or unintentionally, are spreading rapidly across these highlands, outcompeting native flora, altering habitats, and disrupting ecological organization and functional integrity of communities and ecosystems.

In this lecture, we will explore the scale, scope, and impact of alien plant invasions, and deliberate upon the ways and means to "eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent, by 2030, eradicating or controlling invasive alien species especially in priority sites, such as islands" [Target 6 of the Kunming-Montreal Global Biodiversity Framework (GBF)]. We will examine ecological and economic consequences of invasive alien species and the challenges they present to conservation. Through case studies, we will identify the traits that drive invasiveness and also highlight how these species can serve as unique models for advancing our understanding of plant growth and development. Integrating already introduced and widespread invasive alien species into the BioE3 (Biotechnology for Economy, Employment, and Environment) Policy approved by the Govt. of India by leveraging biotechnology to create bio-manufacturing solutions that not only transform invasive species into valuable resources, but also contribute to management and mitigation of their impact. For instance, invasive plants could be used as raw materials for biofuels, bioplastics, or other bio-based products, and thereby can contribute to a circular economy.

By understanding the extent and impact of plant invasions, we can better equip ourselves to protect our Himalayan highlands. It is our collective responsibility as guardians of these peaks to confront and combat the green invaders threatening our natural heritage.

Planet Invaded: The Widespread Threat of Invasive Species

Biological invasions are one of the greatest threats to global biodiversity, second only to the destruction of natural habitats. Since 1800, the annual rate of first records of invasive species has steadily increased, with 37% of these occurrences happening in the last 44 years alone. This trend continues to rise and is predicted to persist (Seebens et al. 2017). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in its report of 2023 on invasive species reveals the alarming scale and impact of invasive species on global biodiversity, ecosystems, and human well-being. Over 37,000 alien species have been introduced worldwide, with approximately 3,500 of these classified as invasive due to their significant negative impacts. The report states that the invasive species are one of the top five drivers of biodiversity loss globally, alongside habitat destruction, climate change, pollution, and overexploitation, and have contributed significantly to 60% of recent global extinctions. On islands, the impact is even more pronounced, with invasive species responsible for 86% of recorded extinctions. These species not only threaten biodiversity but also impose significant economic costs, estimated at $423 billion annually. This figure includes both direct costs such as control and eradication efforts and indirect costs like lost agricultural productivity and ecosystem services.

Human health is also affected by invasive species, which can spread diseases such as Zika, West Nile virus, and malaria, and cause allergic reactions and other health issues, impacting millions of people worldwide. Additionally, invasive species alter ecosystem functions, including nutrient cycling, water flow, and fire regimes. They outcompete native species for resources, leading to reduced biodiversity and changes in community structure.

Climate change is likely to exacerbate biological invasions, particularly in the Himalaya, a region experiencing warming at a rate higher than the global average. As temperatures rise, the changing climate will create new niches and extend the growing season, allowing invasive species to establish and spread more rapidly in these sensitive mountain ecosystems. Additionally, warming temperatures and altered precipitation patterns may weaken native species' resilience, further promoting the dominance of invasive plants and disrupting the region's unique biodiversity.

Despite the challenges, there are successful examples of invasive species management. For instance, the eradication of invasive rats on South Georgia Island led to the recovery of native bird populations, and control programs for the water hyacinth in Lake Victoria have improved water quality and fisheries. These success stories demonstrate that with the right strategies and sufficient resources, it is possible to mitigate the impacts of invasive species.

In view of their significant ecological and economic impacts, there is an urgent need for comprehensive and proactive measures to address the threat of invasive species. Their effective management requires a combination of prevention, early detection, rapid response, and long-term control measures, supported by coordinated international efforts and strong policy frameworks.

Green Invaders in Himalayan Highlands

The Himalaya is a home to a vast diversity of species, consisting of 10,000 vascular plants, 979 birds and 300 mammals, including the snow leopard, the red panda, the Himalayan tahr and the Himalayan monal. The region represents a huge mountain system extending 2,400 kilometres across Nepal, India, Bhutan, Pakistan, China, Myanmar and Afghanistan (Dyola and Rossi, 2023). It has a number of climate types and ecological zones, from tropical to alpine ecosystems including ice and rocks in the uppermost zone. All these ecological zones are compressed within a short elevation span. The Himalaya — along with the related Tibetan Plateau — provides considerable ecosystem services and are also the source of most of Asia's major rivers, a fact that has earned it the additional moniker of "the world's water tower." It is of urgent importance that these fragile ecosystems are conserved and protected.

The Indian Himalayan Region (IHR) spans 13 Indian States and Union Territories, including Jammu and Kashmir, Ladakh, Uttarakhand, Himachal Pradesh, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, hill districts of Assam and West Bengal, spanning over an east to west stretch of 2,500 km. This region is home to nearly 50 million people and is distinguished by its diverse demography and unique economic, environmental, and social systems. Among the plethora of environmental problems, alien plant invasions in the IHR are least highlighted, notwithstanding the fact that 771 alien plant species, including 375 cultivated and 396 naturalized species have been recently reported from this region based on a review of 141 studies published during the years 1934 to 2022 (Wani et al. 2022).

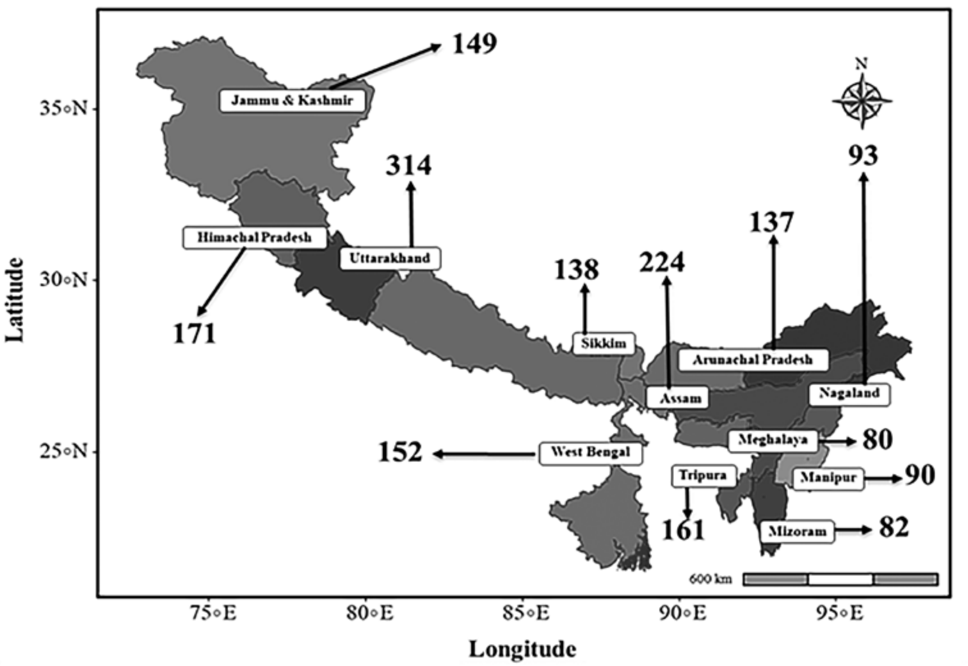


Fig. 1. Number of naturalized alien plant species in Indian Himalayan States.

The number of naturalized alien species varied across the states (Fig. 1) with highest number of species (314) reported from Uttarakhand and least number of 80 species from Meghalaya. The ten families with the highest number of species are shown in Fig. 2. Asteraceae with 64 species is the most speciose family followed by Fabaceae with 46 species, and Solanaceae with 31 species.

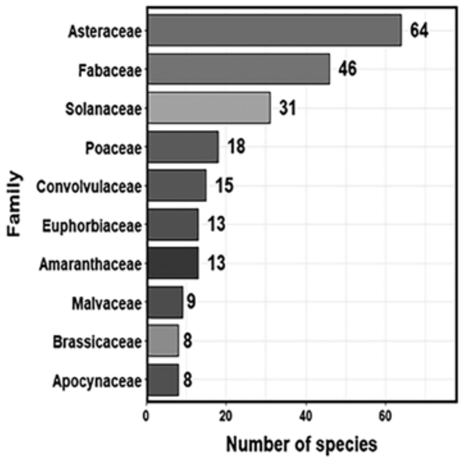


Fig. 2. Distribution of alien plant species across various families.

The ten genera with highest representation of species are presented in Fig. 3. *Solanum* included the highest number of species (12) followed by *Senna* and *Ipomoea* with 10 species each. Euphorbia was represented by 8 species and *Opuntia* by 6 species.

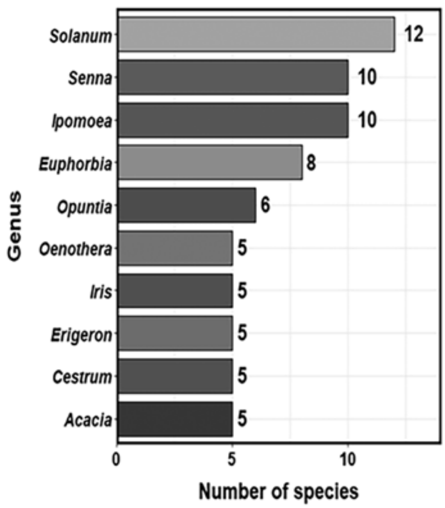
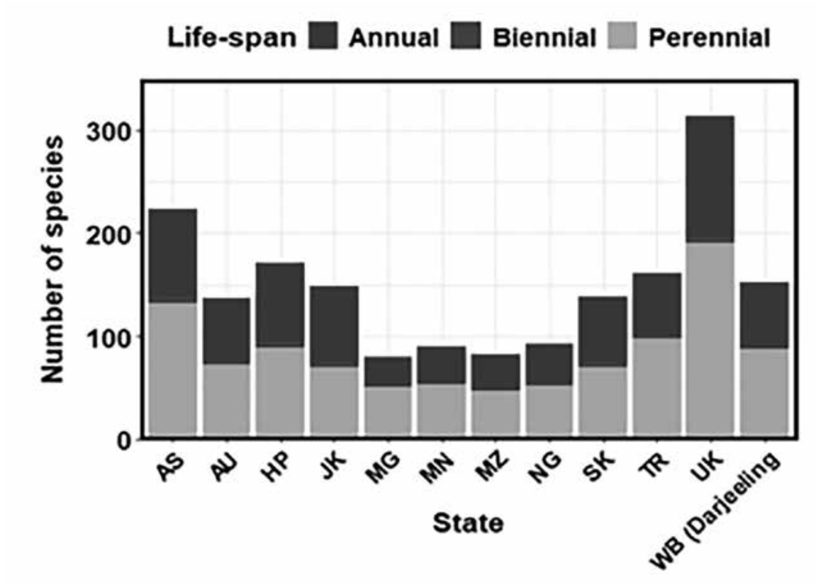


Fig. 3. Distribution of alien plant species across various genera.

The naturalized alien species were mostly annuals and perennials with latter being dominant across all the states. Very few species had biennial habit (Fig. 4). Likewise, herbs were predominant across all the states followed by shrubs and trees (Fig. 4).



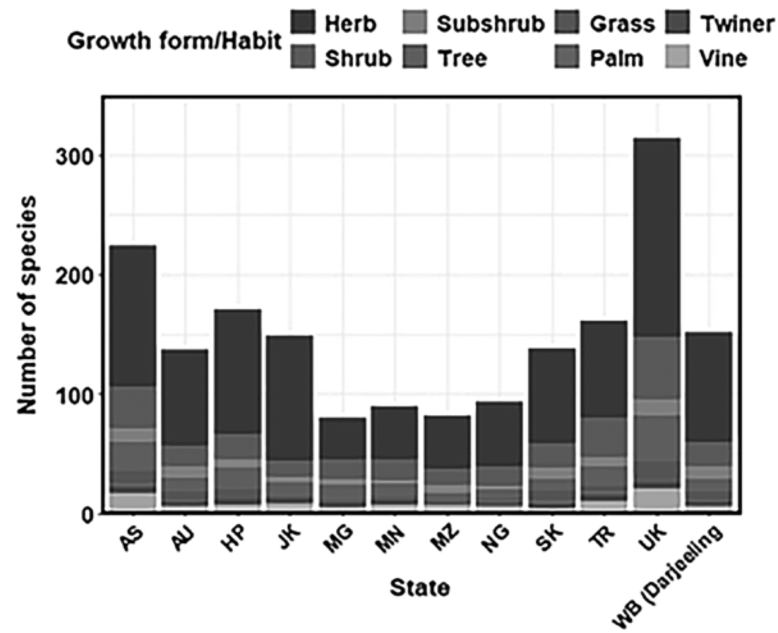


Fig. 4. Distribution of species across different growth forms (above) and lifespan categories (below).

The number of naturalized alien species shared between different states in presented in Fig. 5. Highest number of species (194) was common between Uttarakhand and Assam followed by 166 species between Uttarakhand and Himachal Pradesh.

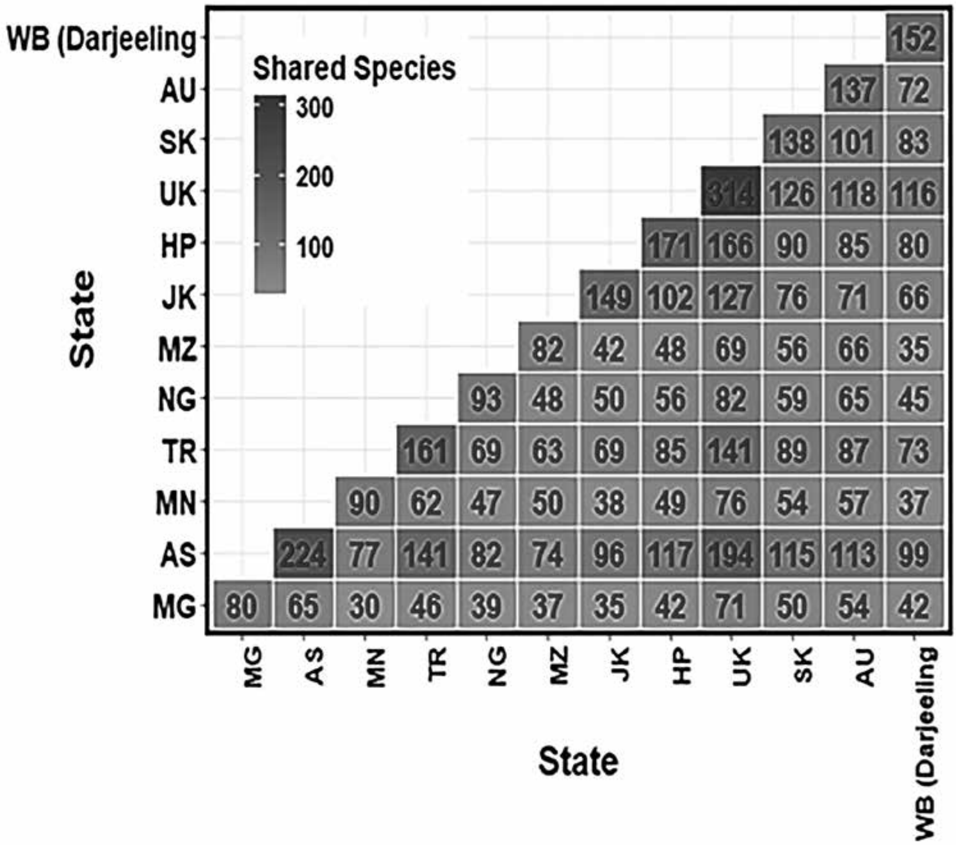


Fig. 5. Number of shared naturalized alien species across the IHR.

This study (Wani et al. 2022) also brought out that most of the alien plant species in the IHR are of Southern America origin. Furthermore, it was revealed that total alien plant richness was best explained by the average annual rainfall, while the naturalized plant richness was best predicted by total traffic (roads including abandoned ones, railway tracks) length.

Tailored Inventories for Effective Management

The inventories of alien species are typically compiled at large spatial scales, which can provide insights into broad macroecological patterns. However, these inventories often lack the detailed information needed to inform local management practices and policies effectively. Local authorities responsible for managing invasive species need specific data on the presence and abundance of these species within their own jurisdictions to implement targeted and effective control measures. A case in point is Kashmir, Jammu and Ladakh, which though geographically contiguous, have distinct climate and topography. In these three regions, we reported a total of 312 alien plant species belonging to 210 genera and 61 families (Zargar et al. 2024). Of these, ca. 62% are naturalized and 28 % belong to invasive category.

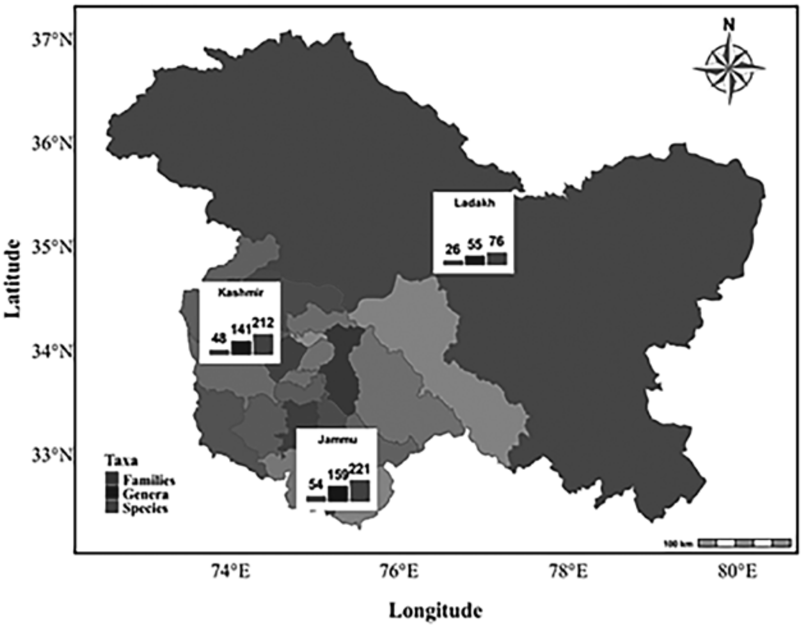


Fig. 6. Taxonomic conspectus of species, genera and families of alien vascular plant species across Jammu, Kashmir, and Ladakh.

Jammu recorded the highest number of alien plant species, totalling 221, with 99 species unique to the region. The Kashmir Himalaya followed Jammu with 212 alien species, 70 of which are exclusive to this area. In Ladakh, 76 alien species were documented, with just one being unique. Additionally, 55 species were found to be common across all three regions (Figs. 6 and 7). This highlights that each region has its own distinct set of alien species, which can be overlooked when inventories are compiled on a larger spatial scale.

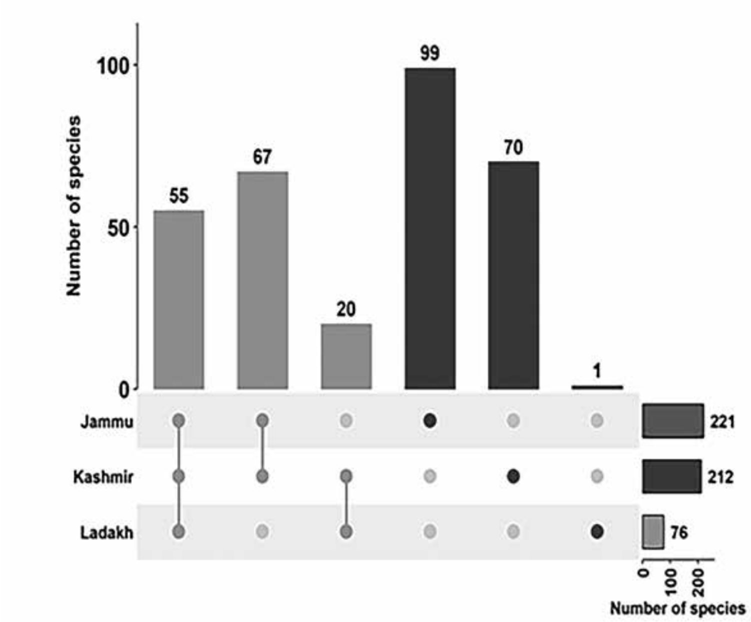


Fig. 7. Upset plot showing total, exclusive and shared alien plant species in the three regions. The golden orange dots connecting the regions represents the shared species between them. Single red dots at the respective regions represent unique species to a region.

Invasive Species on the Move: The Role of Climate Change

Climate change is reshaping ecosystems around the globe, creating new opportunities for invasive species to spread and thrive. As temperatures rise and weather patterns shift, these opportunistic species would move into new areas, outcompeting native species and disrupting local biodiversity. Understanding how climate change influences the movement and impact of invasive species is crucial for predicting and managing future ecological risks. In fact, a recent study on non-native plant distributions along mountain roads in 11 regions, including Kashmir Himalaya across 5 continents found that the number of non-native species increased by about 16% per decade on average across these regions (Iseli et al. 2023). It was also observed that non-native plants moved upwards more than expected in 10 out of 11 regions.

Himalaya is undergoing the most rapid and elevation-dependent warming, particularly

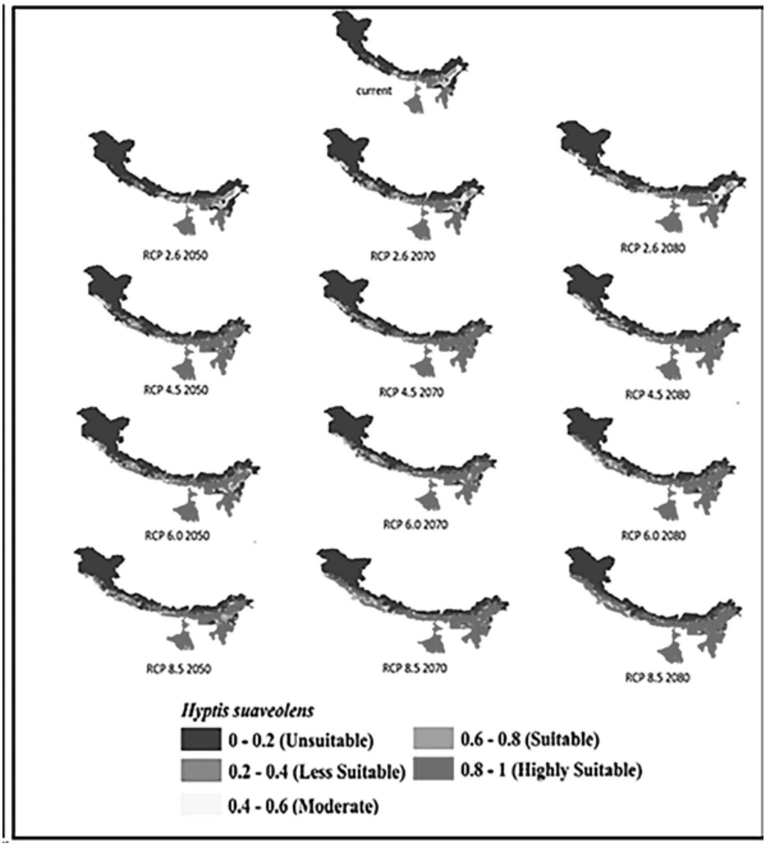


Fig. 8. Current and predicted distribution of Mesosphaerum (Hyptis) suaveolens in the IHR under various RCP scenarios.

since the 1980s (Dimri et al. 2022). The mean annual temperature has increased by approximately 0.1°C/decade over the 1901-2014 period (Ren et al. 2017). Compared to 1961–1990, the mean annual temperature is predicted to increase by about 1–2°C during 2021–2050 (IPCC, 2021). This changing climate is likely to accelerate the spread and impact of invasive species which is being studied through species distribution modelling.

Based on a robust ensemble modelling of six invasive species under various climate change scenarios, Mushtaq (2023) made the most striking prediction of significant increase in the suitable area for *Mesosphaerum (Hyptis) suaveolens* in the IHR under various RCP scenarios with a maximum increase of 46.63% and 48.47% predicted under RCP 8.5 in 2070 and 2080, respectively (Fig. 8).

This is particularly alarming given that there is currently no suitable habitat for this species in the northwest Himalaya, but in the future, substantial increases are predicted for both the northwest and northeast Himalaya. Overall, the Himalaya is at a high risk of invasion by *M. suaveolens.*

Invasive Species: Nature's Unintended Experiment

Invasive species, often seen as ecological threats, also serve as natural experiments to understand rapid adaptation, ecosystem dynamics, and evolutionary processes at play.

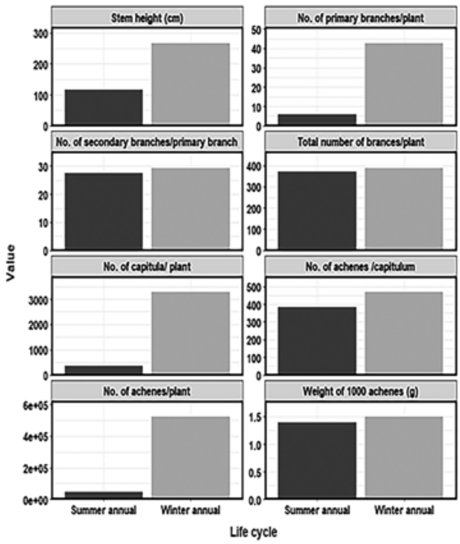


Fig. 9. A comparison of growth attributes of summer and winter annual plants of A. cotula.

By studying these resilient invaders, scientists can gain valuable insights into species interactions, environmental change, and the mechanisms driving invasion success.

Our studies on *Anthemis cotula* L. have revealed intriguing insights into its life history strategy. Commonly called as Mayweed chamomile or Stinking mayweed, it is a monocarpic, annual species native to Eurasia in regions with Mediterranean climates (Adhikari et al. 2020). In Kashmir valley, this ruderal species grows both as a winter as well as a summer annual. The winter annual plants exhibit high fitness, playing a key role in the species' spread and abundance, while the summer annual plants serve as a backup survival strategy if the winter annuals fail to establish and reproduce (Fig. 9).

The winter annuals overwinter as rosettes and bolt in the following spring. Notable differences have been observed in the growth characteristics, leaf microbiome, and type and content of volatile organic compounds between the winter and summer annual plants.The species exhibits allelopathic effects through its aqueous leaf leachate, forms mycorrhizal associations and displays over compensatory growth in response to herbivory (Fig. 10).

In conclusion, dual life strategy of *Anthemis cotula* L in Kashmir, growing both as a winter as well as a summer annual, observed variations in several traits exemplifies the adaptability of this invasive species, making it an ideal model for studying ecological and evolutionary processes. These findings offer valuable insights into the mechanisms driving adaptation and species interactions in dynamic ecosystems.

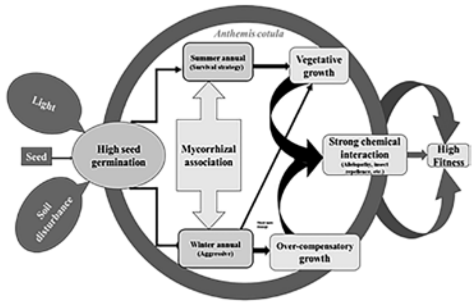


Fig. 10. Syndrome of traits that contribute to invasiveness of *A. cotula* in Kashmir Himalaya.

Green Invaders: The Ripple Effect

Most alien species are benign and coexist without causing significant harm to other species. However, a subset of these species become invasive, leading to substantial ecological disruption and significant economic losses. Their introduction sets off a ripple effect, triggering a cascade of impacts that alter species interactions, disrupt food webs, and transform ecosystems in profound and often unpredictable ways. Understanding this ripple effect is crucial for managing and mitigating the complex challenges posed by these relentless invaders. The thematic assessment report on "Invasive Alien Species and Their Control" by IPBES (2023) brought out that majority of reported impacts (85%) are negative, leading to population declines and extinctions. The invasive alien species have contributed in 60% of recorded global animal and plant extinctions and are the sole cause in 16% of these cases. Most extinctions linked to invasive species have occurred on islands, but mountains, due to their ecological isolation, can also be considered "islands" and hence invasive species pose a significant threat to native biodiversity in the mountainous areas, like the IHR.

There are not many well-documented studies about the impact of invasive alien species in the IHR. However, decrease in density, frequency, and diversity of native species, displacement of fodder grasses and medicinal plants, facilitation of other alien species at the expense of native species (invasional meltdown), inhibition of seed germination, reduction in soil nutrient content, biotic homogenization of natural habitats have been reported (Negi et al. 2018; Pathak et al. 2019). In a recent study, additive, antagonistic and synergistic impacts of plant co-invasions have been observed (Lone et al. 2024).

In a study conducted to examine the impact of *Erigeron canadensis*, Rehman (2012) observed a higher species richness in invaded plots (Fig. 10) and it did not change even after removal of *E. canadensis* (Fig. 11). However, abundance of native species invariably was higher in uninvaded plots and also increased after removal of *E. canadensis* (Fig. 11).

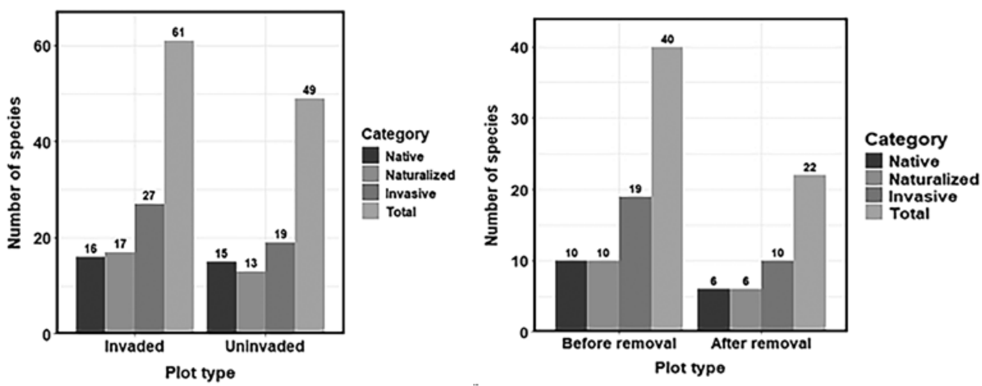
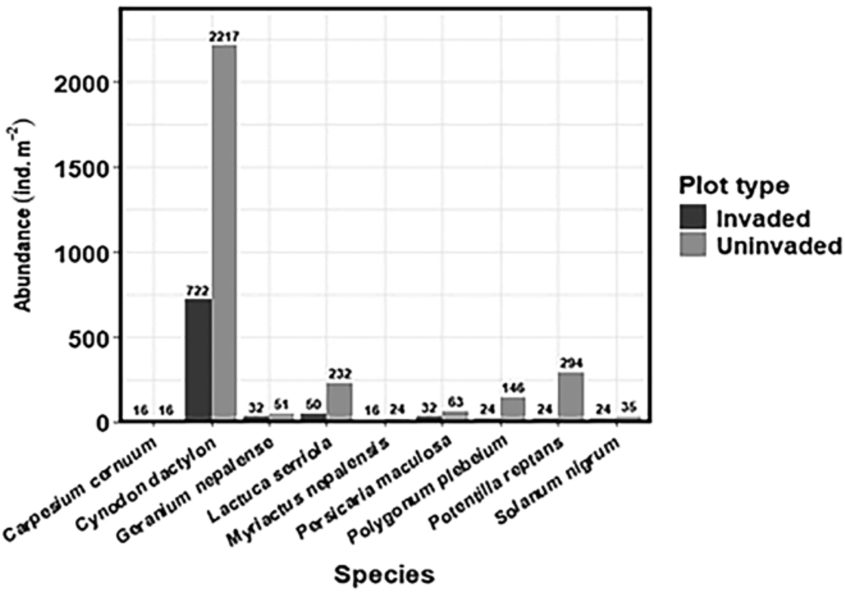


Fig. 11. Impact of *Erigeron canadensis* on the species richness in Kashmir Himalaya.



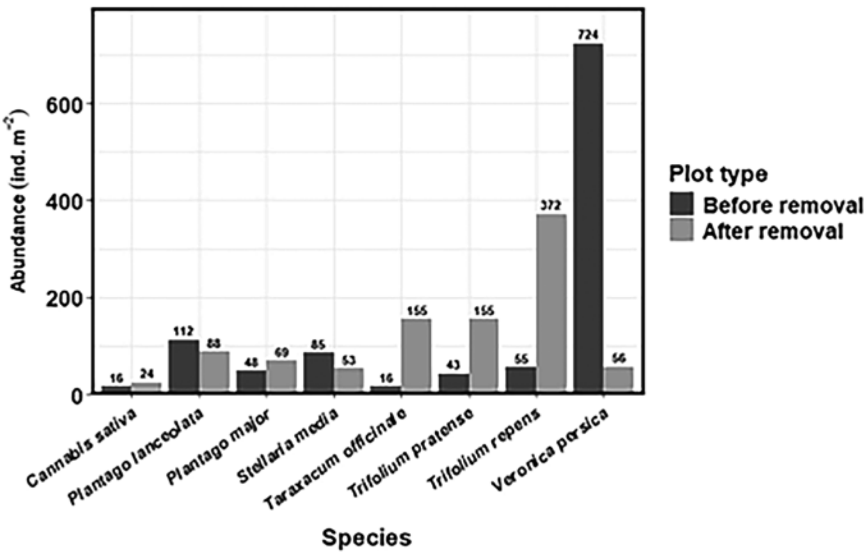


Fig. 12. Impact of *E. canadensis* on the abundance of native species in Kashmir Himalaya.

Significant decline in the number of bacteria, fungi and microbial activity due to invasion of *E. canadensis* was also recorded (Rasool, 2011).

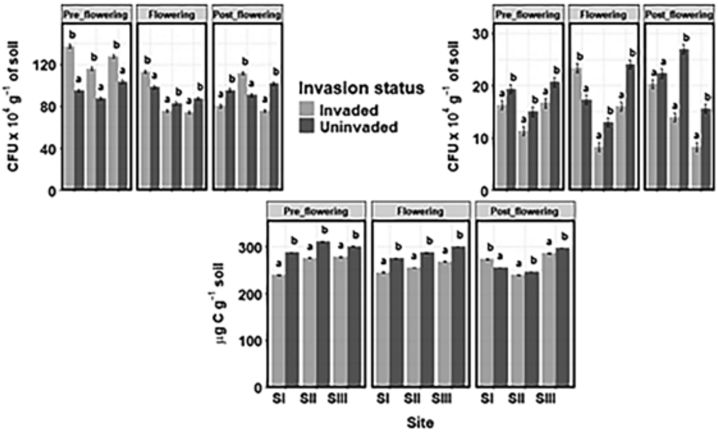


Fig. 13. Impact of E. canadensis on soil bacteria, fungi and soil microbial activity.

Thus it is important to emphasize that the impact of invasive alien species results from a complex interaction between the assemblages of both native and non-native species and the abiotic environment.

Taming the Green Invaders

The preceding discussion clearly shows that "green invaders" are spreading across the IHR, highlighting the urgent need for effective management and control strategies to limit their spread and reduce their ecological impact. Understanding the behaviour of these invasive plant species and developing targeted approaches to manage them are crucial steps in protecting and preserving our native biodiversity.

Invasive alien species can be managed through both short- and long-term measures, with prevention as the cornerstone of effective and efficient management. Effective strategies for the management of biological invasions encompass early detection, eradication, containment, and control, with focus on (a) managing pathways of introduction and spread, (b) targeting specific species at local or landscape scales, and (c) implementing site- or ecosystem-based approaches. In other words, we need to implement both pre-border measures, such as risk assessments to evaluate potential threats before they enter the country, and strict biosecurity controls to regulate imports and prevent invasive species from entering. Additionally, post-border measures should include vigilant surveillance at entry points to detect and intercept invasive species, along with rapid response strategies to address any new invasions swiftly.

India has long acknowledged the negative impacts of invasive alien species (IAS). As a party to the Convention on Biological Diversity (CBD) since February 1994, India developed its first national policy and action plans for biodiversity conservation and sustainable use in 1999. In 2008, the National Biodiversity Action Plan (NBAP) was established, incorporating IAS regulation and management as one of its 11 objectives. Following the CBD's Strategic Plan for Biodiversity 2011–2020, the NBAP was updated to include 12 National Biodiversity Targets (NBTs). In the 2014 Addendum to NBAP 2008, submitted with India's fifth National Report to the CBD, IAS management was highlighted as NBT 4, with nine specific action points (APs 59–67) aimed at controlling the introduction and spread of IAS across the country. Notwithstanding the acknowledgement of adverse impacts of IAS and intent to contain and control them, several roadblocks to their effective management have been identified (Banerjee and Shankaran, 2023) and formation of a National Invasive Species Strategy and Action Plan, with a dedicated agency to implement it, has also been proposed.

Conclusion

In conclusion, the invasion of alien plant species in the Himalayan highlands is a complex and multifaceted challenge that requires a concerted and collaborative effort. While the green invaders pose significant threats to our native ecosystems, biodiversity, and the livelihoods of local communities, they also present an opportunity for us to come together in defence of our natural heritage. Through rigorous scientific research, innovative management strategies, and active community engagement, we can mitigate the impacts of these invasive species and restore the balance of our ecosystems. Let us remember that the guardianship of the Himalayan peaks is a shared responsibility, and it is through our collective vigilance, dedication, and action that we can ensure the preservation of these magnificent landscapes for future generations. Together, we can confront and overcome the green invaders, safeguarding the ecological integrity and beauty of the Himalayan highlands.

Thank you

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G.B. Pant Memorial Lectures

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Dr. T.N. Khoshoo, Jawaharlal Nehru Fellow, TERI, New Delhi – 1992

III
Mr. V. Rajagopalan, Vice President, World Bank, Washington – 1993

IV
Prof. U.R. Rao, Member, Space Commission, New Delhi – 1994

V
Dr. S.Z. Qasim, Member, Planning Commission, New Delhi – 1995

VI
Prof. S.K. Joshi, Vikram Sarabhai Professor, JNCASR, Bangalore – 1996

VII
Prof. K.S. Valdiya, Bhatnagar Research Professor, JNCASR, Bangalore - 1997

VIII
Prof. V.K. Gaur, Distinguished Professor, IIA, Bangalore – 1998

IX
Prof. Y.H. Mohan Ram, INSA Senior Scientist, University of Delhi, New Delhi – 2000

X
Prof. J.S. Singh, Emeritus Professor, BHU, Varanasi – 2004

XI
Prof. Madhav Gadgil, Centre for Ecological Sciences, IISc, Bangalore – 2005

XII
Dr. S.S. Handa, Ex-Director, PRL (CSIR), Jammu – 2006

XIII
Dr. Lalji Singh, Director, CCMB, Hyderabad – 2007

XIV
Prof. Roddam Narasimha, Chairman, FMU, JNCASR, Bangalore – 2008

XV
Dr. R.S. Tolia, Chief Information Commissioner, Govt. of Uttarakhand, Dehradun – 2009

XVI
Prof. Raghavendra Gadagkar, CES & CCS, IISC, Bangalore – 2010

XVII
Prof. V. Nanjundiah, JNCASR, Bangalore – 2011

XVIII
Dr. Kirit S. Parikh, IRADe, New Delhi & Former Member Planning Commission – 2012

XIX
Prof. Jayanta Bandopadhyay, Former Prof. & Head, IIM, Calcutta – 2013

XX
Prof. T.S. Papola, Institute for Studies in Industrial Development, New Delhi - 2014

XXI
Dr. David Moulden, Director General, ICIMOD, Nepal - 2015

XXII
Dr. Vijay Raghavan, Secretary, Department of Biotechnology, New Delhi - 2016

XXIII
Prof. S.P. Singh, Former Vice-Chancellor, HNB Garhwal University, Uttarakhand - 2017

XXIV
Prof. P.S. Roy, Former Director, Indian Institute of Remote Sensing, Dehradun – 2018

XXV
Prof. Raman Sukumar, Professor of Ecology, Indian Institute of Science, Bangalore – 2019

XXVI
Prof. Tej Pratap, Vice Chancellor, G.B. Pant University of Agriculture and Technology,
Pantnagar – 2020

XXVII
Prof. R. Raghavendra Rao, Chairman, Karnataka State Environmental Appraisal Committee - 2021

XXVIII
Dr. Navin Juyal, Formerly with Physical Research Laboratory
Department of Sapce, Ahamedabad, Gujrat - 2022

XXIX
Prof. Mohammed Latif Khan, Distinguished Senior Professor of Botany, Dr. Harisingh Gour Vishwavidyalaya (A Central University) Sagar, Madhya Pradesh