Role of Data Science and Machine Learning in Managing Plant Invasion Under Climate Change: A Case Study with ILORA Database in India

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Joint ICTP-IAEA Advanced School/Workshop
On Machine Learning in Citizen Science
27 February - 3 March 2023

Agenda

About the Aliens
Who they are
Why they are of concern

Indian scenario
Current status
Research and policy needs

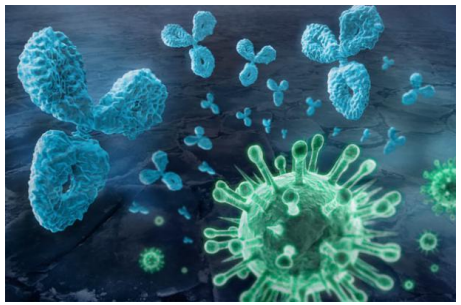
Looking inside ILORA
Inspirations
Species and variables

Analytics
Data Analytical perspectives
Case studies

Closing
Summary
Questions and Answers

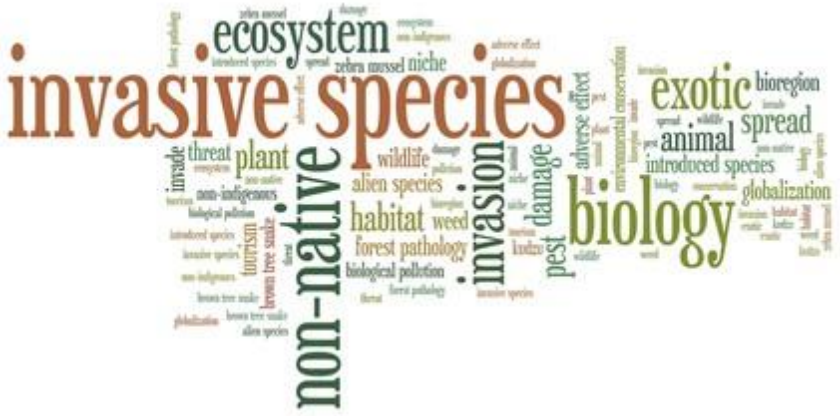
Alien species

A being that came from a different place



Alien species

What's in a name?...

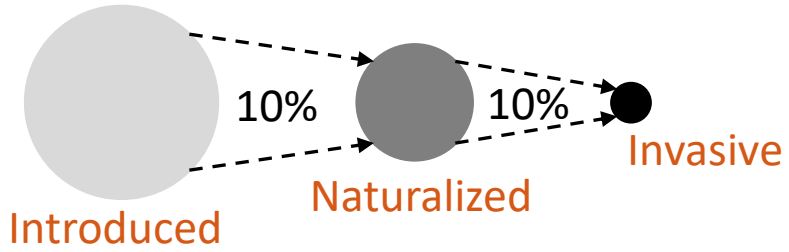


- Alien
- Non-native
- Exotic
- Non-indigenous
- Introduced
- Naturalized
- Invasive
- Weed
- Noxious

Alien species

What's in a name?...

- Alien → Species just enters a geographic space, i.e., crosses the transport barrier, and is being cultivated or in captivity
- Non-native
- Exotic
- Non-indigenous
- Introduced → Species is in the wild, outside human control, i.e., crosses cultivation/captivity barrier
- Naturalized → Species is surviving in the wild, without human assistance, i.e., crosses survival barrier
- Invasive → Species is reproducing on its own and starts dispersing to new environment, i.e., crosses reproduction, dispersal and environmental barriers
- Weed
- Noxious



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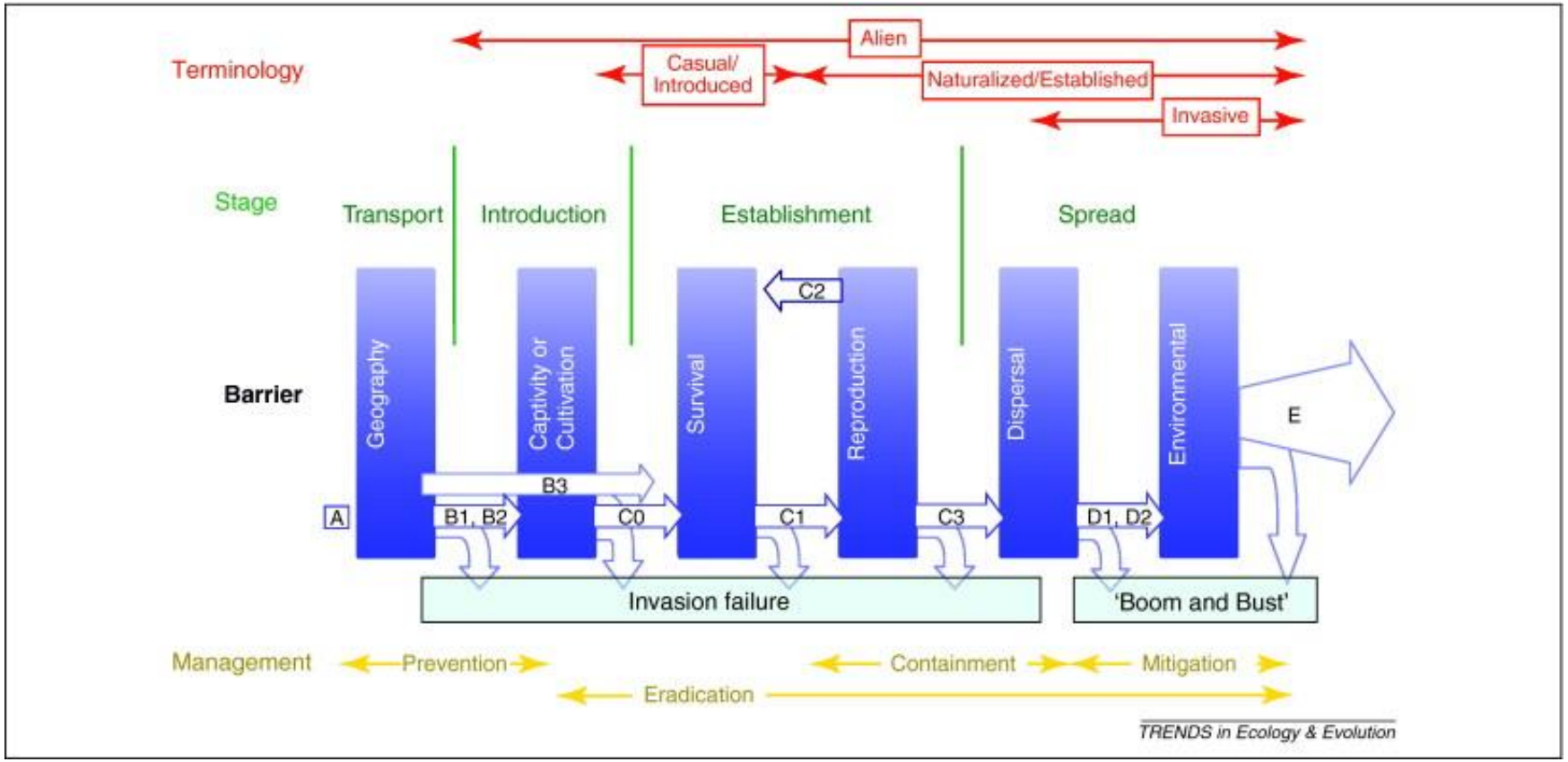


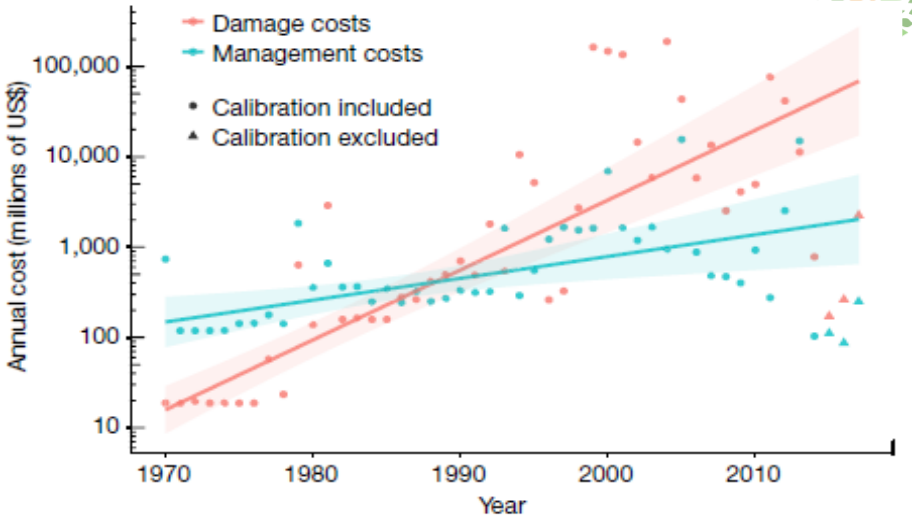
Blackburn et al. *Trends Ecol. Evol.* 2011; 26: 333-339

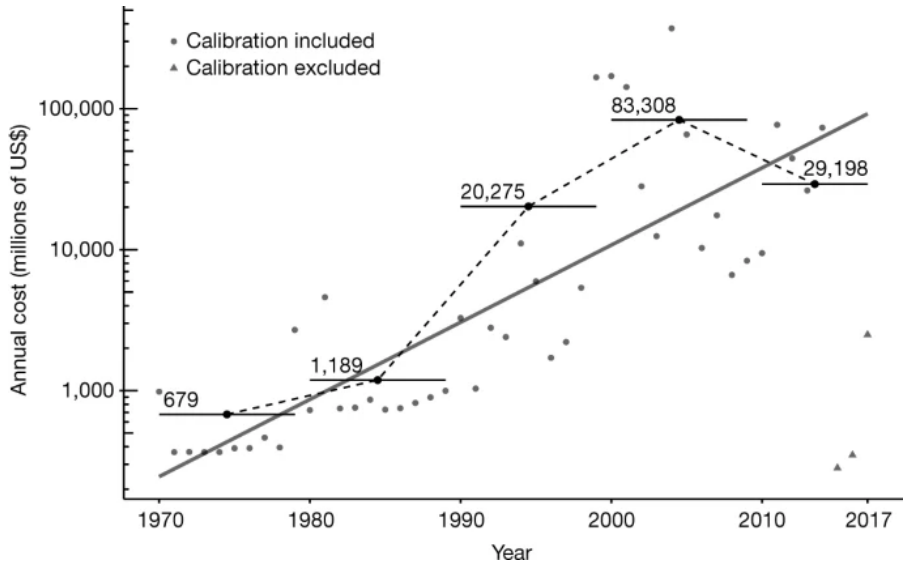
Alien species

Why we should care

Photo: Revive&Restore

- Number of alien species increasing
- Predicted increase in invasion levels in emerging economies
- High and rising economic cost





Diagne et al. *Nature* 2021; 592: 571–576

Need attention!

Global perspective

Economic issue?...

- Alien
- Non-native
- Exotic
- Non-indigenous
- Introduced
- Naturalized
- Invasive
- Weed
- Noxious

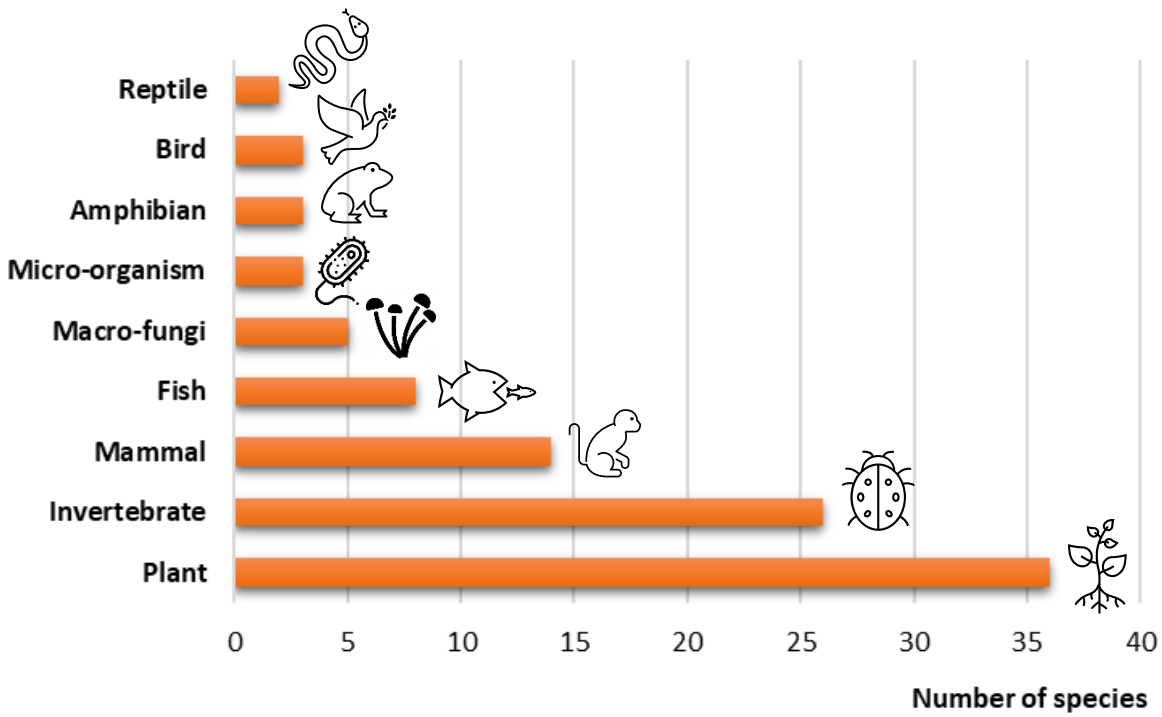
- In the 2001–02 financial year, the combined estimated cost (economic losses and control) of invasive species was **$9.8 billion, rising to $13.6 billion** in the 11–12 financial year (Hoffmann and Broadhurst, 2016, NeoBiota).
- Approximately **$726 million of grants funded through the Commonwealth of Australia** was spent on invasive species management and research between 1996 to 2013.
- In 01–02, total national expenditure on invasive species was $2.31 billion, rising to $3.77 billion in 11–12.
- Of the approximately 2700 exotic plants species now established within **Australia, 429 species** have been declared noxious or are under some form of **legislative control (NRMMC 2006)** with considerably more subject to eradication and control measures such as plant species listed on the National Environmental Alert List.

Source: http://www.environment.gov.au/biodiversity/invasive/weeds/weeds/lists/alert.html

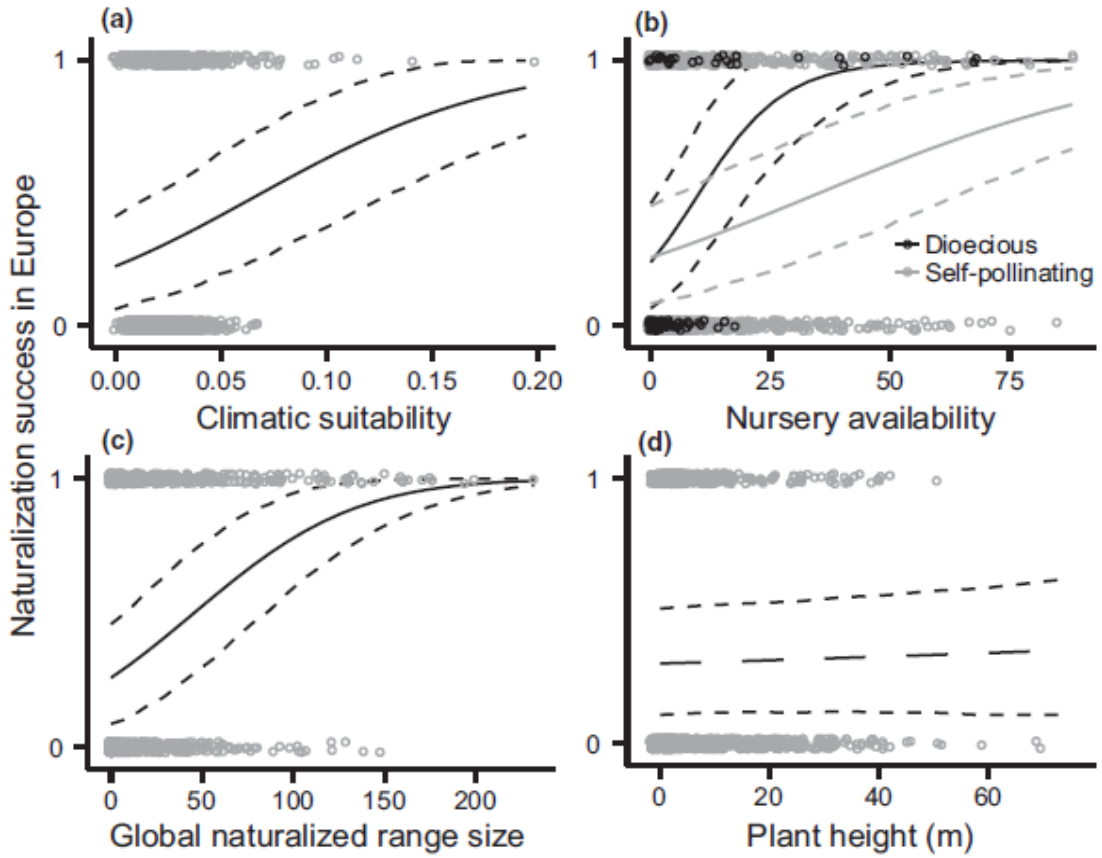
Process Initiated

Other countries started

Invasive plants are the major shareholder



Lowe et al. 2000, 100 OF THE WORLD's WORST INVASIVE ALIEN SPECIES, The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN)



Haeuser et al. J Appl Ecol. 2018;1–10.

- Identified species with **high future naturalization risk** and species with high projected increases in naturalization potential in Europe under **climate change.**
- This species list allows for prioritization of monitoring and **regulation of ornamental plants** to mitigate the invasion debt.

Alien plants in India

Some popular ones: Its everywhere!

Eichhornia crassipes,
Herb Aquatic

Parthenium hysterophorus,
Herb/Shrub

Lantana camara,
Shrub

Acacia auriculiformis,
Tree

Mikania micrantha,
Vine

Citizen Science (Indian Context)

Google Search: Citizen Science in India

- Citizen Science for Biodiversity
- https://citsci-india.org/
- Total number of projects: 31

- Project on Invasive plants: 1
- Machine Learning: Only for experts

Citizen Science (Indian Context)

Google Search: Citizen Science in India

- Center for Citizen Science
- http://citizenscience.in/

- SATARK Landslide Prediction System
- Microbial analysis of river Ganga
- Microbial analysis of 'Dust Storm' event
- Asteroid occultation observation
- Projects: Meghdoot, Shayadri
- Project on Invasive plants: 0
- Machine Learning: **Only for experts**

Need attention!

Indian perspective

Economic issue?...

Prosopis juliflora

Lantana camara

- In the Western Ghats, for example, **lantana (*Lantana camara*)**, a Central and South America shrub that was introduced to India in **1809 as a garden ornamental**, has spread extensively.

- In Karnataka's Biligiri Rangaswamy Temple Tiger Reserve, Soliga farmers have suffered from reduced abundances of (Non-timber forest products) NTFPs, such as amla, which they harvested for supplementary income. Lantana affects regeneration of other forest plants that wild herbivores depended upon.

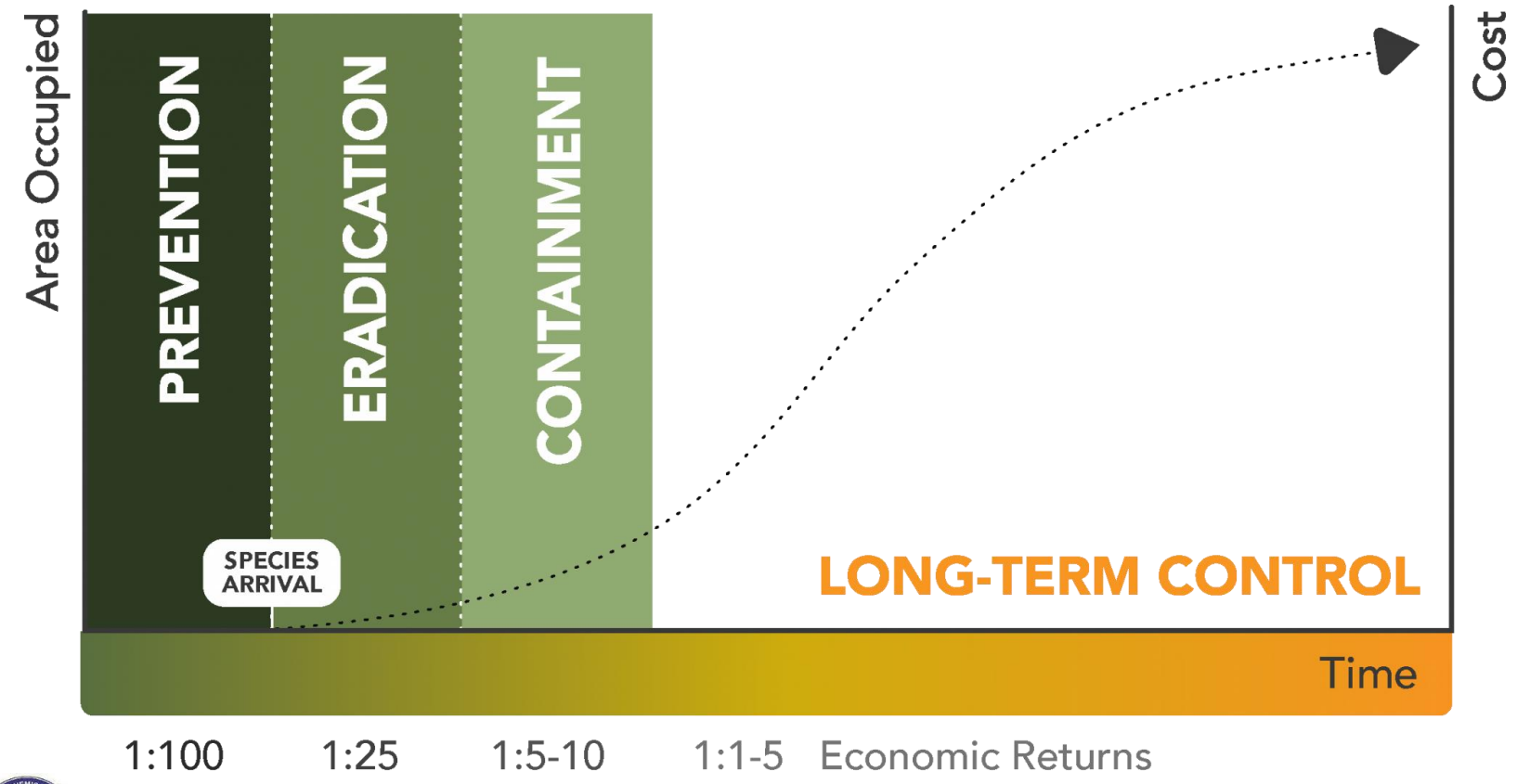
- **Prosopis (*Prosopis juliflora*)**, variously known as **vilayati keekar, gando bawar and seemai karuvel** in different parts of the country. Also from South America, this thorny tree was introduced to India around **1870 for its extreme drought tolerance and as a source of fuelwood**.

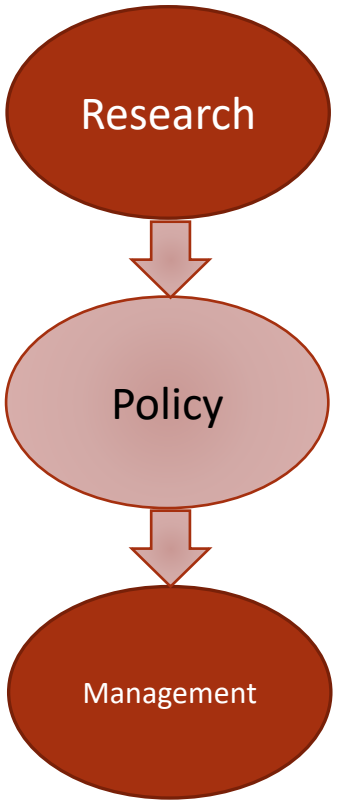
- Rapid spread in **Rajasthan, Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh and Karnataka**. In parts of Tamil Nadu, the invasion has entirely transformed agricultural lands and grazing commons, forcing people to seek new livelihood opportunities.

Source: The Wire: https://thewire.in/environment/invasive-species-prosopis-lantana

Data-driven action plan

When and how we should care





- Identify
- Invasion process
- Species biology
- Environment

- Prevention
- Eradication
- Containment
- EDRR (Early detection and rapid response)

Alien plants in India

Multiple checklists, little coordination

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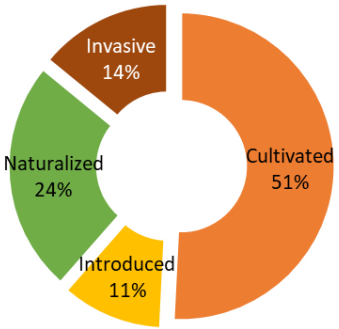
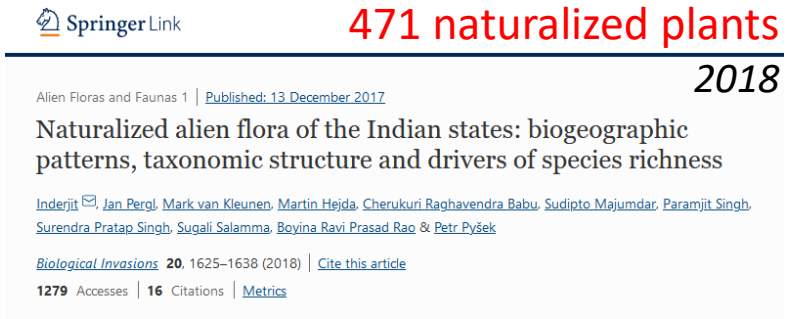


1599 alien species

Alien Flora of India

Khuroo et al. 2012



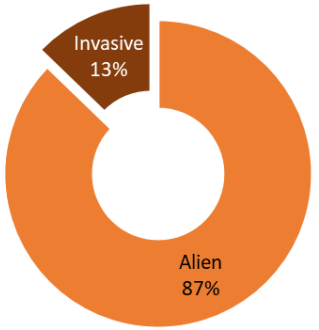
471 naturalized plants

2018

राष्ट्रीय जैव विविधता प्राधिकरण
National Biodiversity Authority, India
2003

Invasive plant species:
54 terrestrial, 8 aquatic

National Biodiversity Authority, 2018



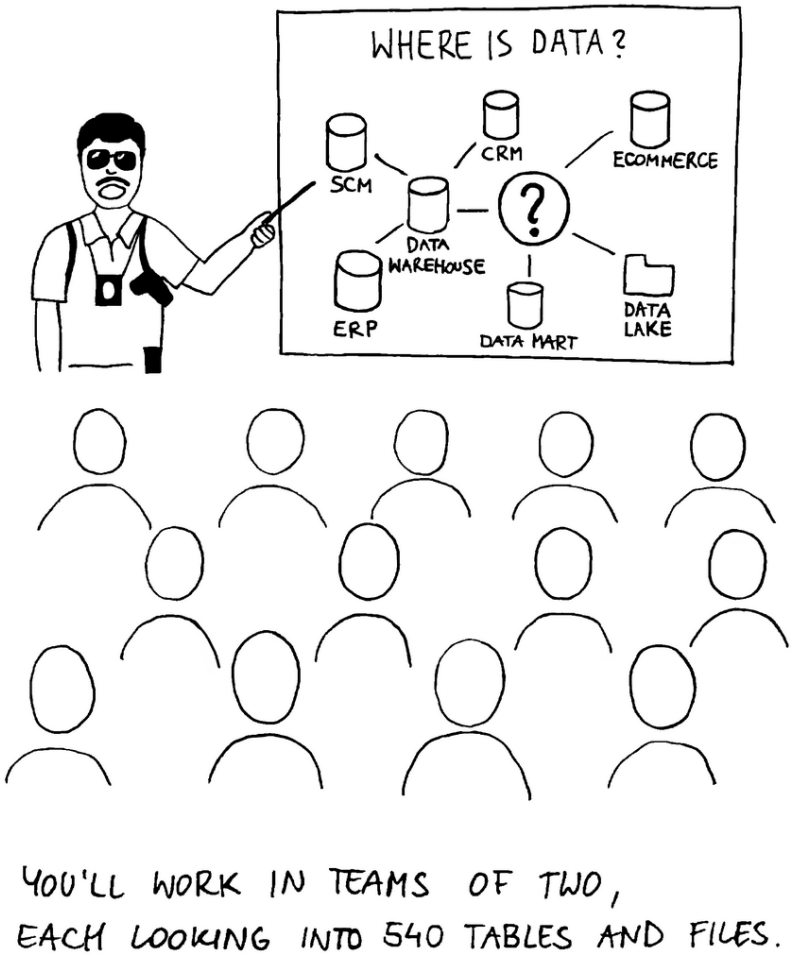
2082 alien species

Global Register of Introduced and Invasive species, 2020

Alien plants in India

Where is the data?

- Scattered across multiple databases
- Intensive and informed query-directed search
- Tedious access to data
- Low resolution at national and regional scales
- Lack of comprehensive database



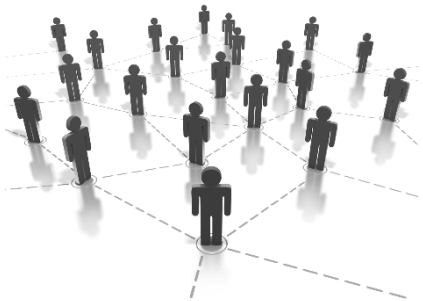
ILORA

Inspirations

- A database having information of variables responsible for invasion process for INDIAN alien plant species

Open access

Dynamic



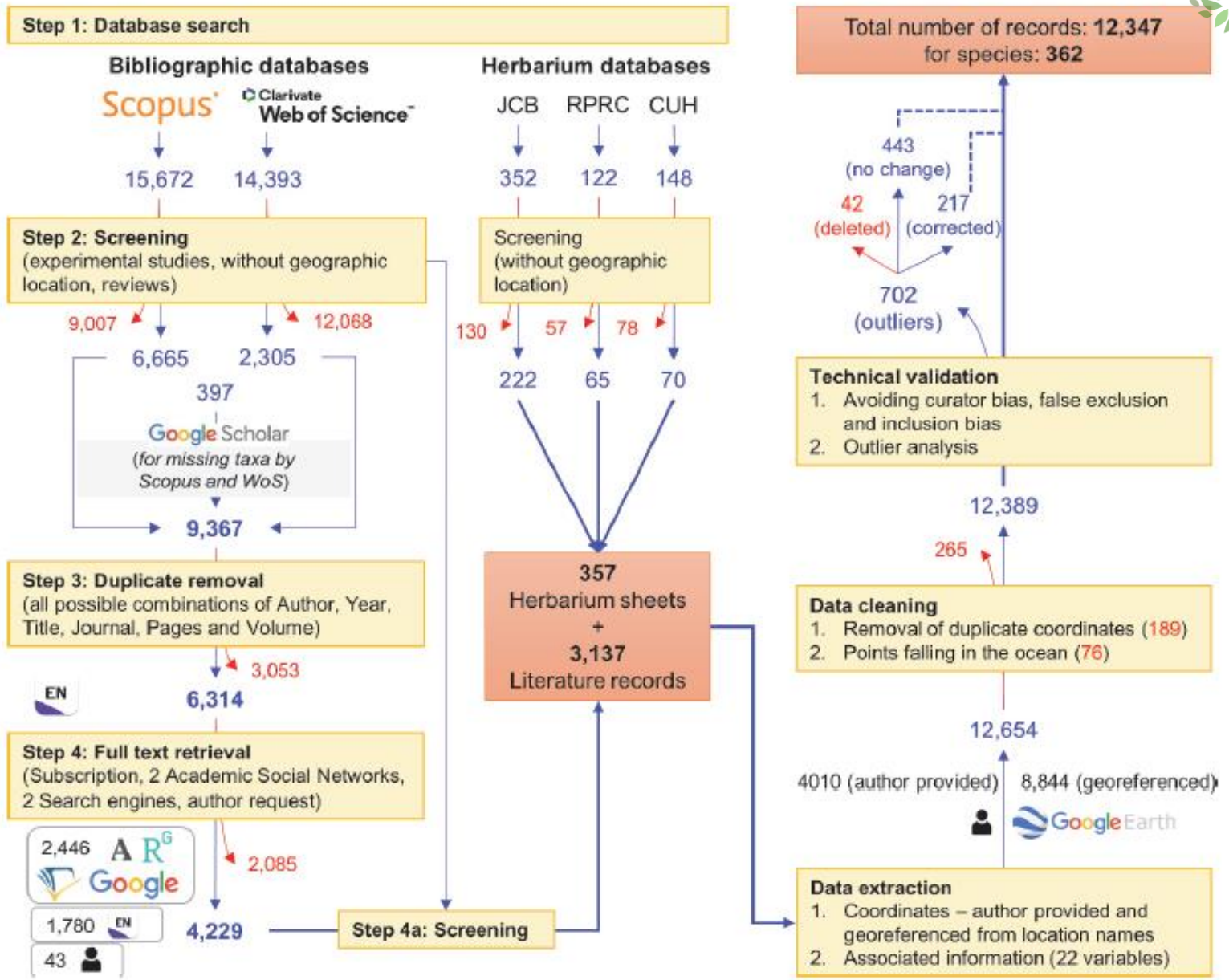
Networking

Indian ALien FlOra InfoRmAtion database

ILORA

The process

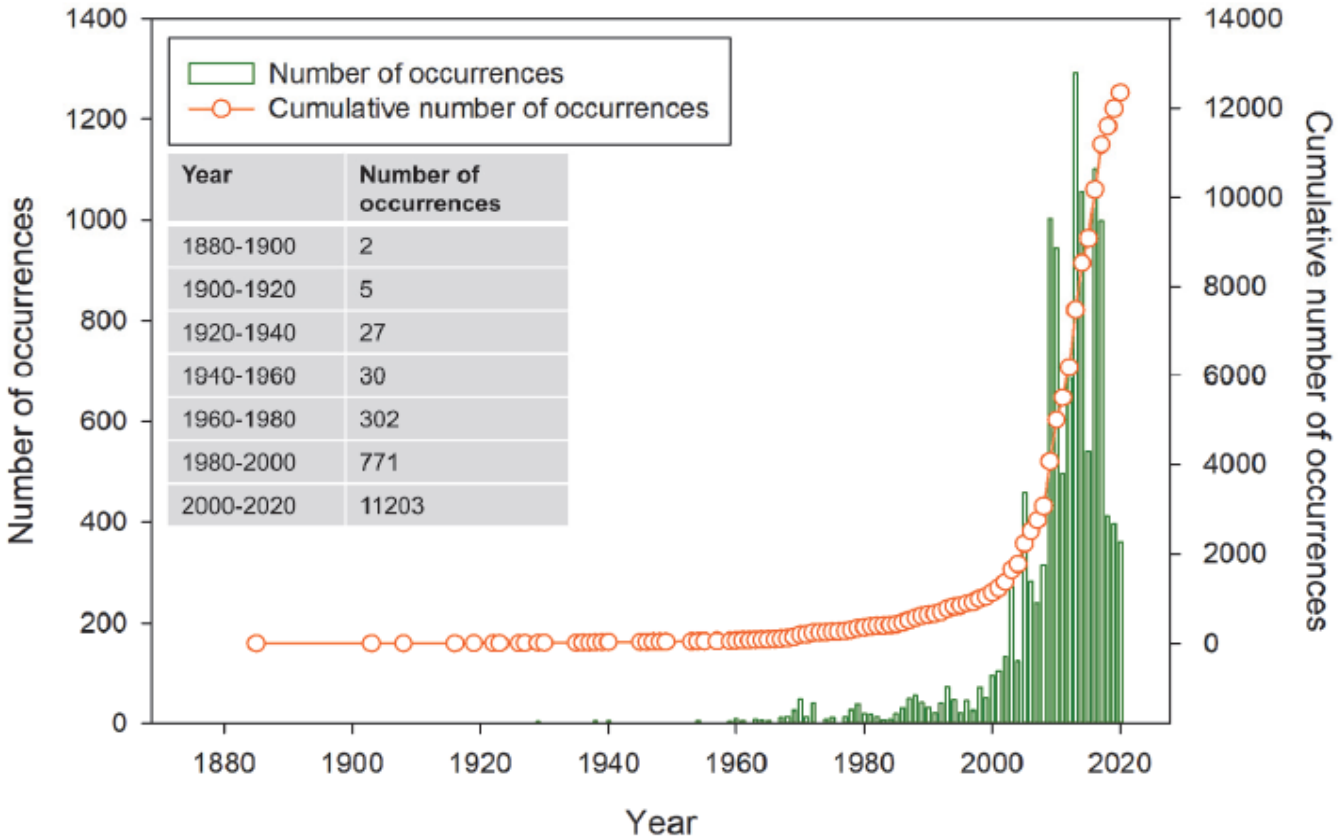
- Automated data extraction process using codes written in Python (Thanks to Interns and PhD students)
- Manual verification of each record



ILORA

Overview

- Number of species: **1747**
- Number of variables: **14**
  - Species categorization
  - General information
  - Introduction history
  - Biogeography
  - Uses
  - Occurrence and distribution
  - Climate
- Number of sources: **22**
- Standardized following international stand



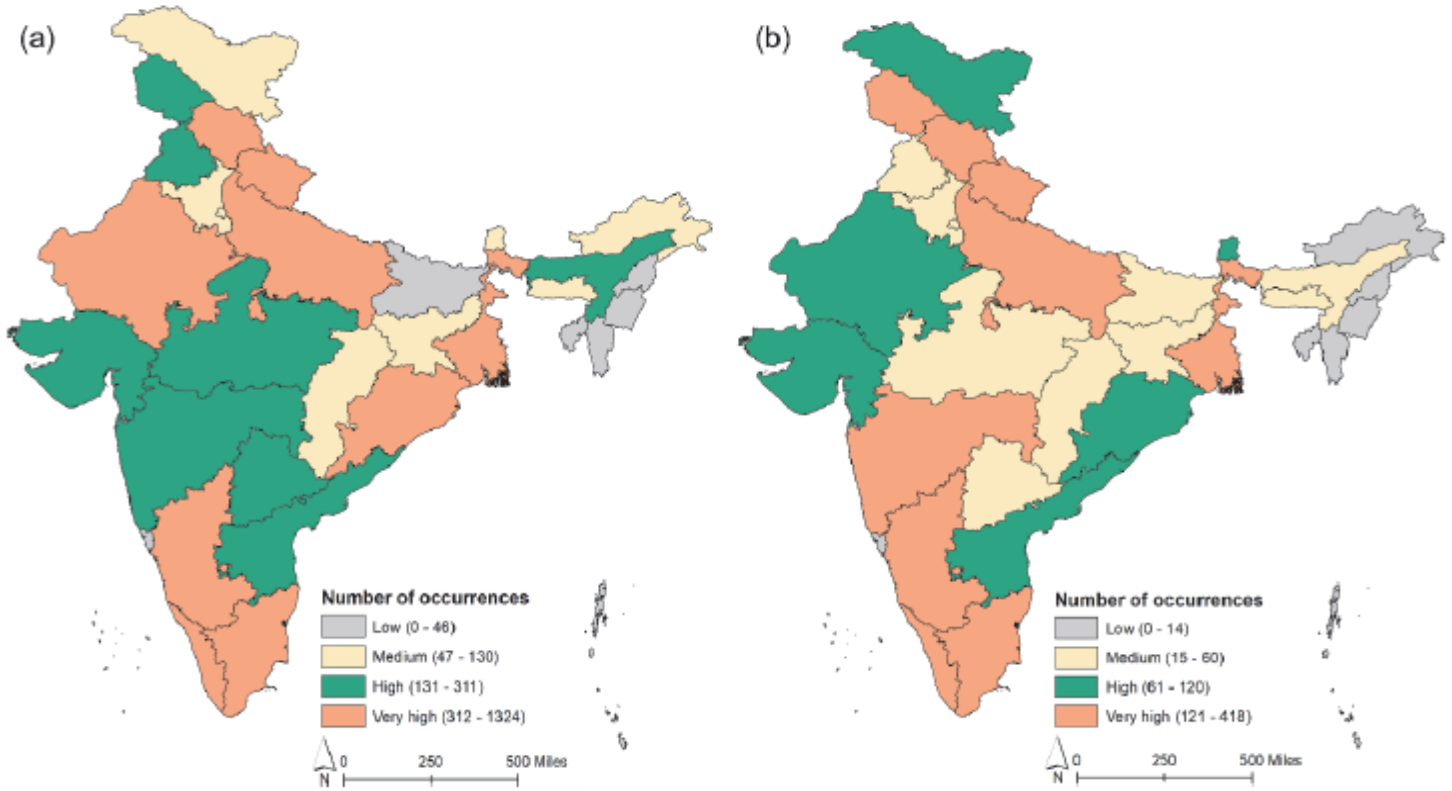
Year	Number of occurrences
1880-1900	2
1900-1920	5
1920-1940	27
1940-1960	30
1960-1980	302
1980-2000	771
2000-2020	11203

Prajapati et al. 2022, Ecology 103 (11): e3794.

ILORA

Overview

- State-wise distribution of occurrence data of (a) invasive and b) naturalized alien species in India.

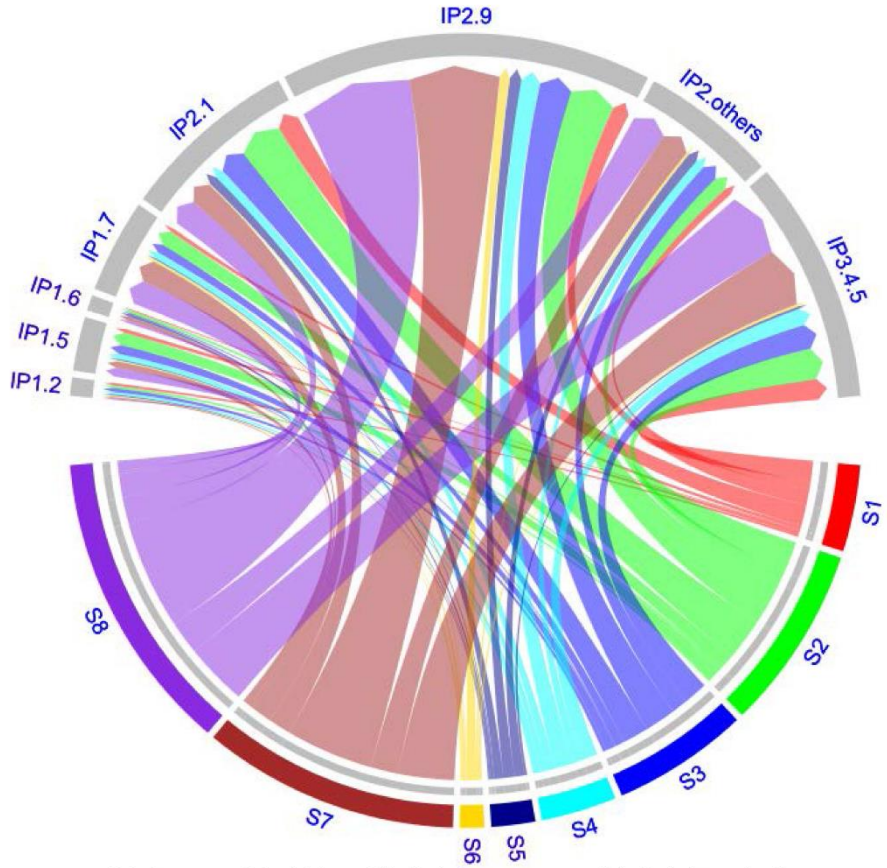


ILORA

How and When - Introduction history

- Introduction pathways (how the species came) - categorical
- First record date (year when the species was first recorded) - numeric
- Earlier and more pathways of entry often facilitate successful naturalization and invasion

IP: Introduction Pathways –
1.2: Erosion control; **1.5**: Landscape improvement; **1.6**: Conservation; **1.7**: Release in nature for use; **2.1**: Agriculture; **2.9**: Ornamental; **2.others**: Botanical garden + Aquarium species + Forestry + Horticulture + Food + Other escape; **3.4.5**: Contaminant (Nursery, Food, Plant, Seed, Habitat materials), Stowaway (Packing, Ballast water), Interconnected waterways

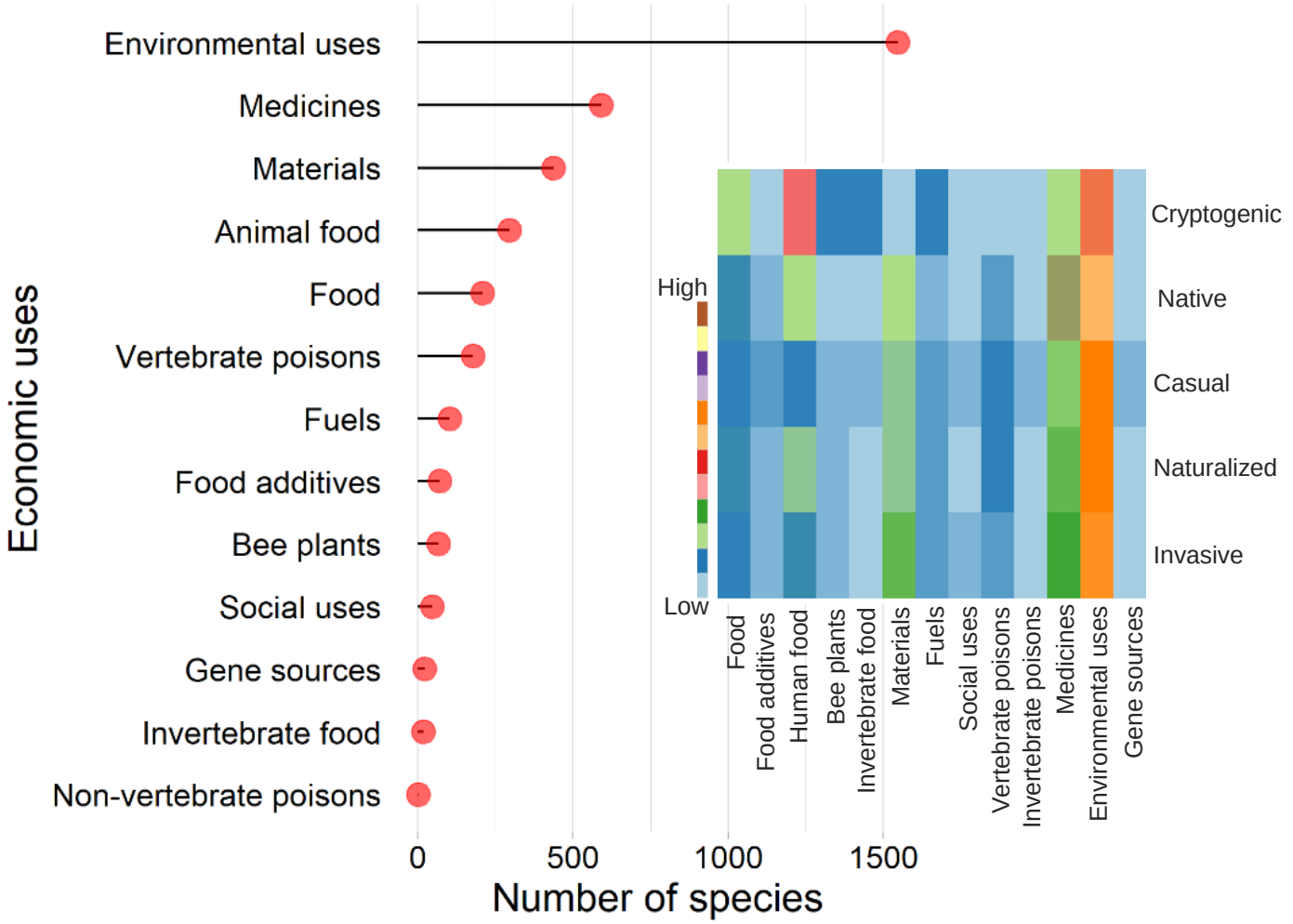


S1: Europe; S2: Africa; S3: Asia-Temperate; S4: Asia-Tropical;
S5: Australasia; S6: Pacific; S7: Northern America; S8: Southern America

ILORA

Uses

- Categories (13) and subcategories (50) of uses - categorical
- More number of uses facilitate alien species naturalization and invasion



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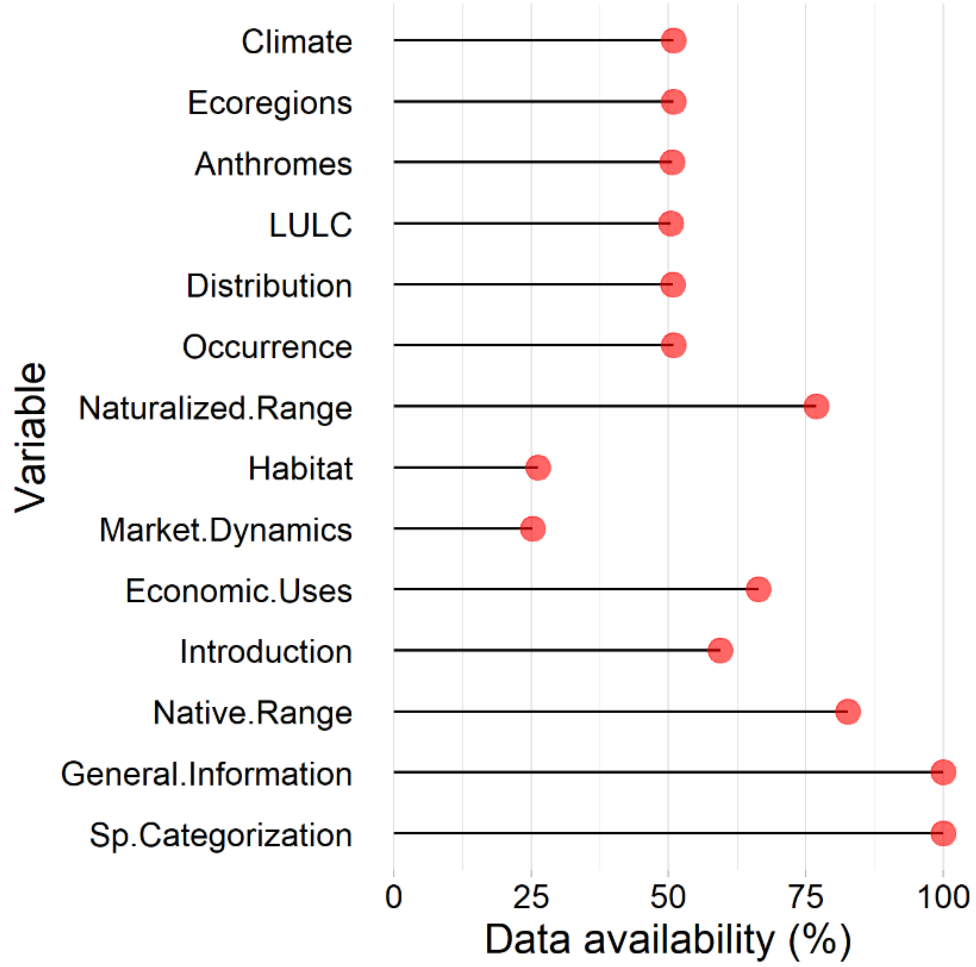
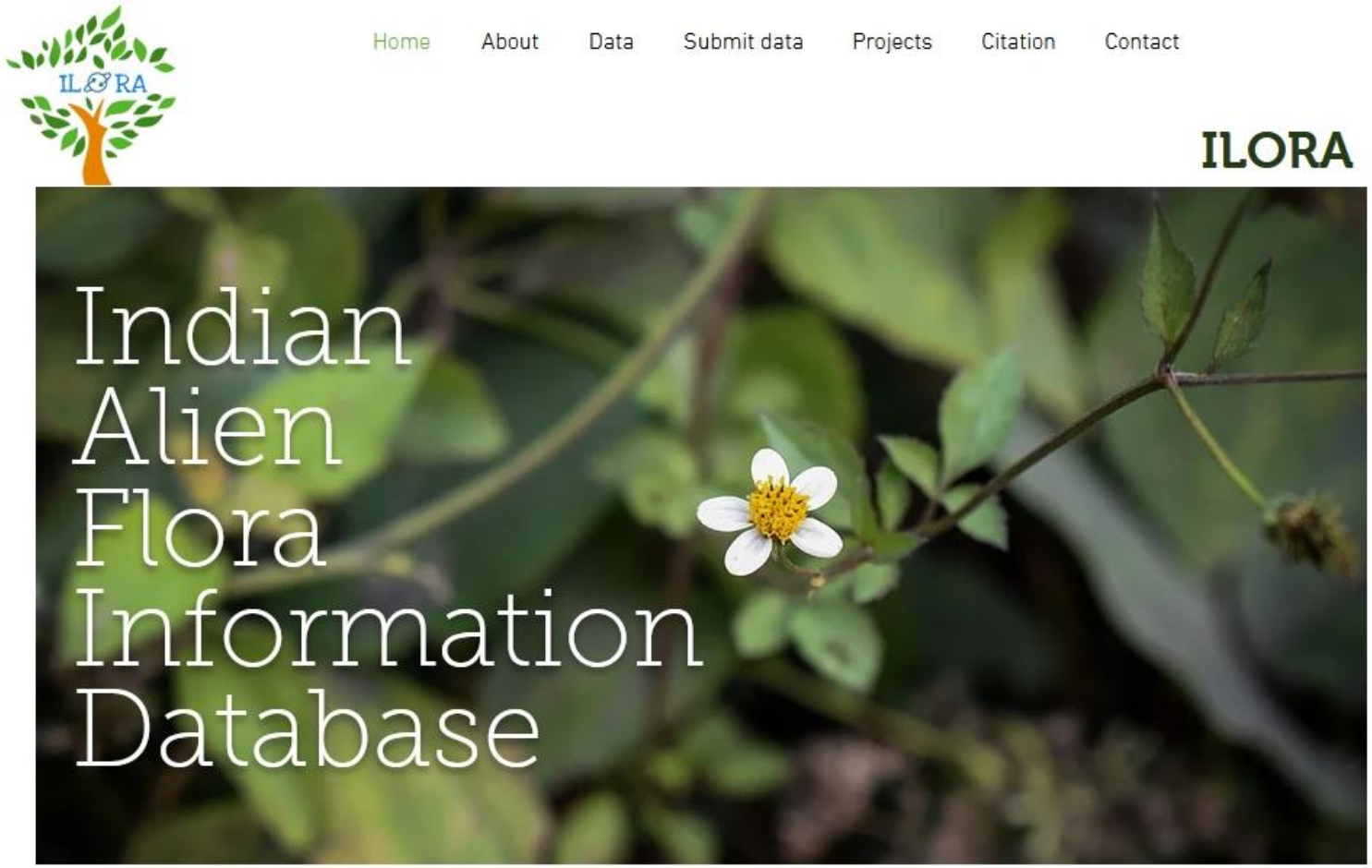


How we use ILORA

The database itself

- Robust data validation
- Variables arranged in CSV files
- Published as open access
- Dedicated website



https://ilora2020.wixsite.com/ilora2020

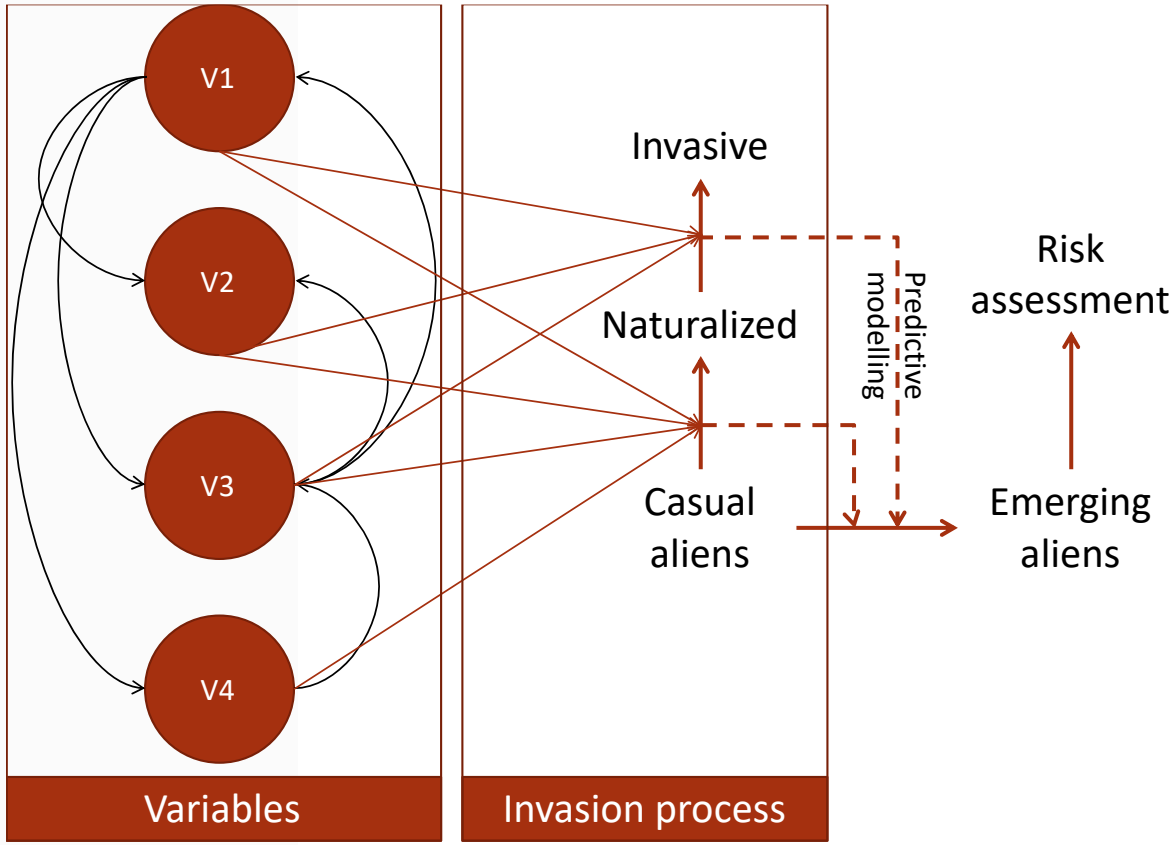
Pant et al. *Ecological Solutions and Evidence.* 2021; 2: e12105

How we use ILORA

Identifying emerging invaders

- Considered the invasive, naturalized and casual aliens
- Based on the relationship between variables and invasion process
- Identify the aliens which can become invasives

- Risk assessment
- Proactive management

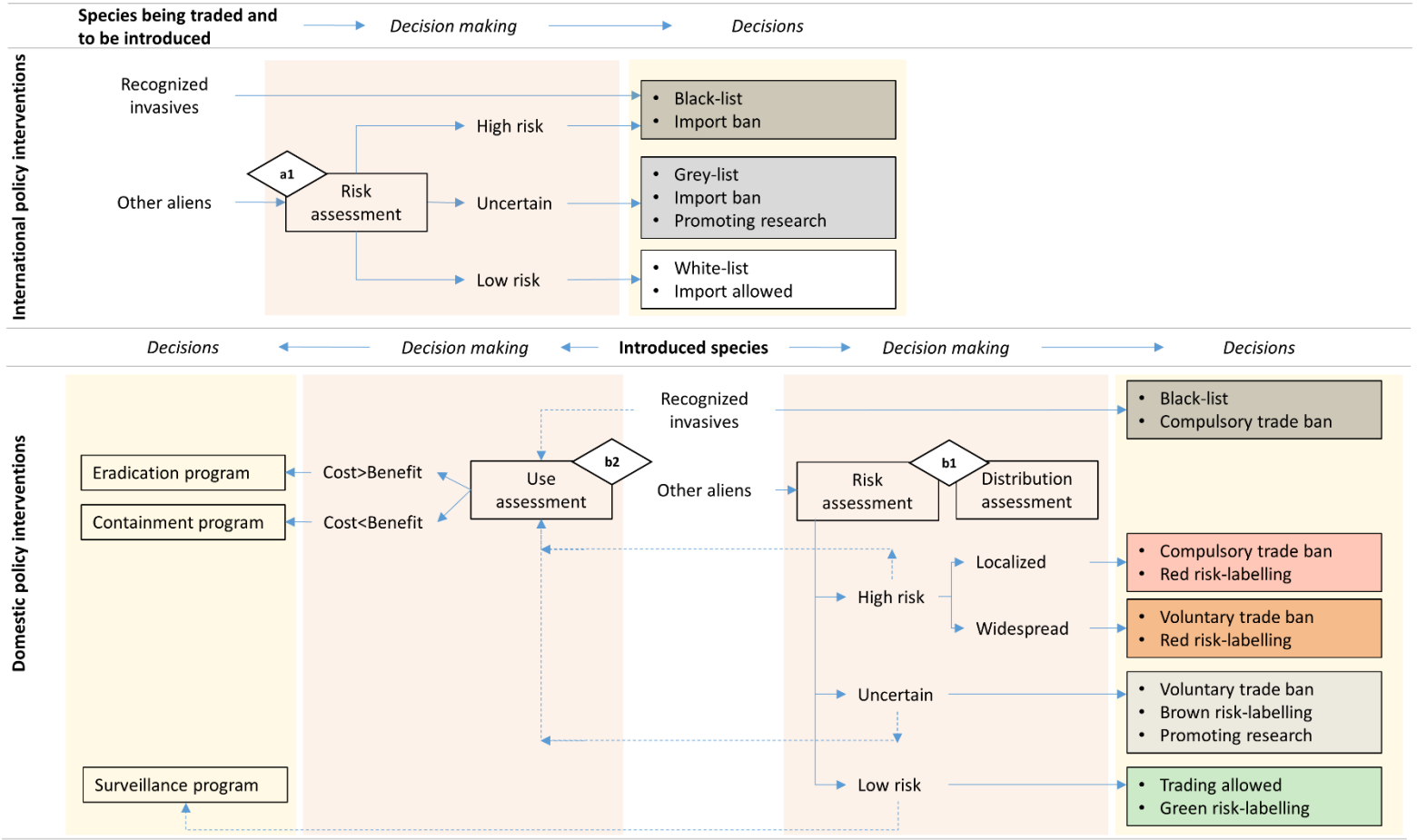


Banerjee et al. *J. Environ. Manage.* 2021; 294:113054

Policy framework

An action plan specific to India

- Policy interventions proposed for regulating trade and managing invasive alien plant species in India (a) international and (b) domestic



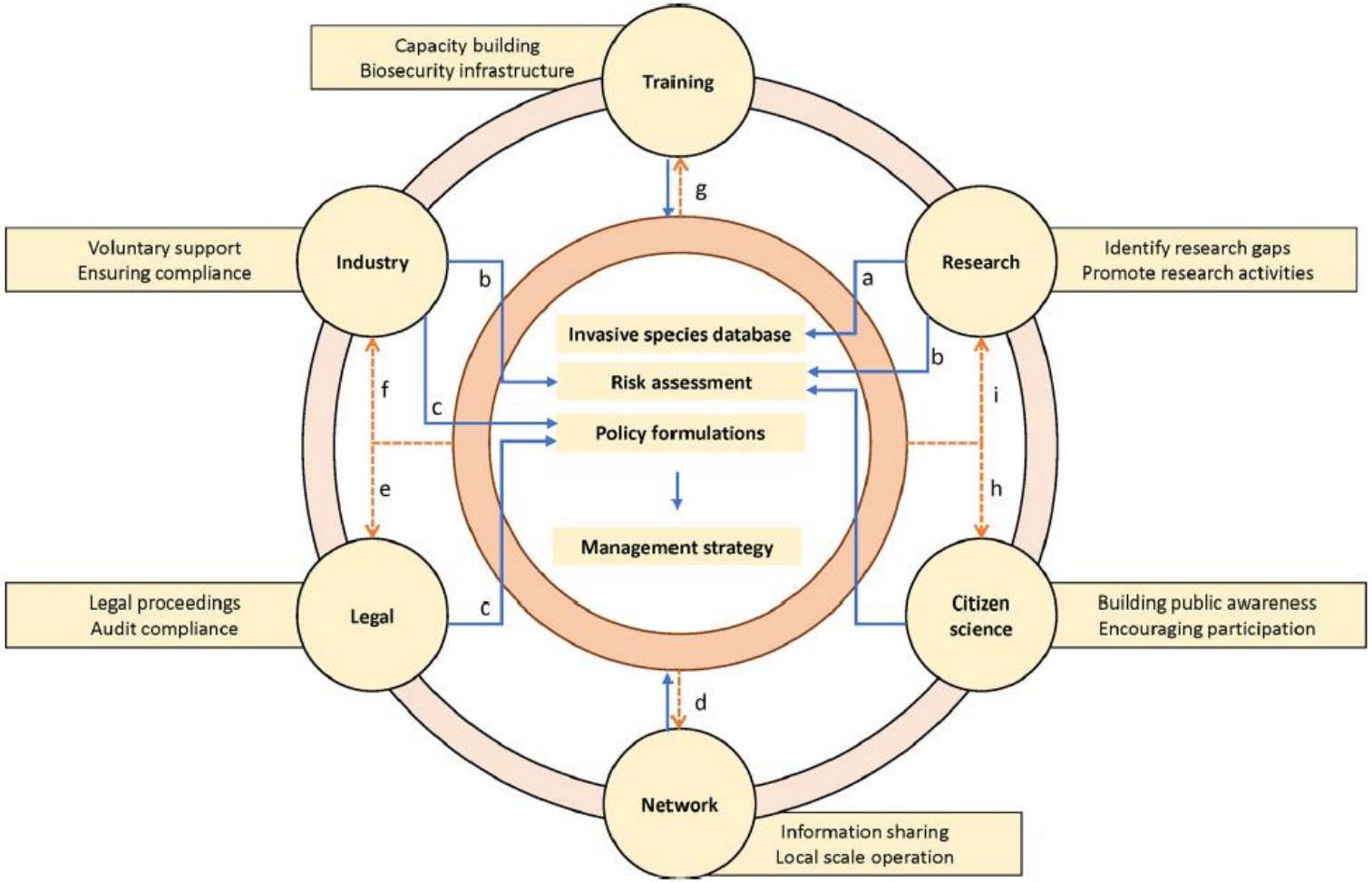
https://ilora2020.wixsite.com/ilora2020

Banerjee et al. *Environmental Science and Policy.* 124, 64-72, 2021

Multidisciplinary approach

An action plan specific to India

- A decentralized system tasked with coordination between different agencies involved in the trading of invasive alien plant species in India



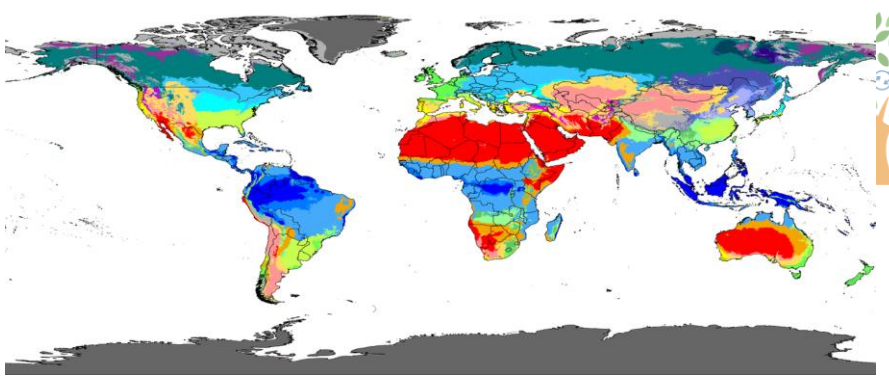
https://ilora2020.wixsite.com/ilora2020

Banerjee et al. *Environmental Science and Policy.* 124, 64-72, 2021

27

Emerging invaders

Data processing and statistical modelling

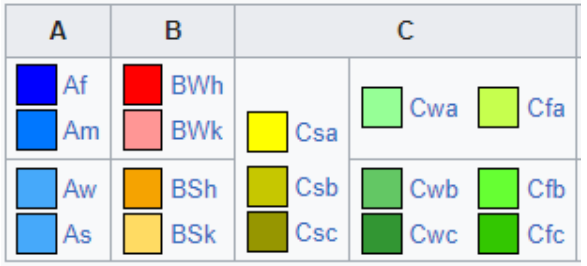


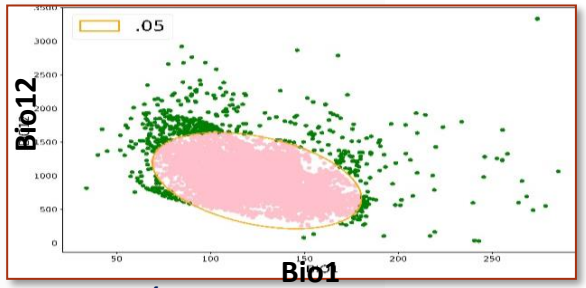
Species selection
- ILORA
- 220 IAPS
- Occurrence (www.gbif.org)
- Occurrence Records 6355150

Data Cleaning
- Removing missing coordinates
- Duplicates removal
- Removing points falling in ocean
- Removing geographic bias

Deliming geographic range
- Extract temperature (Bio1)
- Extract precipitation (Bio 12)
- 95% ellipsoid in Bio1 and Bio12
- Occurrence within confidence ellipsoid

Background selection
- **Köppen-Geiger climate Class** www.gloh2o.org/koppen
- Climate data extraction www.worldclim.org
- Future climate data (RCP 4.5 and RCP 6.0)
- Union of K-G classes for occurrence records



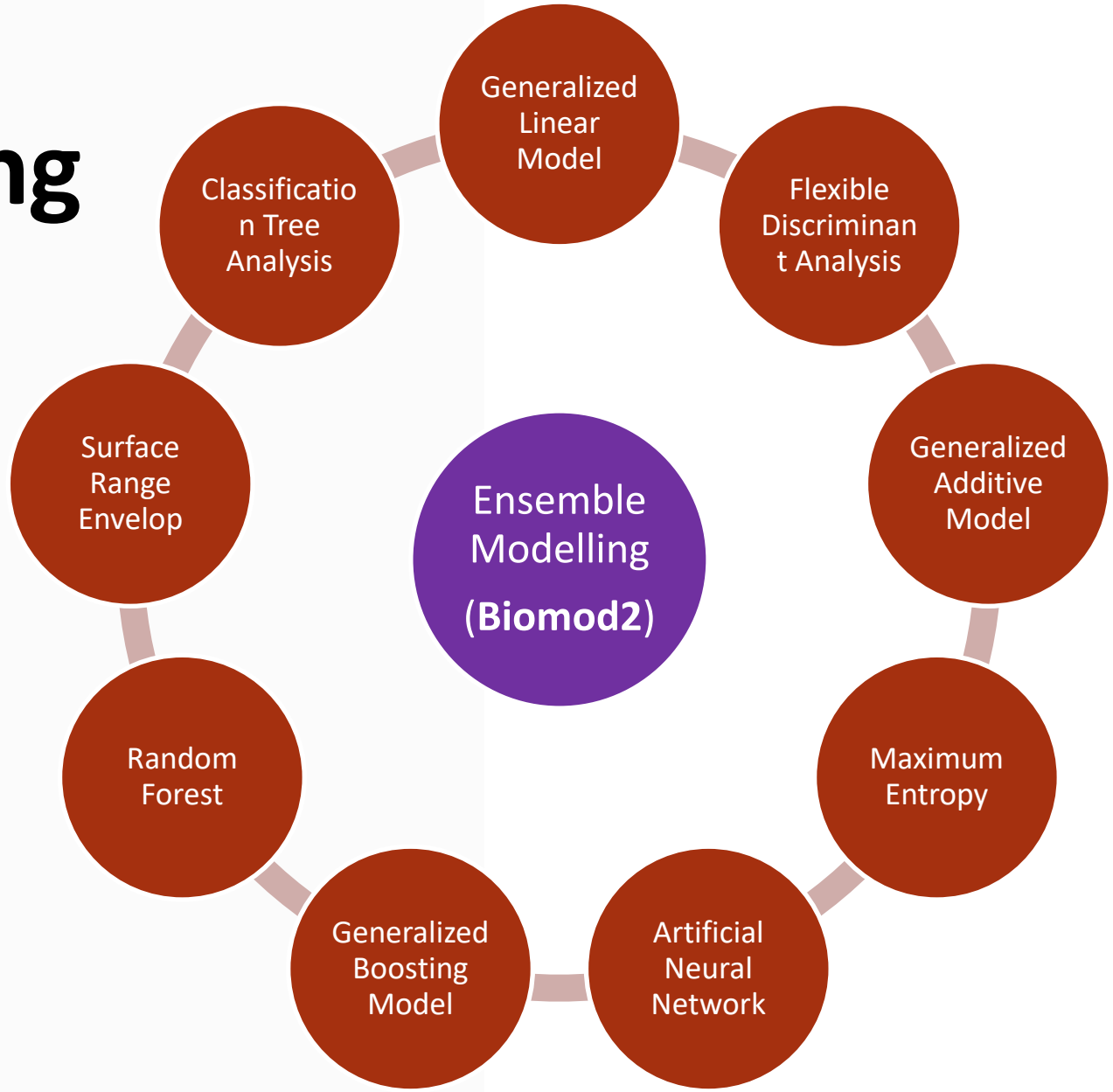


Basic Introduction: https://sites.google.com/site/amiyaiitb/research/ecological-niche-modelling

Ensemble modelling

biomod2: Ensemble Platform for Species Distribution Modeling

- Generalized Linear Model (Searle and McCulloch, 2001)
- Flexible Discriminant Analysis (Hastie et al., 2009)
- Generalized Additive Model (Guisan et al., 2002)
- Maximum Entropy (Favretti, 2017)
- Artificial Neural Network (Zhang, 2010)
- Generalized Boosting Model (Einziger et al., 2019)
- Random Forest (Nordhausen, 2014)
- Surface Range Envelop (Hannah, 2012)
- Classification Tree Analysis (Breiman et al., 2017)



Selection of predictors

Identifying invasion hotspots

- First four bioclimatic variables from the first two principal components with highest loadings in PC1 & PC2 using PCA package in R. (Guisan et al., 2017)
- Variables with a correlation value less than 0.7 using stats package (Braunisch et al., 2013)
- Principal components developed globally using bioclimatic variables using the **kuenm** package in R and used first 5 principal components as predictors (Cobos et al., 2019)
- Variation Inflation Factor with a threshold as 5 using **regclass** package in R (Mpakairi et al., 2017; Rodríguez-Rey et al., 2019)
- Based on a pilot run on 10 randomly selected species, the performance of the ensemble model approach has been evaluated using all the above four variable selection strategies.
- No significant difference was obtained for different variable selection predictors.

Ensemble predictions

Input to the models

- Native Occurrences
- Climatic Variables
- Model Background

Modelling (218 species)

- 9 Model algorithm
- 3 Pseudo-absence sampling
- 4 cross-validation runs

Native range prediction

- Intrinsic Model validation
- Projection on invasive range
- Predicted distribution under current climate
- Distribution under future climate RCP 4.5 2050

True Skill Statistics (TSS > 0.55)

Allouche et al. Journal of Applied Ecology: Volume43 (6) 2006, 1223-1232

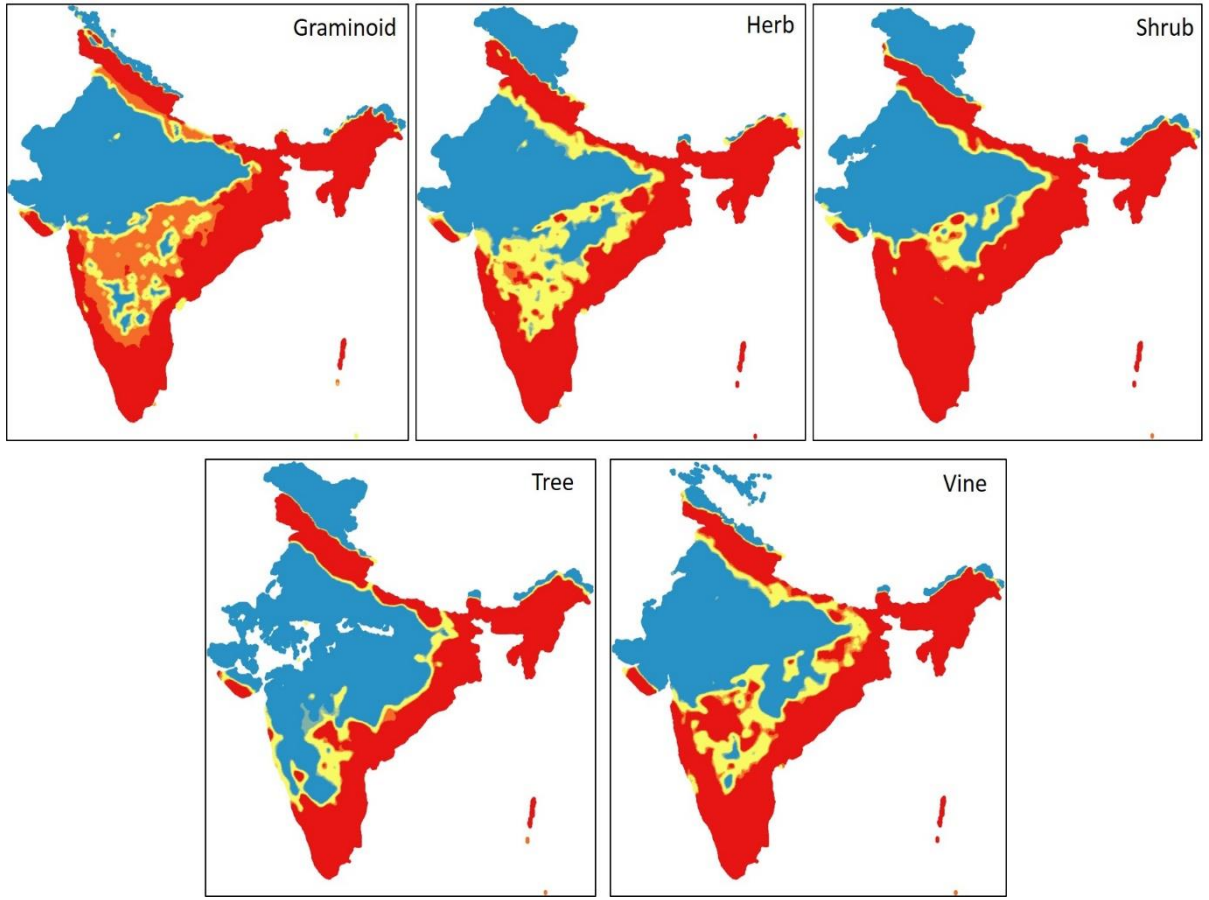
How we use ILORA

Identifying invasion hotspots

- Considered the invasive aliens (218)
- Ensemble species distribution modelling framework
- Identify climatically suitable areas

- Both under current and future climates
- Management implications

- The analysis has been carried out using QGIS plugin

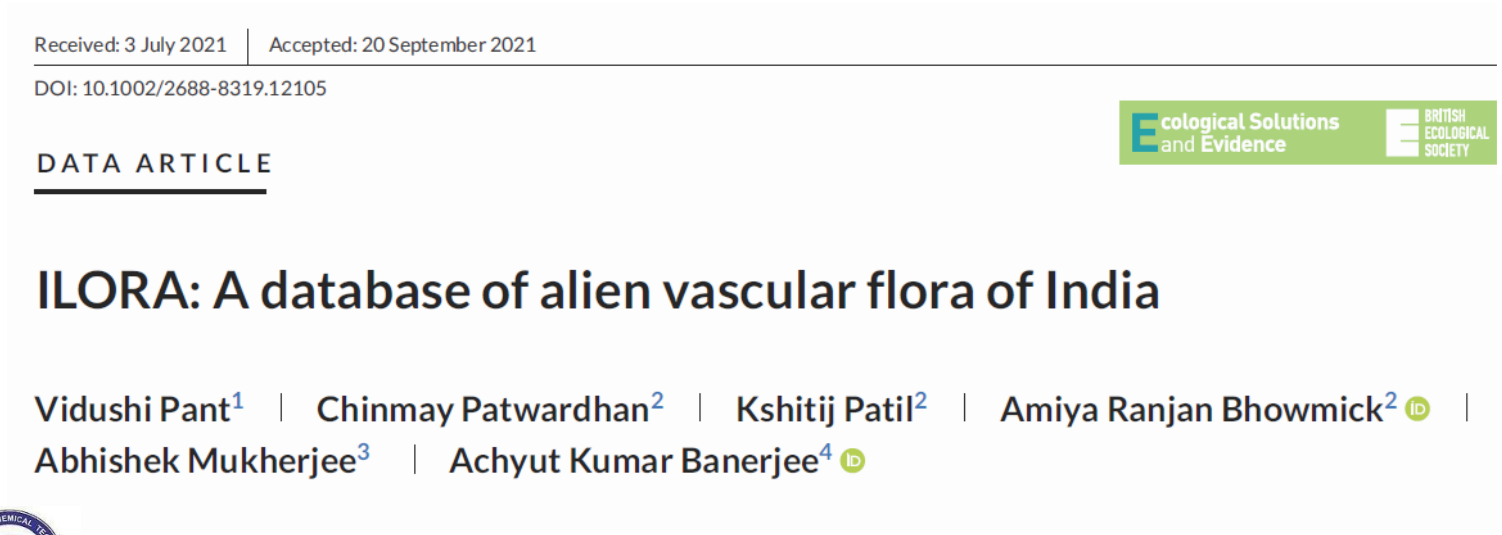


FAQs - ILORA

Time to wrap up

- From where can I read ILORA publications?

While ILORA is open access, some of our papers are not. Check the abstracts in ResearchGate and send us request for full texts. We will respond as soon as (humanly) possible.


Received: 3 July 2021 | Accepted: 20 September 2021

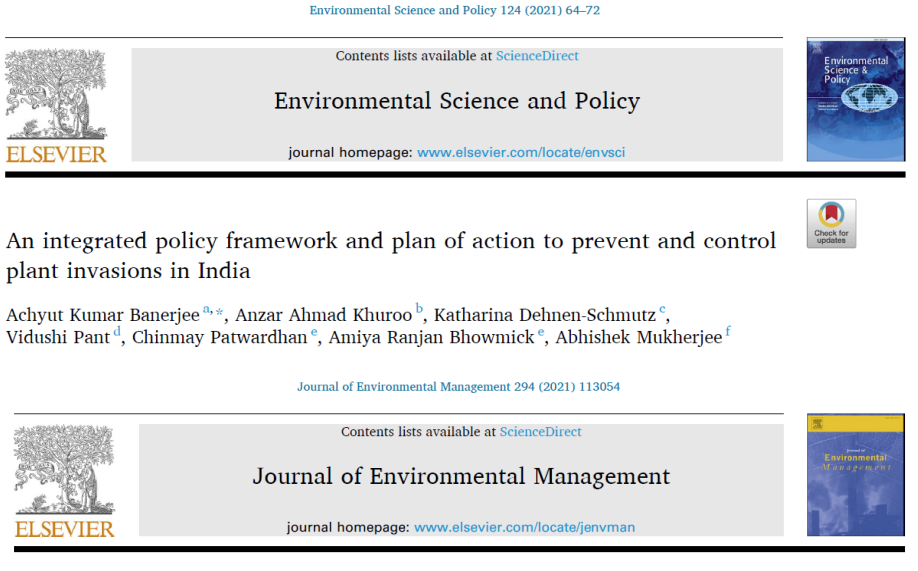
DOI: 10.1002/2688-8319.12105

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

DATA ARTICLE

ILORA: A database of alien vascular flora of India

Vidushi Pant[1] | Chinmay Patwardhan[2] | Kshitij Patil[2] | Amiya Ranjan Bhowmick[2] | Abhishek Mukherjee[3] | Achyut Kumar Banerjee[4]


Environmental Science and Policy 124 (2021) 64–72

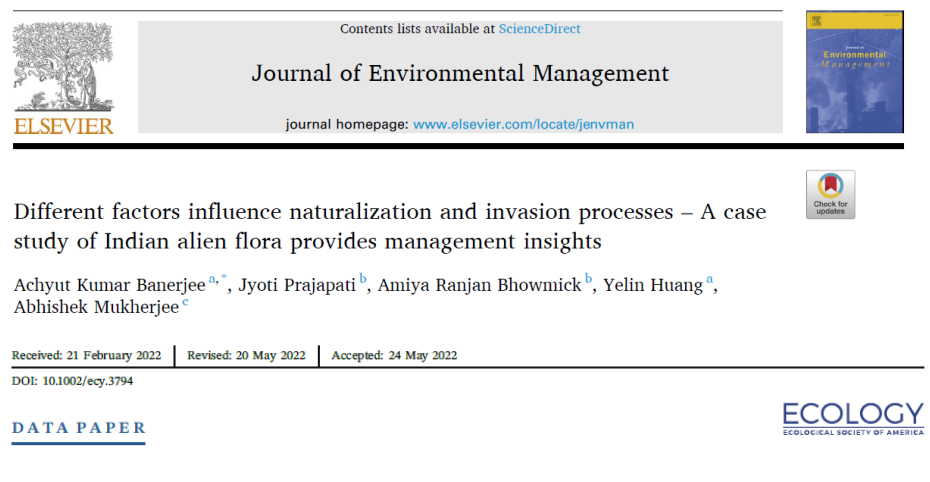
Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

An integrated policy framework and plan of action to prevent and control plant invasions in India

Achyut Kumar Banerjee[a,*], Anzar Ahmad Khuroo[b], Katharina Dehnen-Schmutz[c], Vidushi Pant[d], Chinmay Patwardhan[e], Amiya Ranjan Bhowmick[e], Abhishek Mukherjee[f]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Different factors influence naturalization and invasion processes – A case study of Indian alien flora provides management insights

Achyut Kumar Banerjee[a,*], Jyoti Prajapati[b], Amiya Ranjan Bhowmick[b], Yelin Huang[a], Abhishek Mukherjee[c]


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DATA PAPER

ECOLOGY ECOLOGICAL SOCIETY OF AMERICA

An occurrence data set for invasive and naturalized alien plants in India

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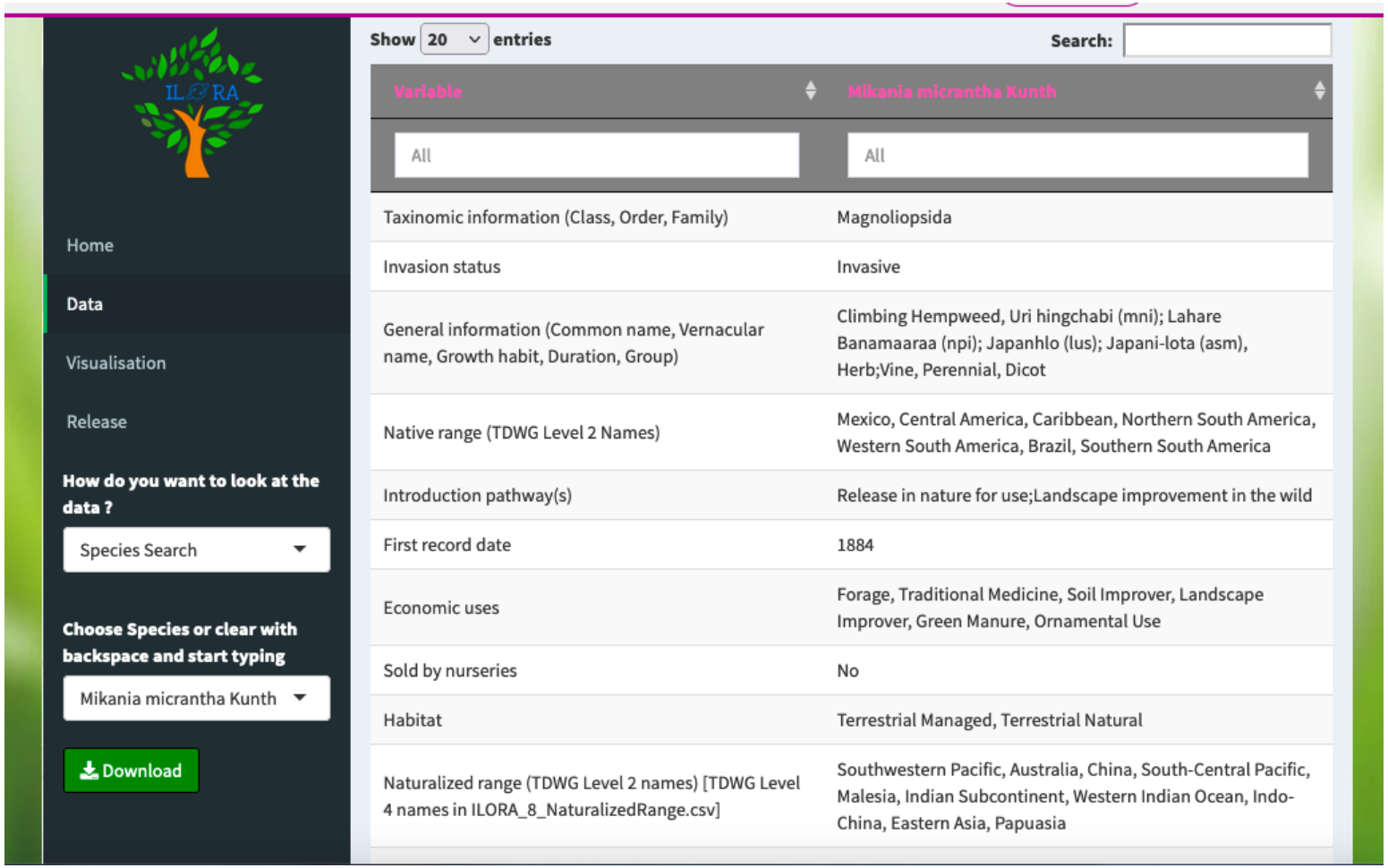
How you can use ILORA

Become a user and contributor

- Easy and open access to all data
- Query-based data retrieval system
- Multidisciplinary applications

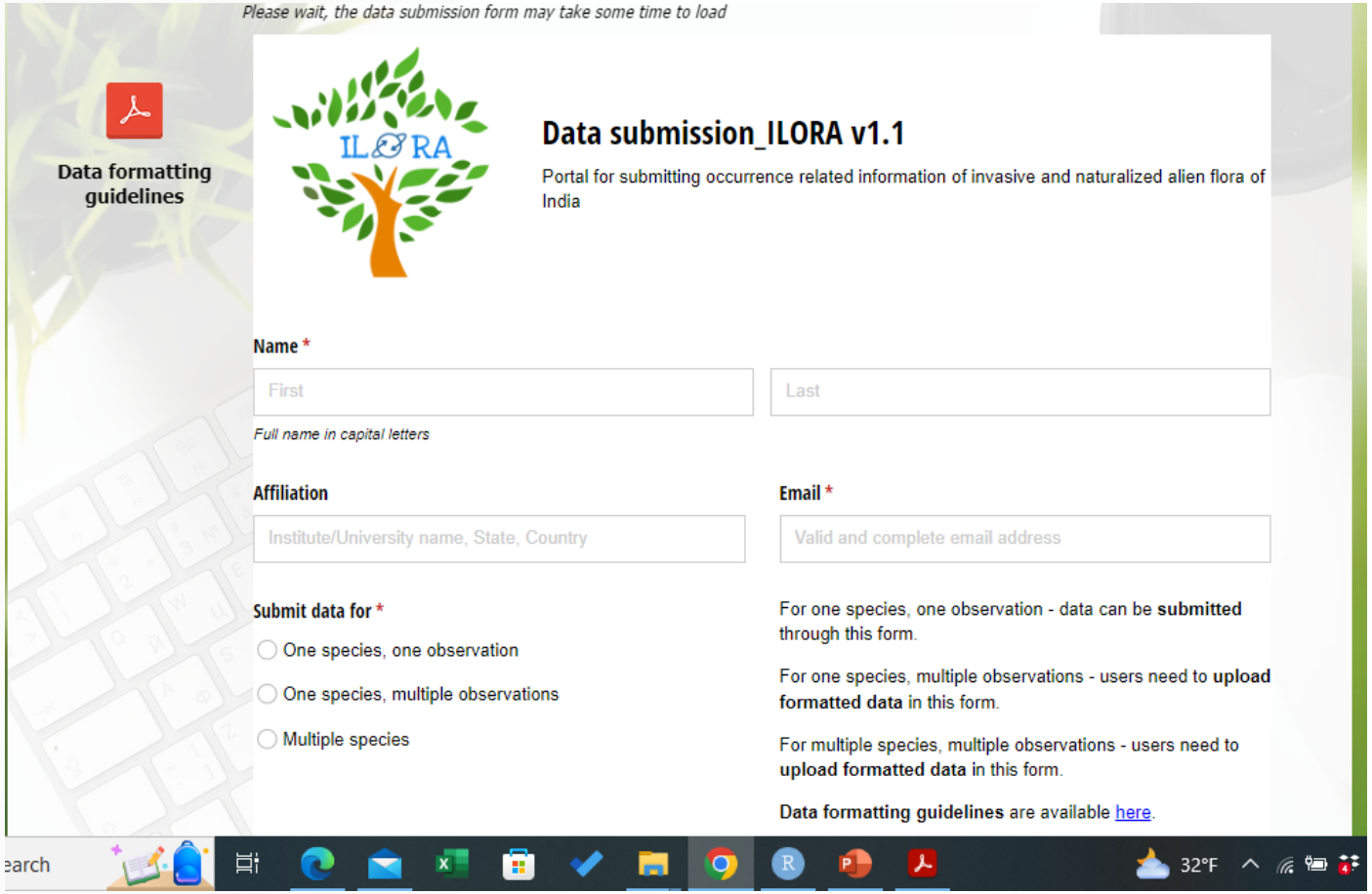
- Provision for data submission
- Data validation
- Associated with source information



How you can use ILORA

Become a user and contributor

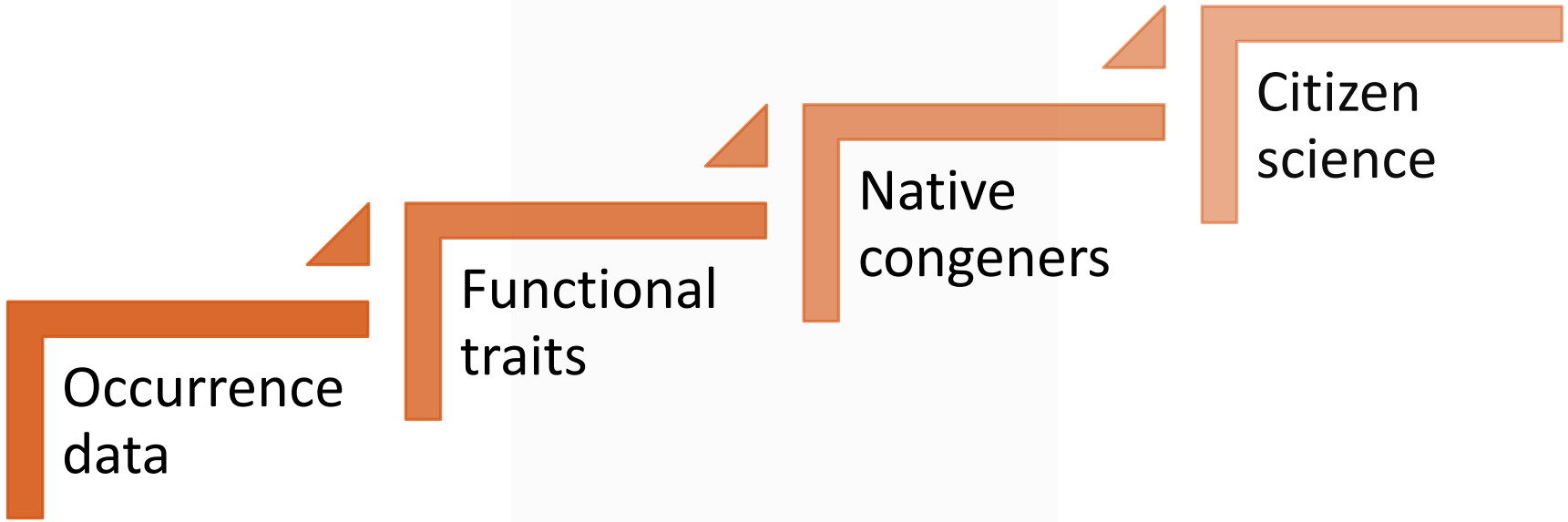
- Standard for data submission (Version 1.1)
- Data submission guidelines



38

A long term vision

Be a part of this…



ILORA version 1.1

ILORA version 1.0

Training Program

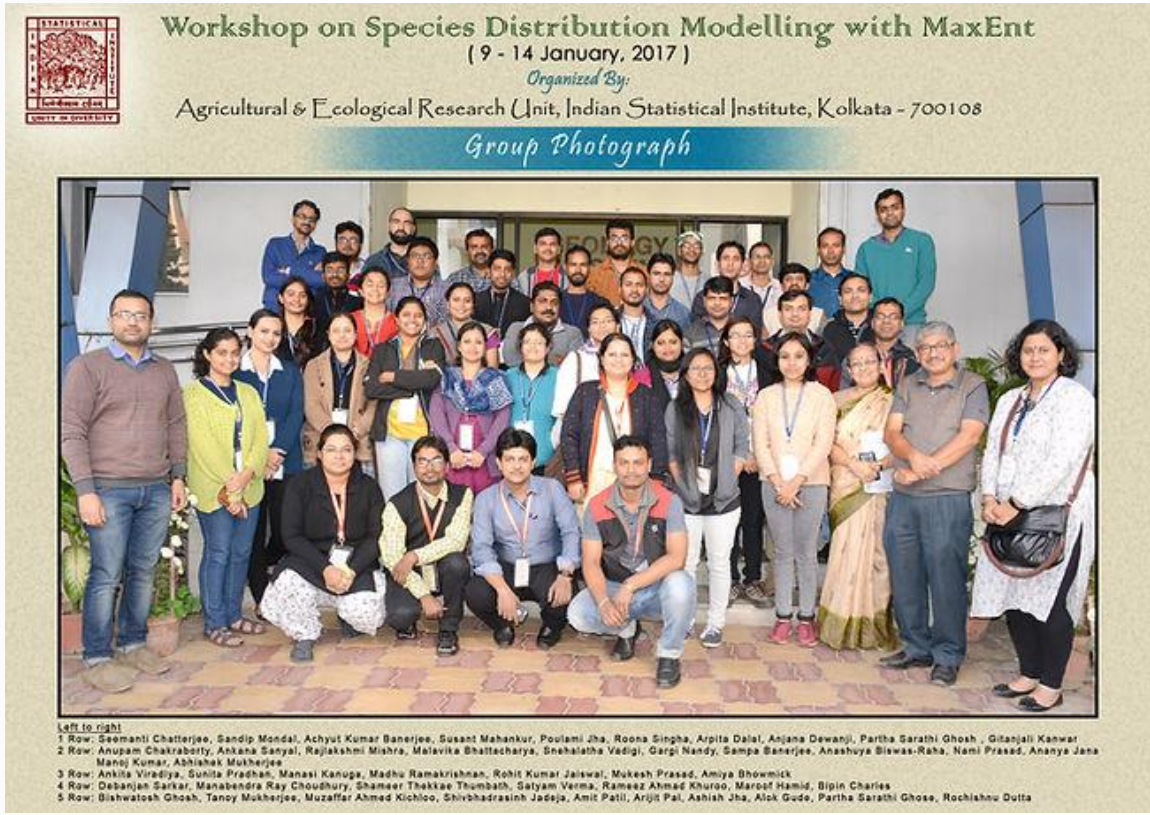
Reaching ML Applications to Citizen Scientists

Involve Citizens?...

- Statistical Methods
- Programming
- Research Methodology

- Biological Research
- Ecological Data Science
- Environmental research
- NGOs
- Students
- Ph.D.
- Postdocs

- Workshop on Species Distribution Modelling (2017, 2018)
- Workshop on Statistical Methods for Interdisciplinary Researchers (Target group: Citizen Scientists, NGO) (10 workshops across India)

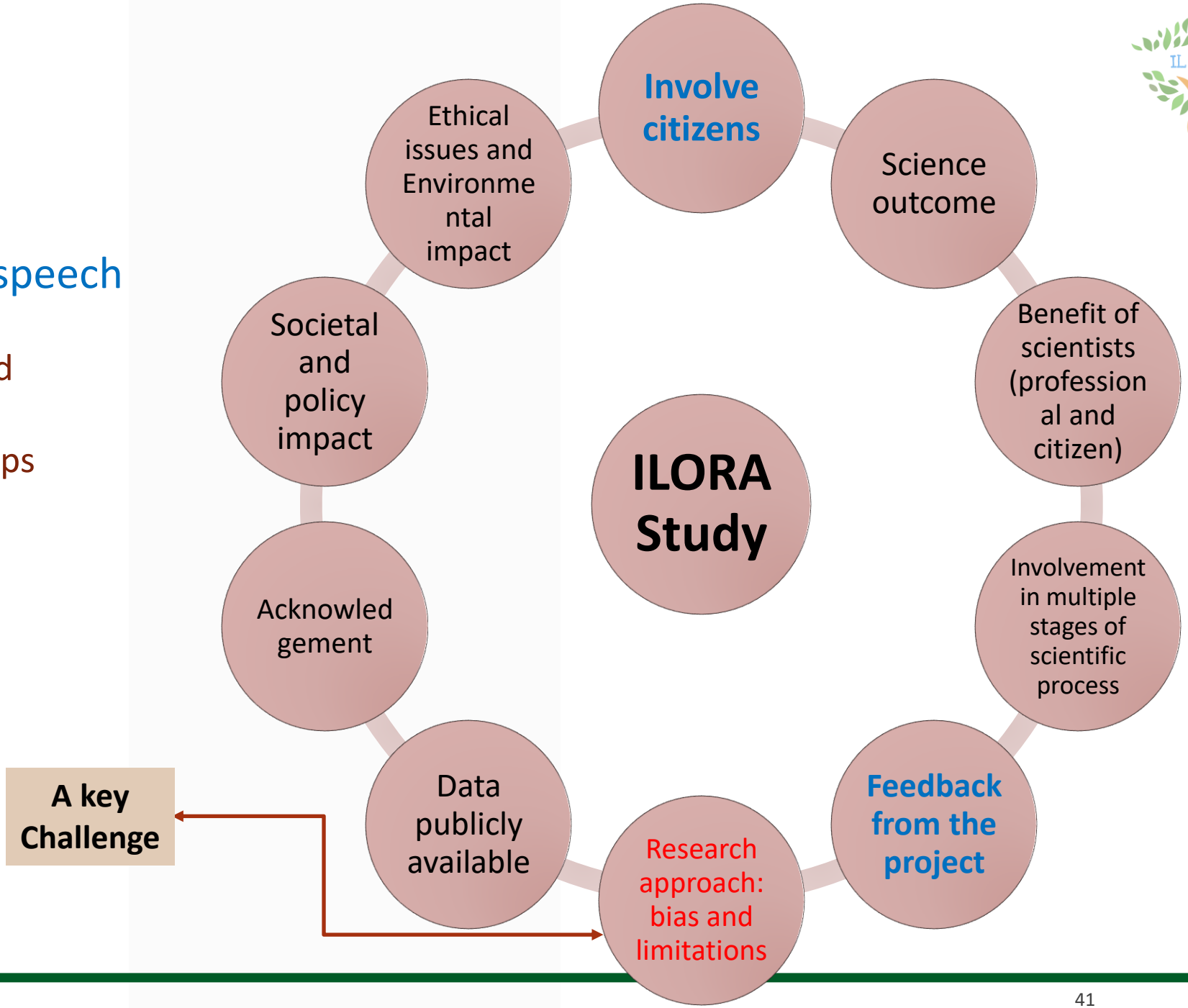


Self assessment

10 Principles

Thanks to Simona Carreto's speech

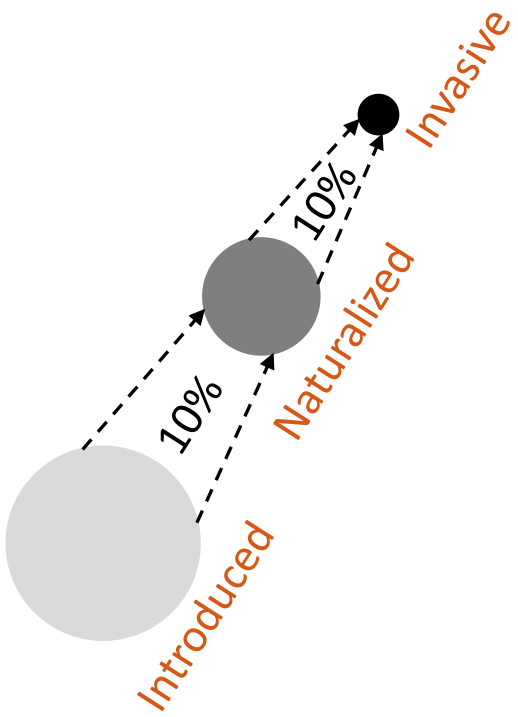
- Infusing machine learning and data science among applied researchers through workshops and conferences
- An action plan to convert the scientific findings into policy formulations.
- Not only data collection, infusing an objective way of doing science.



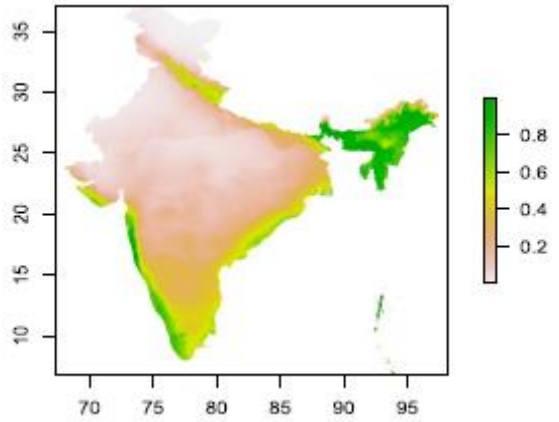
Future plan

A collaborative framework

A long way to go…



- Estimate the risk associated with each naturalized species to be a successful invader
- Identify their projected distributions under climate change
- Develop an Application which compute the probability score for each species and may be installed in the borders



- It is not only a prediction problem, but also an inference problem.
- We would like to identify the important predictors so that best practices can be undertaken to minimize the risk.

- **Secure funding to develop the technology that include our research and integrate the policy/regulatory framework.**

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Abhishek Mukherjee
Indian Statistical Institute, Giridih

Blessed to have wonderful and hardworking Ph.D. students
Research: https://sites.google.com/site/amiyaiitb/research

We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.

Thank you

QUESTIONS?

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Edward O. Wilson
'Darwin's natural heir'
Jun 10, 1929 - Dec 26, 2021