BIODIVERSITY BUILDING BLOCKS FOR POLICY

Occurrence Cubes & Biological Invasions

Examples using Python and R

`b3alien` & **`invasimapr`**

Maarten Trekels & Sandra MacFadyen

Funded by the European Union

Meise Botanic Garden

NITheCS
National Institute for Theoretical and Computational Sciences

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

From Biodiversity Observations to Insights

Hands-on Training

FEBRUARY TO MARCH

Programme

20 February, 15:00 CET - Species occurrence cubes
Andrew Rodrigues (GBIF) and Lina Estupinan Suarez (Martin Luther University Halle-Wittenberg)

27 February, 15:00 CET - Occurrence cubes and biological invasions
Maarten Trekels (Meise Botanic Garden) and Sandra MacFadyen (Stellenbosch University)

6 March, 15:00 CET - Indicators for national invasion reporting
Tsungai Alfred Zengeya (South African National Biodiversity Institute)

13 March, 15:00 CET - Mapping biodiversity turnover with `dissmapr`
Sandra MacFadyen (Stellenbosch University).

20 March, 15:00 CET - Making use of colorblind friendly maps
Duccio Rocchini (University of Bologna).

27 March, 15:00 CET - b3verse: an R package suite to process cubes and calculate indicators
Shawn Dove (Justus Liebig University), Ward Langeraert (Research Institute for Nature and Forest) and Jasmijn Hillaert (Research Institute for Nature and Forest).

Introductions

Occurrence cubes and biological invasions

Who are we

Dr Sandra MacFadyen is a research fellow at the Mathematical Biosciences Lab, Stellenbosch University, South Africa. She completed a joint PhD in Botany at Stellenbosch University and Landscape Ecology at Vrije Universiteit Amsterdam, holds an MSc in Geographic Information Science, and postgraduate qualifications in Nature Conservation. Based in the Kruger National Park for over 27 years, her research focuses on macroscale ecosystem dynamics, applying spatiotemporal statistics, mathematical ecology, and complexity theory to advance biodiversity monitoring and conservation in large protected areas.

Mr Maarten Trekels is a biodiversity data scientist and project coordinator at Meise Botanic Garden, Belgium. Trained in physics and working in aerospace and medical tech, he moved into biodiversity informatics by developing standards for Biodiversity Information Standards (TDWG) in EU-funded projects supporting the DiSSCo research infrastructure. He coordinates DiSSCo implementation in Flanders, contributes to FAIR interoperability via the Research Data Alliance, leads a work package in Biodiversity Building Blocks for Policy, and pursues a Stellenbosch BioMath PhD in community ecology.

Maarten will present the possibilities of the b3alien Python package. The package provides a technical solution to track Target 6 of the KM-GBF. It mainly focuses on the headline indicator: rate of invasive alien species establishment, but can provide input to some of the complementary indicators. Sandra will give you a brief overview of the Invasibility Cube, which integrates trait, environment (and site), and community (species) data to quantify invasion fitness and generate spatial indicators of site invasibility and species and/or trait invasiveness.

Occurrence cubes and Biological invasions

Examples using the `b3alien python package` and `invasimapr` R package

Course Outline

- **Part 1: Data cubes and `b3alien` to monitor invasions** (Maarten)
  - A general overview of the **b-cubed Project**
  - **Essential Biodiversity Variables** (EBVs) explained
  - A brief introduction to **CBD targets** on **invasive alien species**
  - **Hands-on** with **`b3alien`**

- **Part 2: Species Invasiveness** and **Site Invasibility** with **`invasimapr`** (Sandra)
  - Biological invasions are a major threat to biodiversity.
  - Traditional Species Distribution Models and their limitations
  - The Fourth-Corner Problem >> Linking traits with environment
  - **`invasimapr`** computes **invasion fitness** = **abiotic suitability** - **niche crowding** - **site saturation**

BIODIVERSITY BUILDING BLOCKS FOR POLICY

Part 1: `b3alien`

A python package to report on KM-GBF Target 6.1

Maarten Trekels

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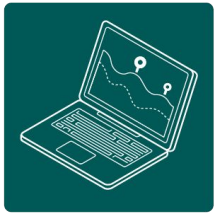
04 June 2025
Online
NITheCS mini-school

b3alien

A python package to report on KM-GBF Target 6.1

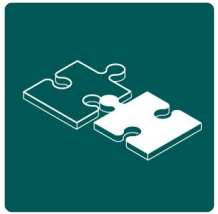
Maarten Trekels

About



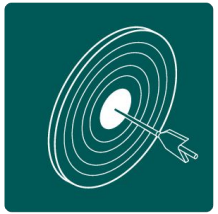
Challenges

The global biodiversity crisis requires **rapid, reliable and repeatable biodiversity monitoring data** which decision makers can use to evaluate policy.



Opportunities

Such information – from local to global level and within relevant timescales – calls for an **improved integration of data on biodiversity** from different sources.



Aim

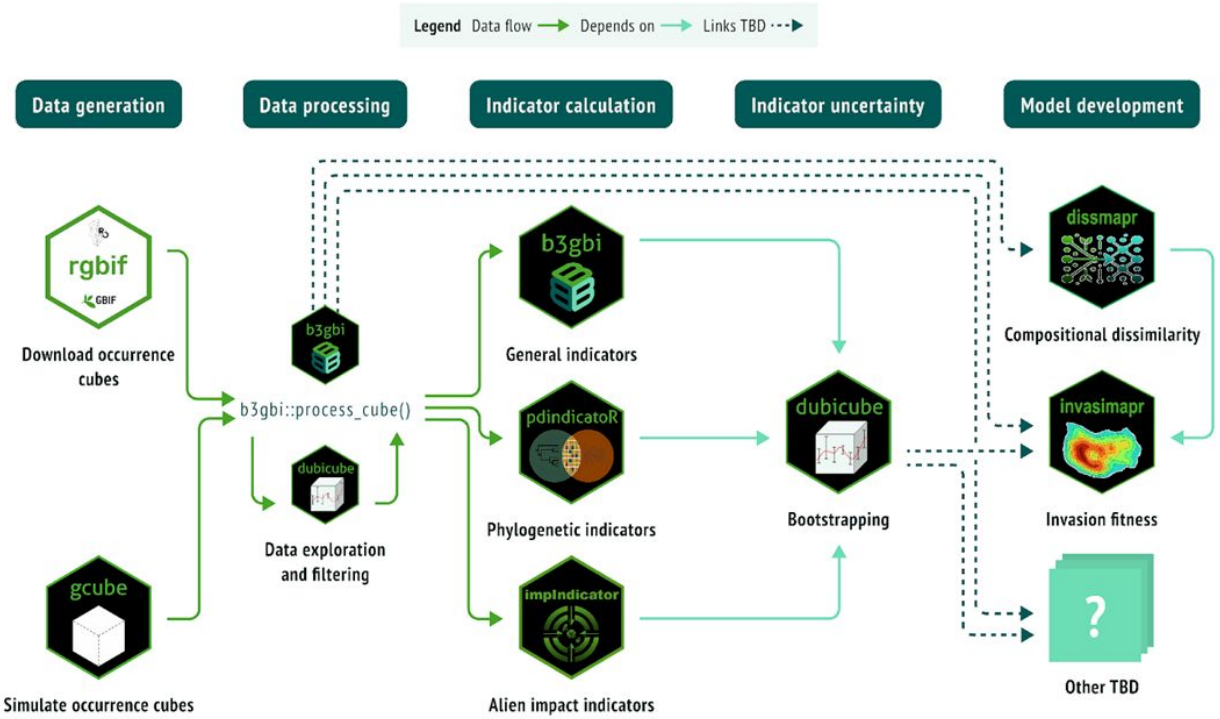
B-Cubed is **standardising access to biodiversity data**, empowering policymakers to address the impacts of biodiversity change.

B-Cubed

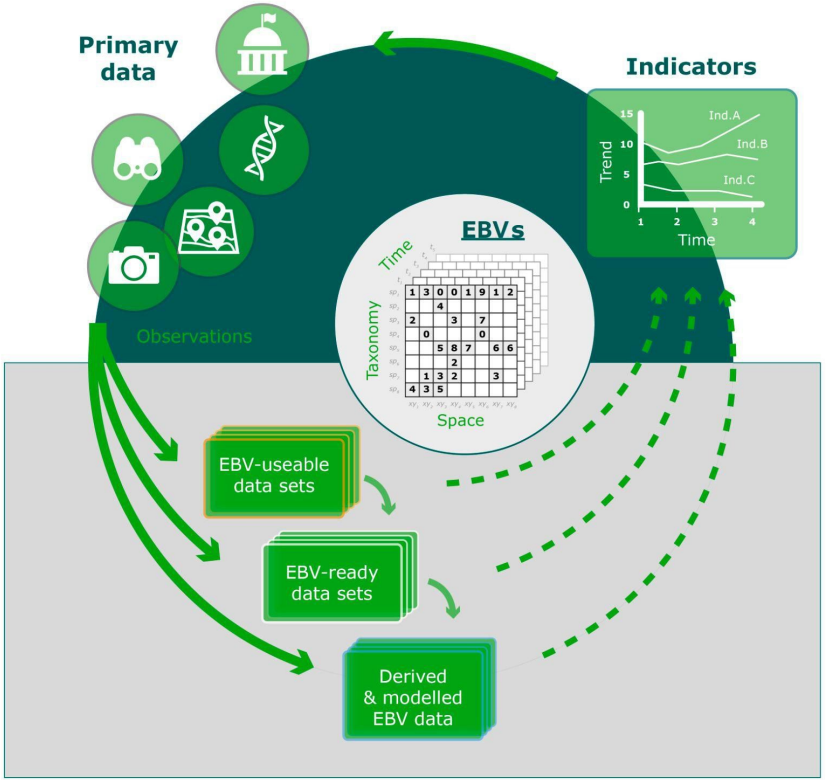
Biodiversity data cubes for monitoring

Not just diversity of species

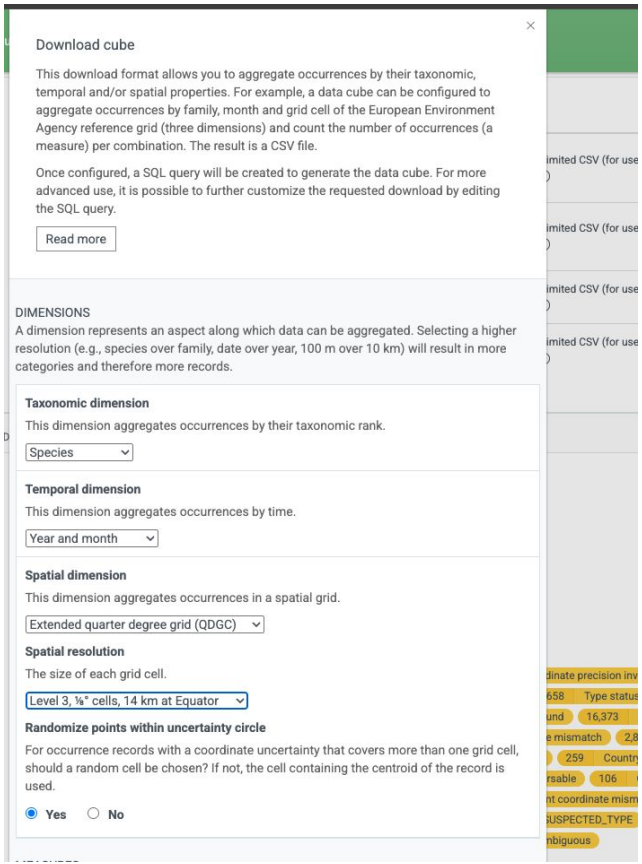
B-Cubed uses biodiversity data cubes to generate **indicators** that translate complex data into clear measures of biodiversity status and trends → **`b3verse` - an open-source software ecosystem containing a suite of interoperable R packages**.

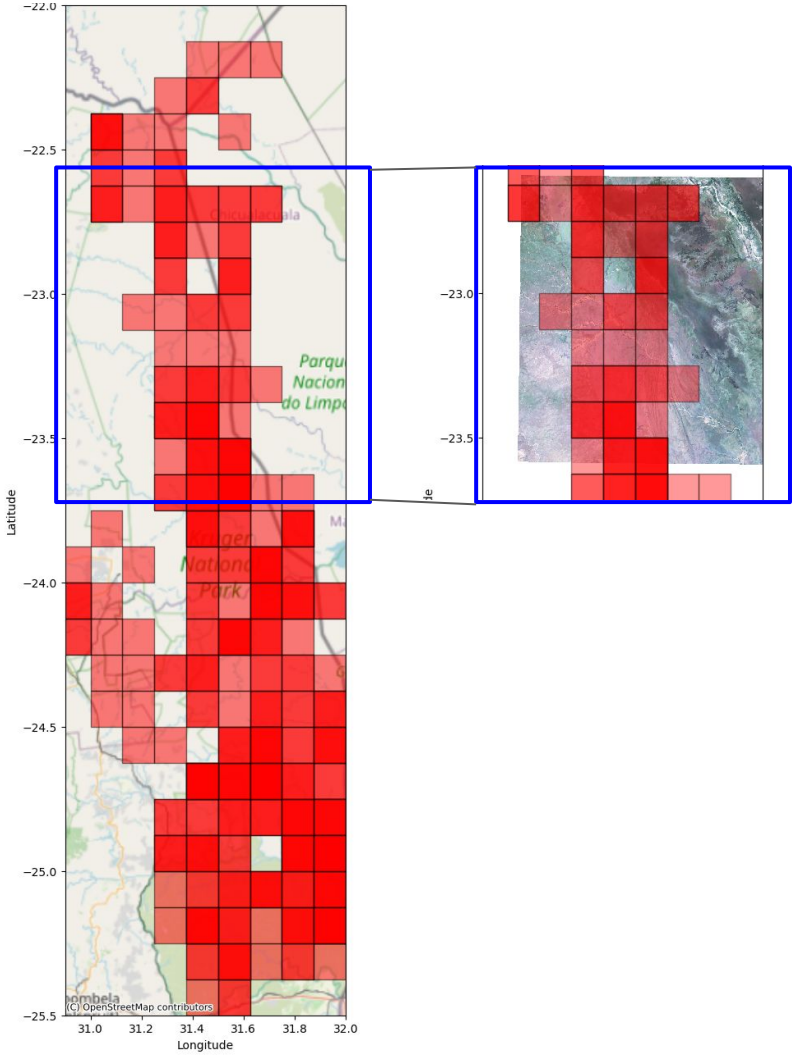


Essential Biodiversity Variables (EBVs)



Practical implementation





CBD targets on invasive alien species

Practical use of the data cubes

Convention on Biological Diversity (CBD)

Kunming - Montreal
GLOBAL BIODIVERSITY

GBF HOME // TARGET 6

Target 6

Reduce the Introduction of Invasive Alien Species by 50% and Minimize Their Impact

Eliminate, minimize, reduce and or mitigate the impacts of invasive alien spec biodiversity and ecosystem services by identifying and managing pathways of introduction of alien species, preventing the introduction and establishment o priority invasive alien species, reducing the rates of introduction and establish 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.

Following are the guidance notes prepared by the Secretariat for Target 6

E. Indicators

The monitoring framework for the Kunming-Montreal Global Biodiversity Framework identifies the following indicators for this target:

Headline indicators:

- 6.1 Rate of invasive alien species establishment

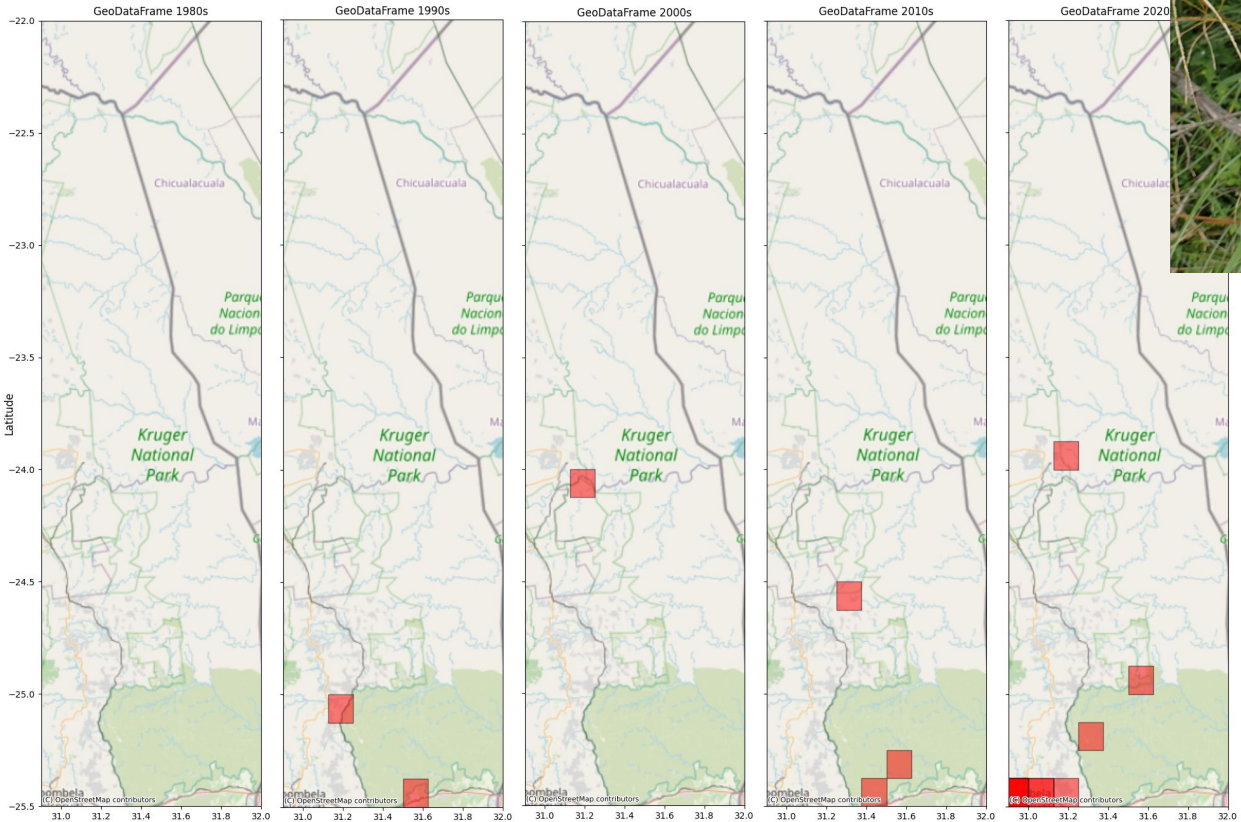
Component indicators:

- Rate of invasive species impact and rate of impact
- Rate of invasive alien species spread
- Number of invasive alien species introduction events

Complementary indicators:

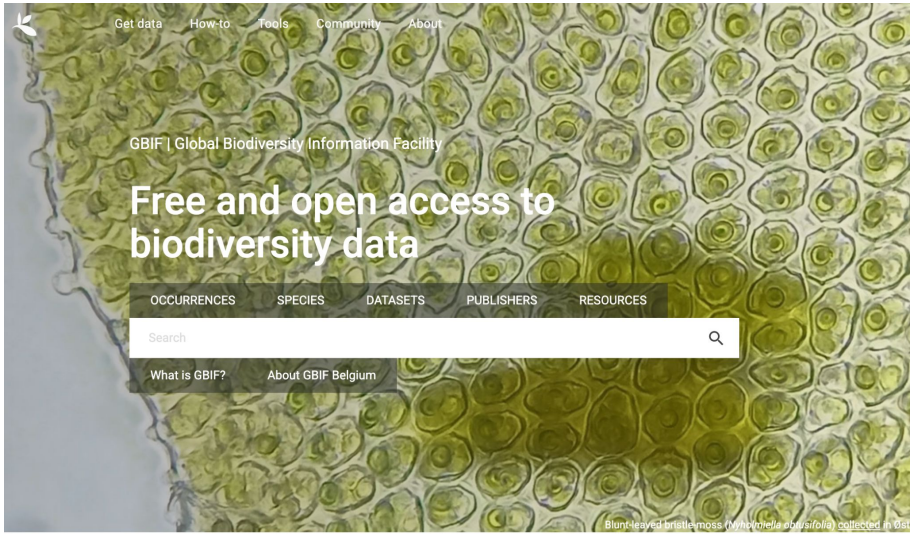
- Number of invasive alien species on national lists as per the Global Register of Introduced and Invasive Species
- Trends in abundance, temporal occurrence and spatial distribution of non-indigenous species, particularly invasive, non-indigenous species, notably in risk areas (in relation to the main vectors and pathways of spreading of such species)
- Red List Index (impacts of invasive alien species)

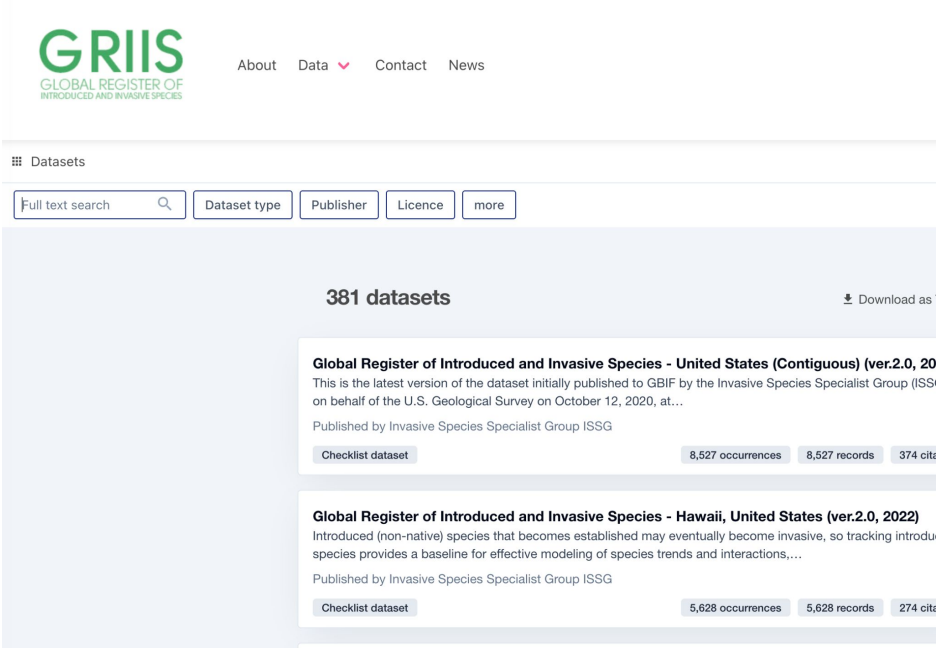
Data cubes to monitor invasions



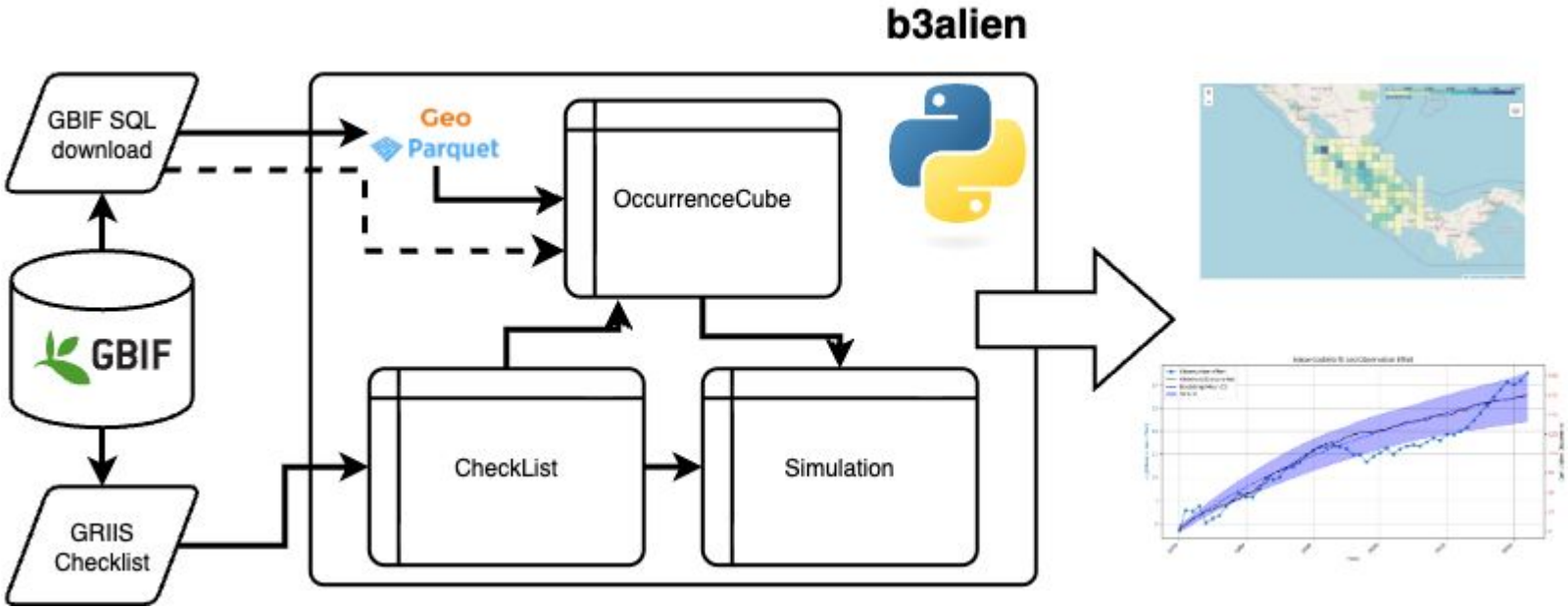
Chromolaena odorata (L.) R.M.King & H.Rob.
Observed in South Africa
by Mahomed Desai (licensed under http://creativecommons.org/licenses/by/4.0/))

Data sources

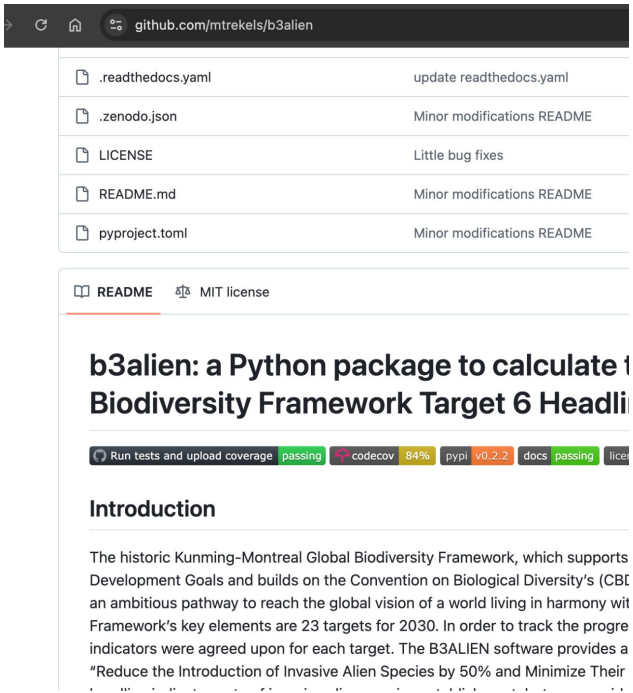




b3alien as a practical implementation



b3alien as a practical implementation



APPENDIX B: Exemplar workflow to determine the Rate of Establishment

This Jupyter notebook will guide the user of the b3alien Python package to generate a measure of the rate of establishment of alien species in a specific region or country. This workflow can be modified to match the needs of the user.

Install the b3alien Python package

[ ]:
```
%pip install b3alien
```

Load the software package and additional libraries

[1]:
```
from b3alien import b3cube
from b3alien import simulation
from b3alien import griis

import pandas as pd
import geopandas as gpd

import folium
from folium import Choropleth
from IPython.display import display

import matplotlib.pyplot as plt

%matplotlib inline
```

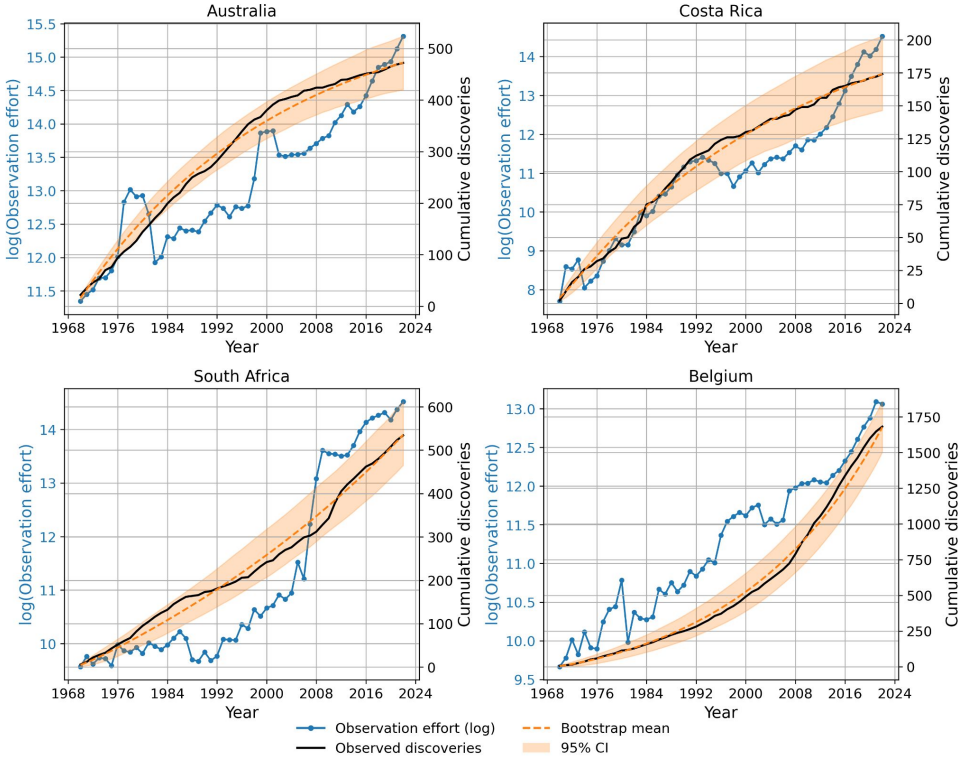
Step 1: Generate a Biodiversity Data Cube from GBIF

This step can be skipped if you already have generated a GeoParquet file with your data cube.

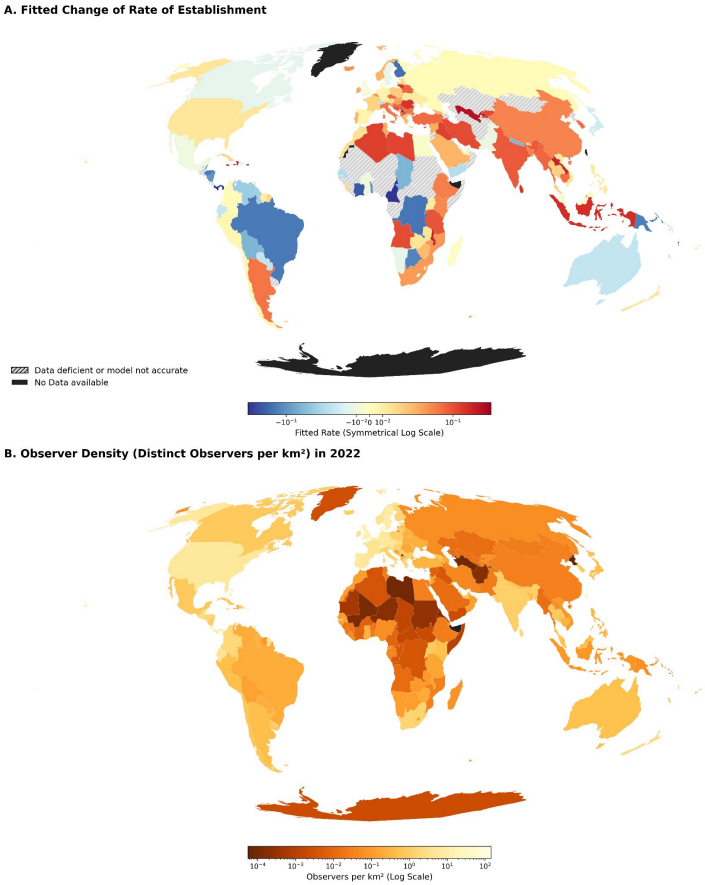
The basic warkflow assumes as an input a basic occurrence cube generated on the GBIF infrastructure. It uses the SQL API interface to GBIF data. How to generate this cube is described in Appendix A.

b3alien as a practical implementation

Country	Change in Rate of Establishment ($Year^{-1}$)	95% confidence interval
Belgium	+ 4.3 % +6.5%	2.7% ; 7.0% 3.8% ; 7.9%
South Africa	+ 1.6 %	0.2% ; 8.7%
Australia	- 0.31 %	- 3.9% ; - 0.29%
Costa Rica	- 2.7 %	- 4.7% ; - 1.3%



Rapid and repeatable workflow



- Simple workflow, readily usable by any country
- Heavily relying on the GRIIS checklist (GBF data source): high demand for updated checklists on alien species
- Easy to integrate in existing workflows
- Future plans: optimize the handling of the data cubes, faster reporting for more countries.
- Report on the complementary indicators

https://github.com/mtrekels/b3alien_training

Occurrence Cubes & Biological Invasions - `b3alien`

Maarten Trekels

Questions?


QUICK BODY BREAK
Occurrence Cubes & Biological Invasions
Examples using Python and R
b3alien & invasimapr

Part 2: `invasimapr`

A framework to visualise trait dispersion and assess species **invasiveness** & site **invasibility**

Dr Sandra MacFadyen

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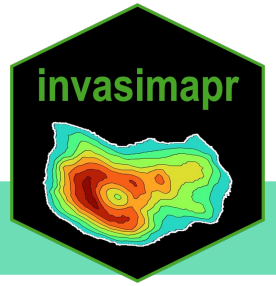
Stellenbosch University iYunivesithi Universiteit

invasimapr

An R Package to assess Species Invasiveness and Site Invasibility Analyses



Trait dispersion to assess species invasiveness and site invasibility

https://b-cubed-eu.github.io/invasimapr/

invasimapr 0.1.0 Reference Changelog Articles Search for

invasimapr

A Novel Framework to visualise trait dispersion and assess species invasiveness or site invasibility

Introduction

Biological invasions are a leading driver of biodiversity loss. Establishment success depends on a species' functional traits, local environments, and the competitive pressure from resident communities—so ad-hoc, single-component analyses are insufficient. **invasimapr** provides a transparent, trait- and site-specific framework that integrates these components into a single, reproducible workflow to estimate **invasion fitness** and derive decision-ready indicators of **species invasiveness** and **site invasibility**.

At its core, the package (i) models **intrinsic growth potential** from trait–environment responses, (ii) quantifies **competitive penalties** imposed by resident communities via trait overlap and environmental filtering, and (iii) combines these to compute a site- and species-resolved fitness surface that can be summarised and mapped. It relies on standard statistical tools (e.g., GLMM/GAM) and explicit distance/kernels, making it accessible and extensible for applied invasion ecology and conservation planning.

Core concepts (what the framework estimates)

- **Invasion fitness (λ)** - Net potential for a species to increase when rare at a site: $\lambda = \Gamma r - \alpha C - \beta S + k$, where r is intrinsic (abiotic) performance, C niche crowding, S site saturation, and Γ, α, β are sensitivities.
- **Invasiveness (V_i)** - Propensity of a species to establish across sites (spatial aggregation of λ).
- **Invasibility (V_s)** - Openness of a site to establishment by newcomers (aggregation of λ over candidate invaders).

Links
Browse source code
Report a bug

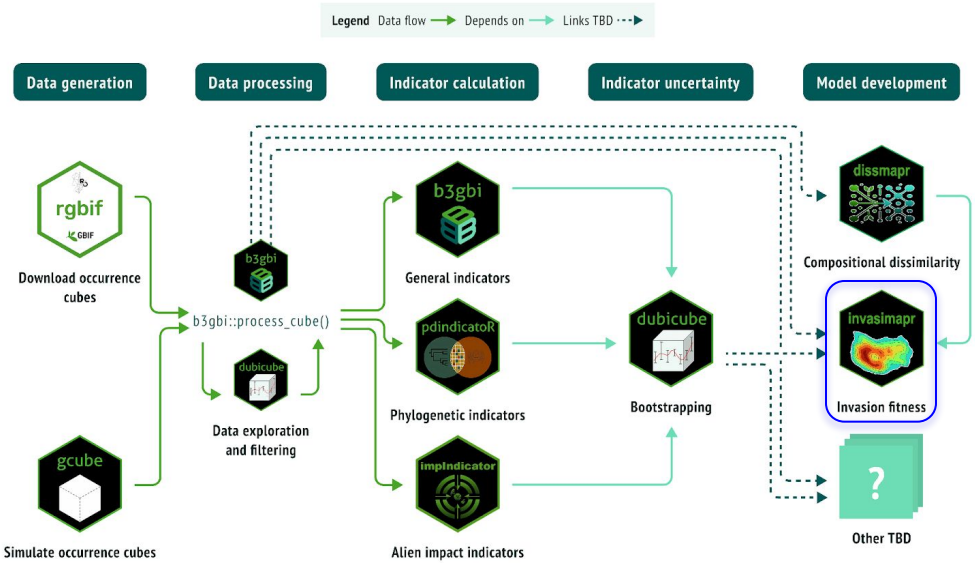
License
MIT + file LICENSE

Community
Code of conduct

Citation
Citing invasimapr

Developers
Sandra MacFadyen
Author, maintainer

Dev status
repo status Active
release v0.1.0
r-universe 0.1.0
CRAN not published
R-CMD-check.yaml failin
codecov 0%
DOI awaiting upload to zenodo
r-universe b-cubed-eu
License MIT

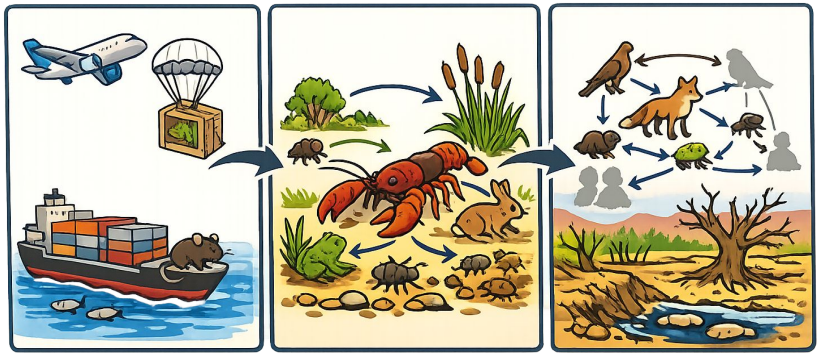


Invasive Alien Species (AIS)

Biological invasions are a major driver of biodiversity loss

Altering ecosystem processes, and displacing native taxa

- Biological invasions are a leading driver of biodiversity loss worldwide
- Impacts cascade through food webs and ecosystem functioning



- **Understanding establishment is key to prevention and mitigation**
- **Forecasting enables proactive, evidence-based management**

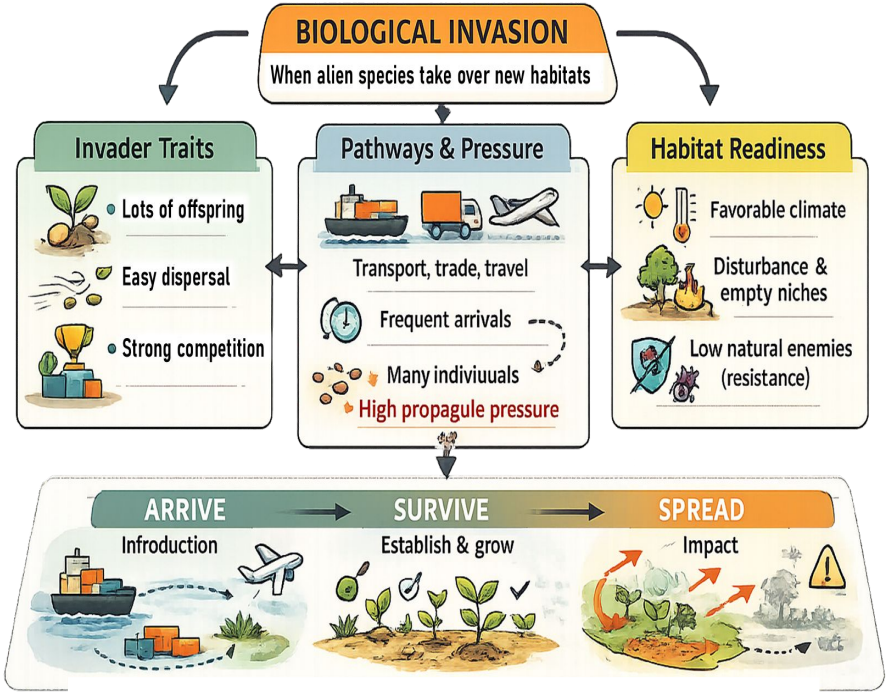
Invasive Alien Species (AIS)

Biological invasions are a major driver of biodiversity loss

Why Predict Establishment and Spread?

- Only a subset of introduced species successfully establish
- Risk varies across environmental gradients and communities

- **How can we make reliable predictions?**

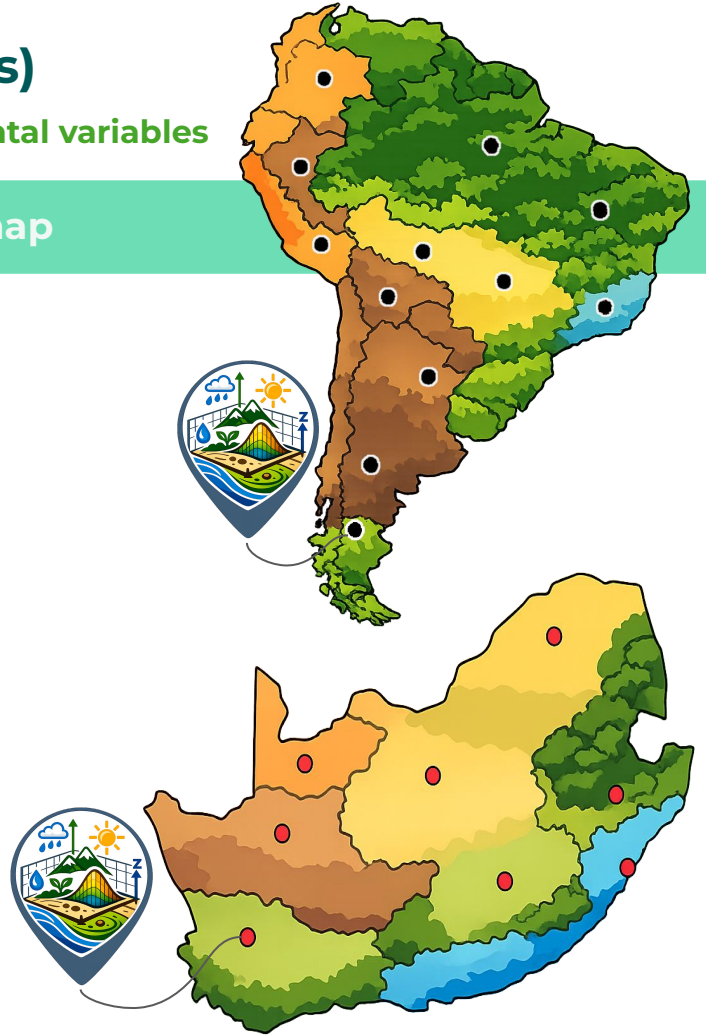


Traditional Species Distribution Models (SDMs)

Looks at where a species is now and correlate that with environmental variables

SDMs project discovered 'niche' onto a new distribution map

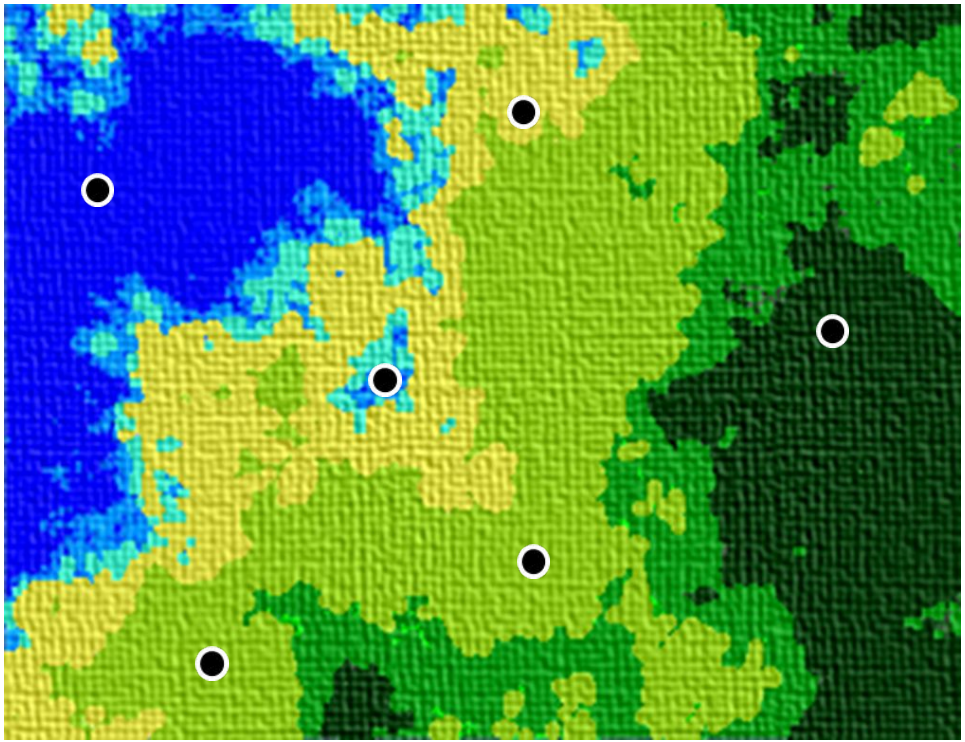
- Correlate species occurrences with environmental variables
- Infer ecological niche and project habitat suitability
- Assume distributions reflect environmental equilibrium
- **Predict geographic suitability from abiotic conditions**



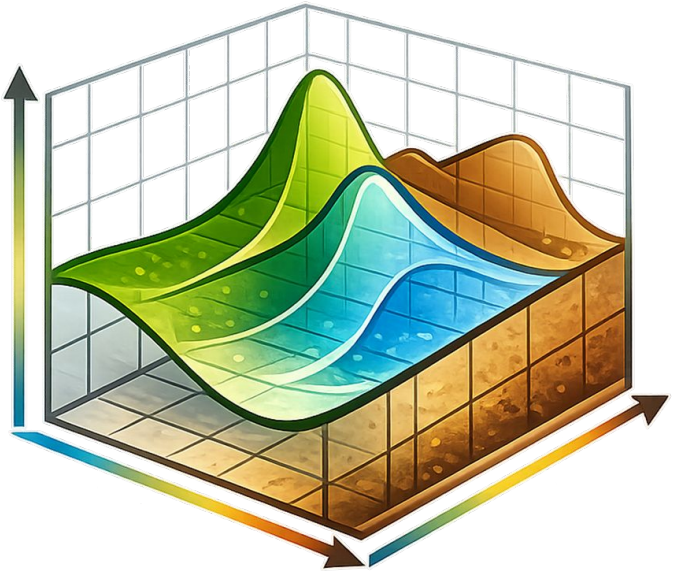
Traditional Species Distribution Models (SDMs)

Predict geographic suitability from abiotic conditions

How SDMs work



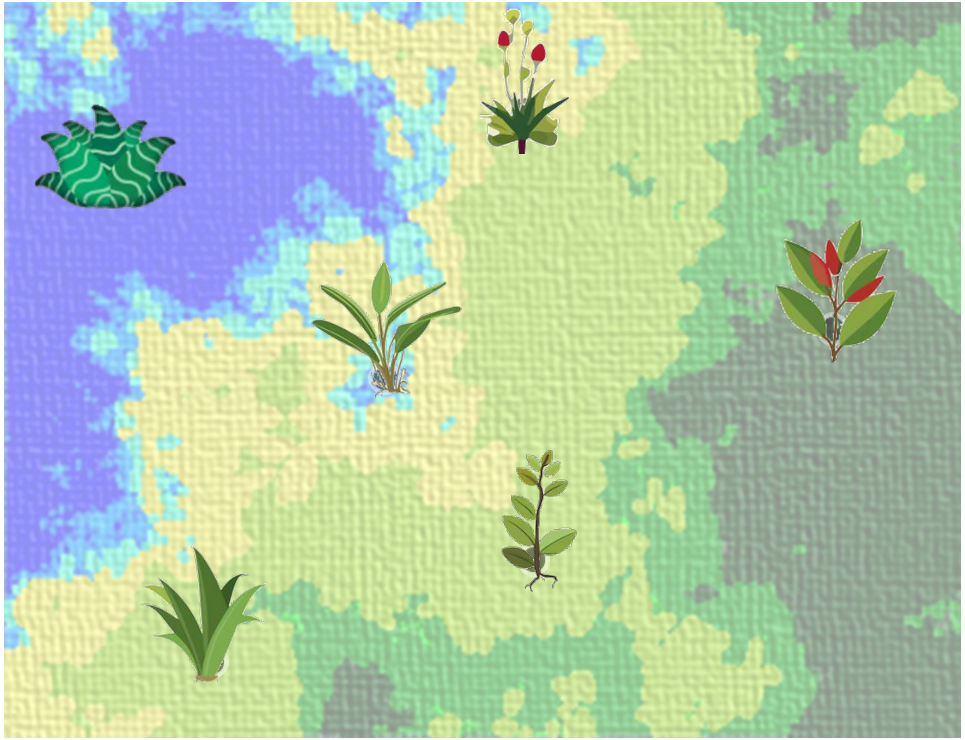
Unique ecological signature or *niche*

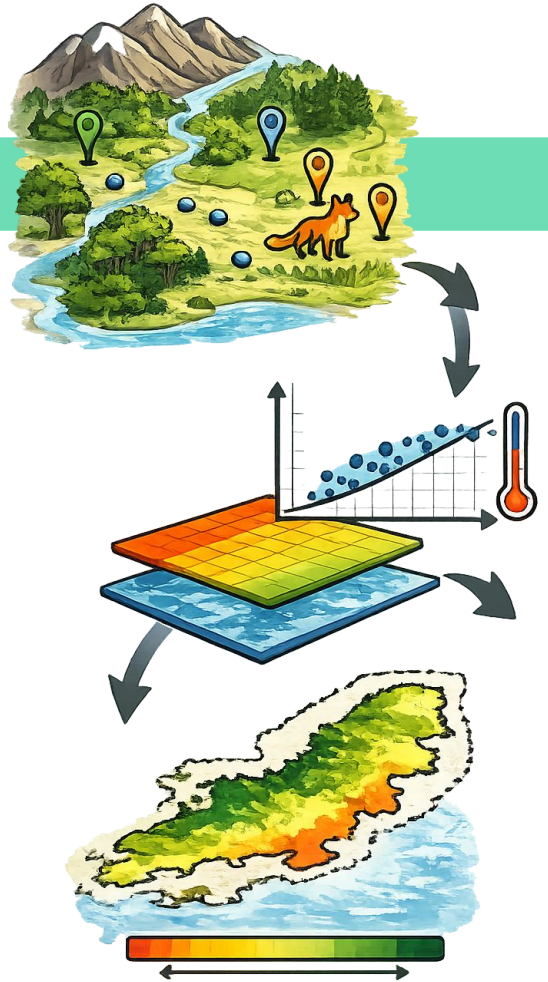


Traditional Species Distribution Models (SDMs)

Predict geographic suitability from abiotic conditions

Correlate species occurrences with environmental variables





Traditional Species Distribution Models (SDMs)

Predict geographic suitability from abiotic conditions

Limitations of SDMs for Invasions

- Often ignore resident community interactions (biotic resistance)
- Assume equilibrium with environment (rare for invaders)
- Risk of misleading forecasts when time and adaptation are ignored
- May overpredict suitability in novel environments

⚠️ **Ecologists must be cautious when applying equilibrium SDMs to dynamic invasions.**

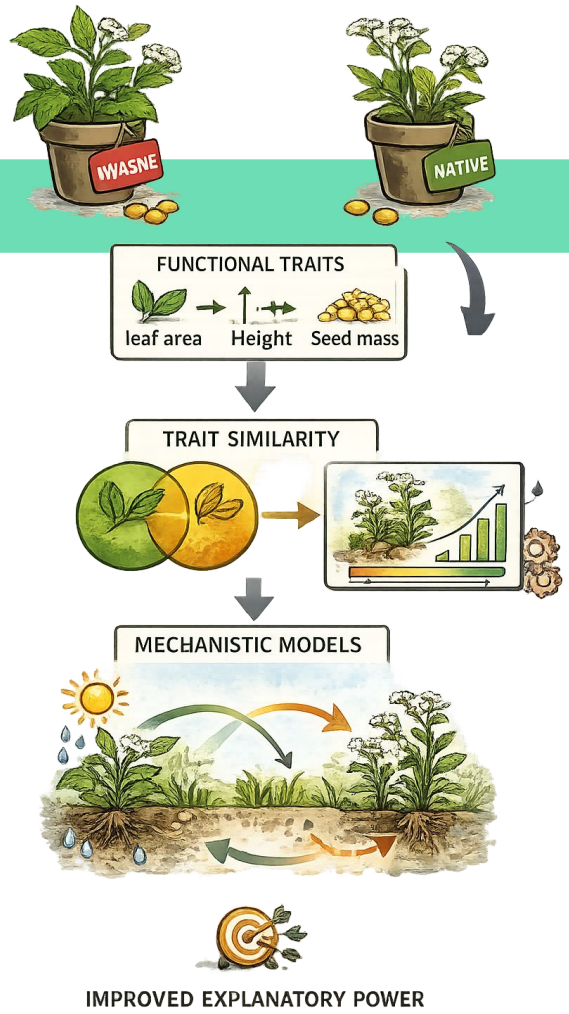
Moving Beyond Environment-Only Models

Biological invasions are a major driver of biodiversity loss

Functional traits describe ecological strategies

- Functional traits determine growth, survival, and competition
- Trait similarity mediates coexistence and competitive exclusion
- Mechanistic models improve explanatory power

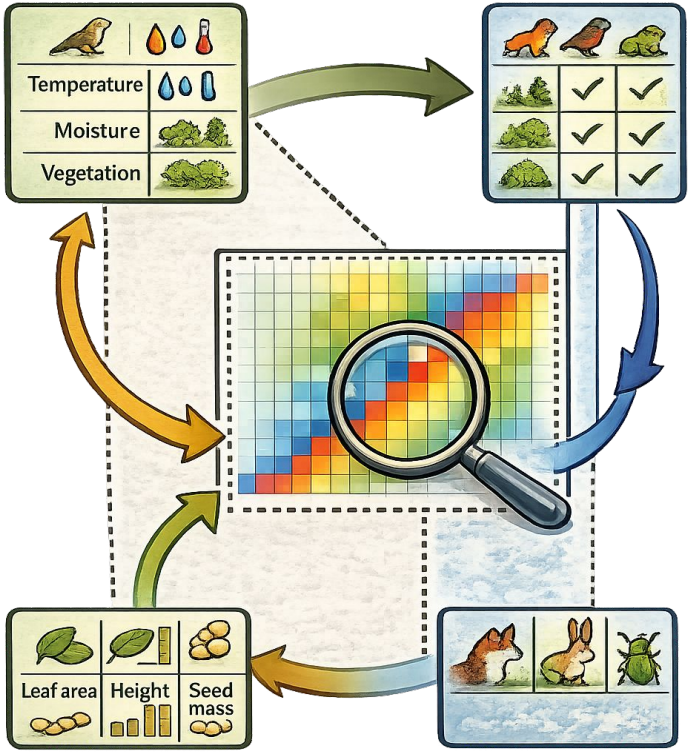
Linking traits to environment is a “fourth-corner” problem



The Fourth-Corner Problem

Linking Environment and Traits

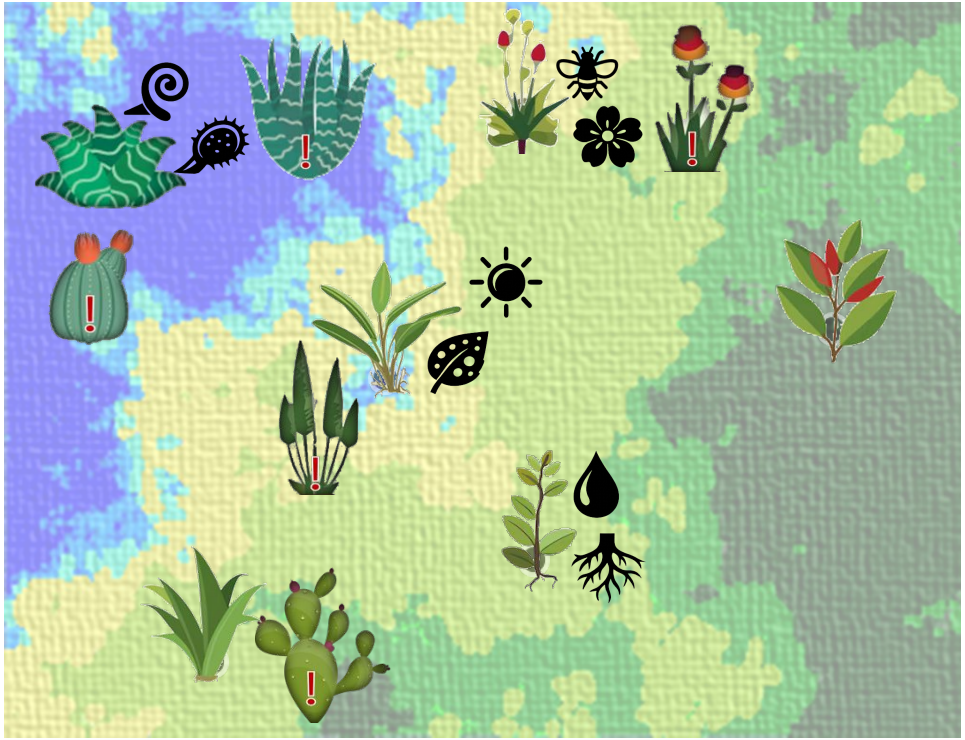
Connecting environmental gradients to trait responses

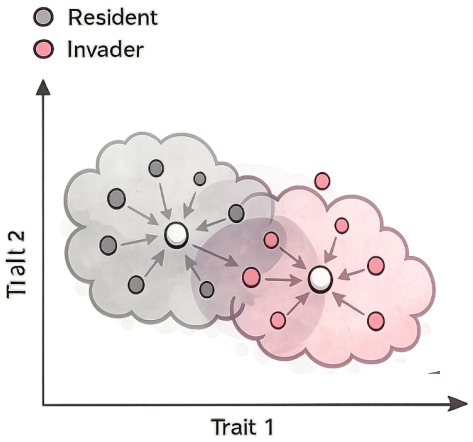


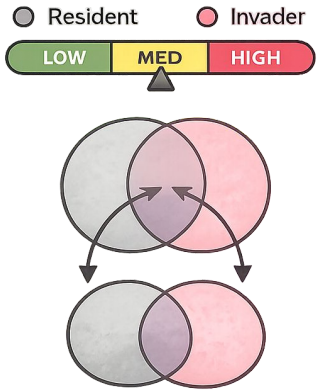
The Fourth-Corner Problem

Linking Environment and Traits

Shared trait-space to predict invader success







`invasimapr`

An R Package to assess Species Invasiveness or Site Invasibility Analyses

Trait dispersion to assess species invasiveness or site invasibility

- `invasimapr` helps quantify **establishment potential** at specific sites and to compare that potential **across species and landscapes**.

- It is a **trait-based**, **site-specific** R package that estimates **invasion fitness** for candidate invaders, assembles the resident community context that constrains establishment, and turns these quantities into mappable indicators for decision making. The workflow links three pillars:

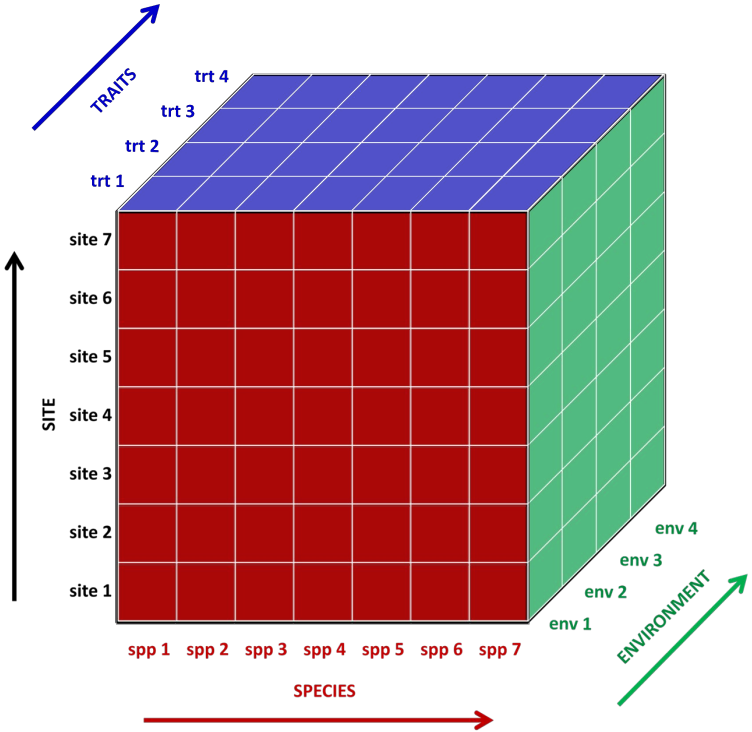
    1. **Functional trait space**, which governs competitive overlap.
    2. **Environmental suitability**, which determines how well species perform at a site.
    3. **Biotic competition**, which reduces the chance of establishment.

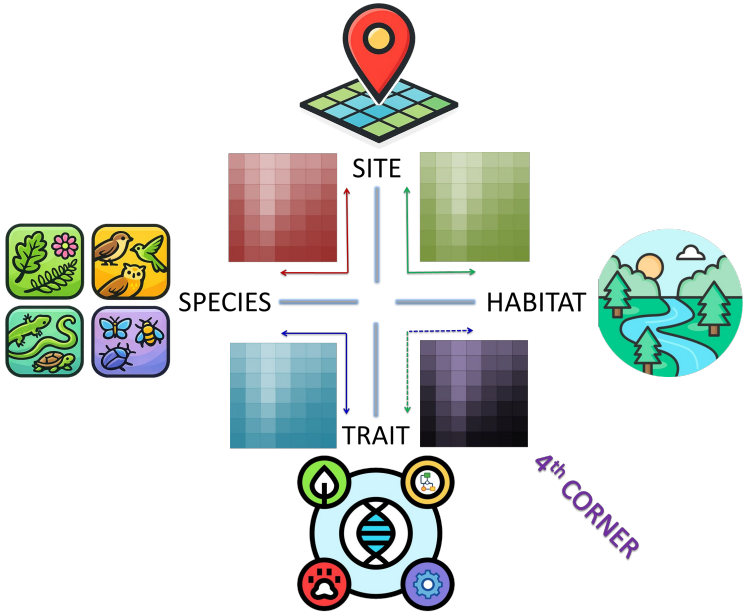
https://b-cubed-eu.github.io/invasimapr/

Data Cubes

Biodiversity data cubes for monitoring

Site-by-Species | Site-by-Environment | Species-by-Trait



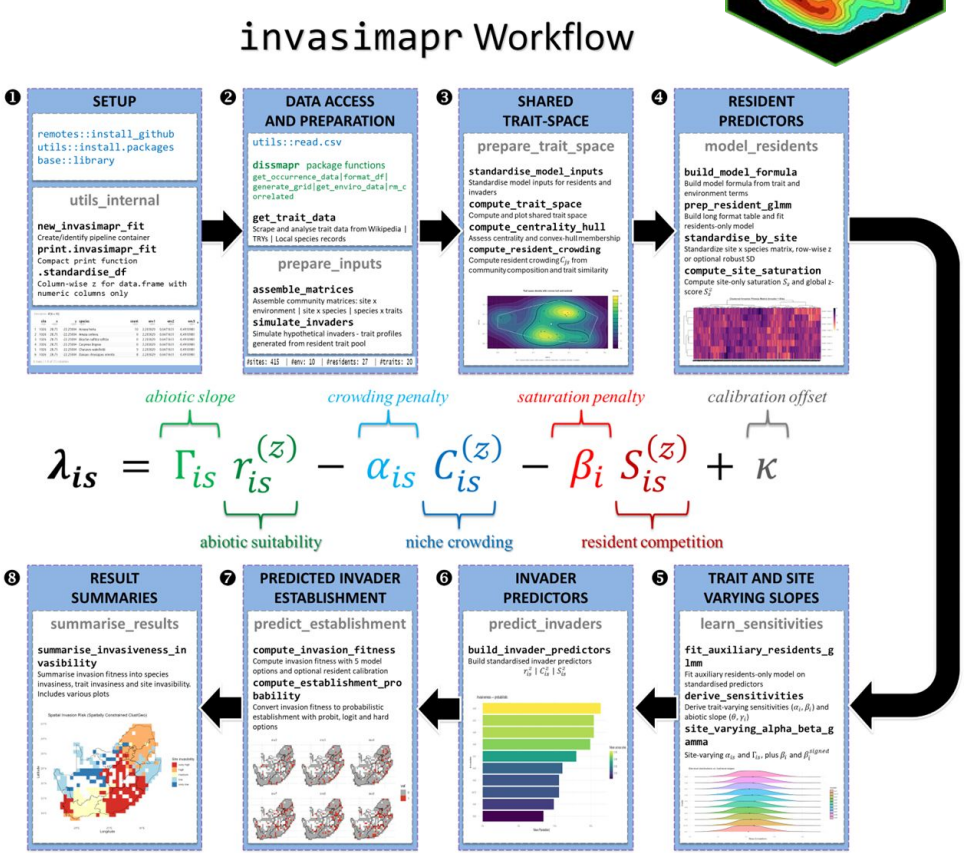


Introducing `invasimapr`

Biological invasions are a major driver of biodiversity loss

Workflow

- Modular, transparent **R workflow**
- **Prepare** resident community and trait **data**
- Constructs a **shared** multidimensional **trait space**
- Estimate **environmental** and **competitive** sensitivities
- Estimates **invasion fitness** and **establishment probability**
- Summarise indicators like **Invasiveness** and **Invasibility**



Invasion Fitness: A Conceptual View

An R Package to assess Species Invasiveness or Site Invasibility Analyses

Decomposing Invasion Fitness

- λ: Can an invader i grow/establish at site s?
- **Environmental match increases** potential **growth**
- Resident **competition reduces growth** potential

$$\lambda_{is} = \overbrace{\Gamma_{is}}^{\textit{abiotic slope}} \underbrace{r_{is}^{(z)}}_{\text{abiotic suitability}} - \overbrace{\alpha_{is}}^{\textit{crowding penalty}} \underbrace{C_{is}^{(z)}}_{\text{niche crowding}} - \overbrace{\beta_i}^{\textit{saturation penalty}} \underbrace{S_{is}^{(z)}}_{\text{resident competition}} + \overbrace{\kappa}^{\textit{calibration offset}}$$

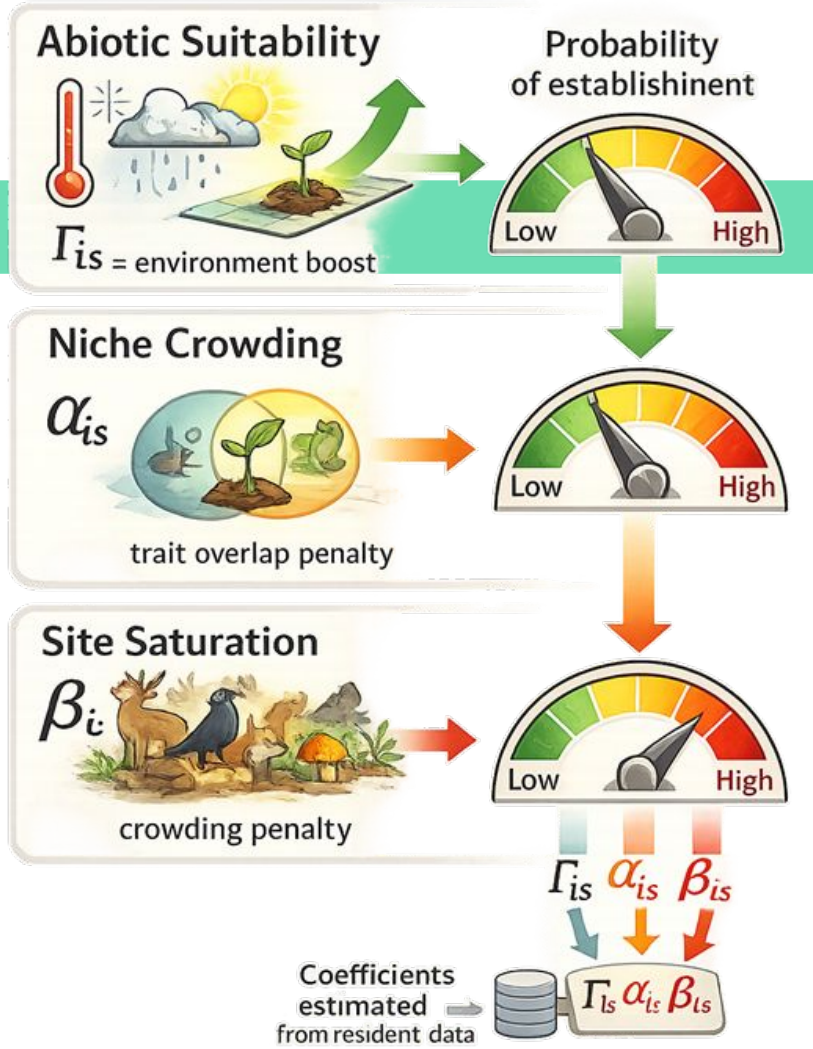
- **Abiotic suitability**: Trait fit to environmental conditions
- **Niche crowding**: Competition from trait-similar residents
- **Site saturation**: Overall competitive pressure

Invasion Fitness: A Conceptual View

Assess Species Invasiveness or Site Invasibility Analyses

Decomposing Invasion Fitness

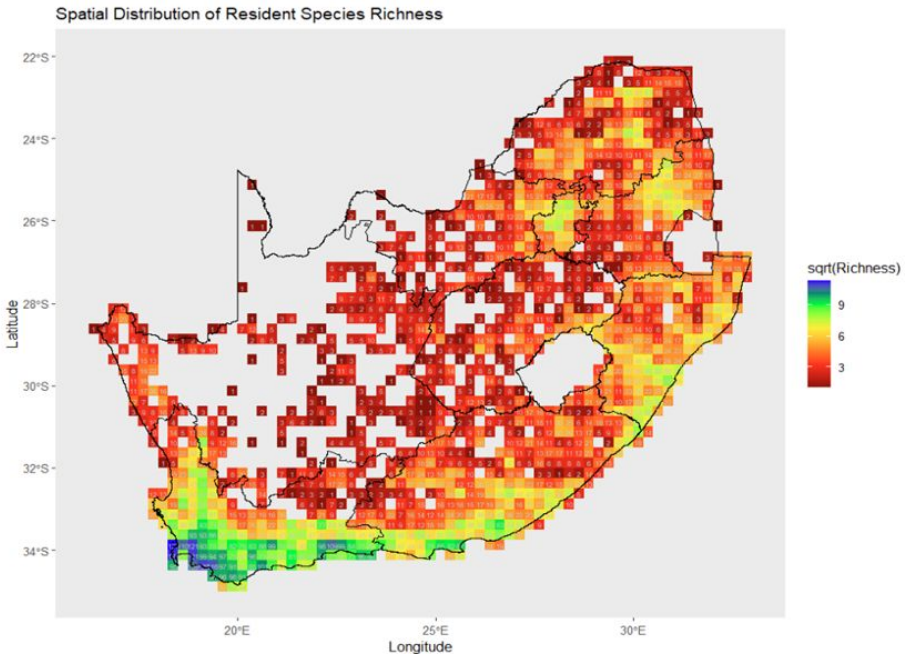
$$\lambda_{is} = \underbrace{\Gamma_{is}}_{\text{abiotic slope}} \underbrace{r_{is}^{(z)}}_{\text{abiotic suitability}} - \underbrace{\alpha_{is}}_{\text{crowding penalty}} \underbrace{C_{is}^{(z)}}_{\text{niche crowding}} - \underbrace{\beta_i}_{\text{saturation penalty}} \underbrace{S_{is}^{(z)}}_{\text{resident competition}} + \underbrace{\kappa}_{\text{calibration offset}}$$

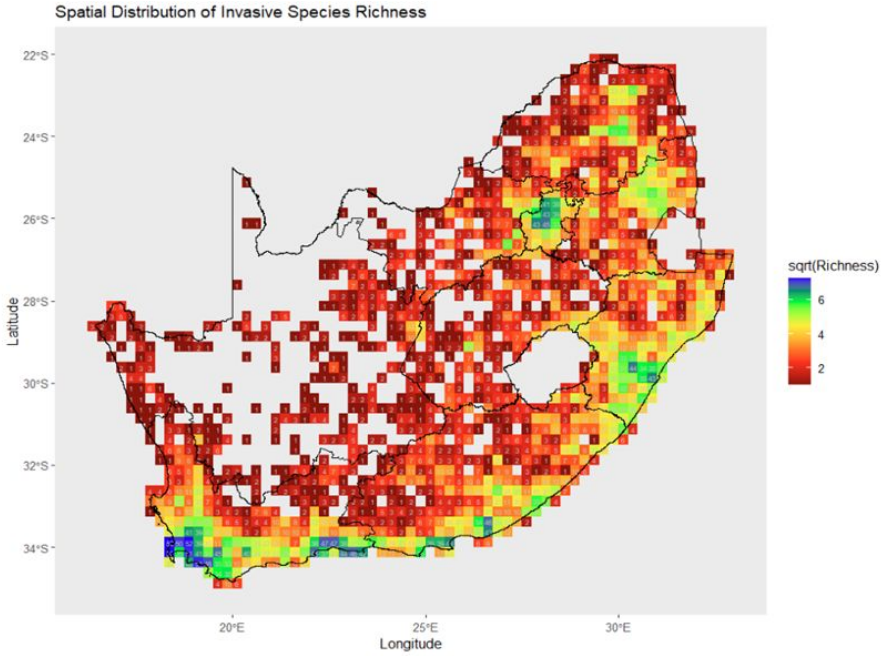


invasimapr

An R Package to assess Species Invasiveness and Site Invasibility Analyses

Trait dispersion to assess species invasiveness and site invasibility

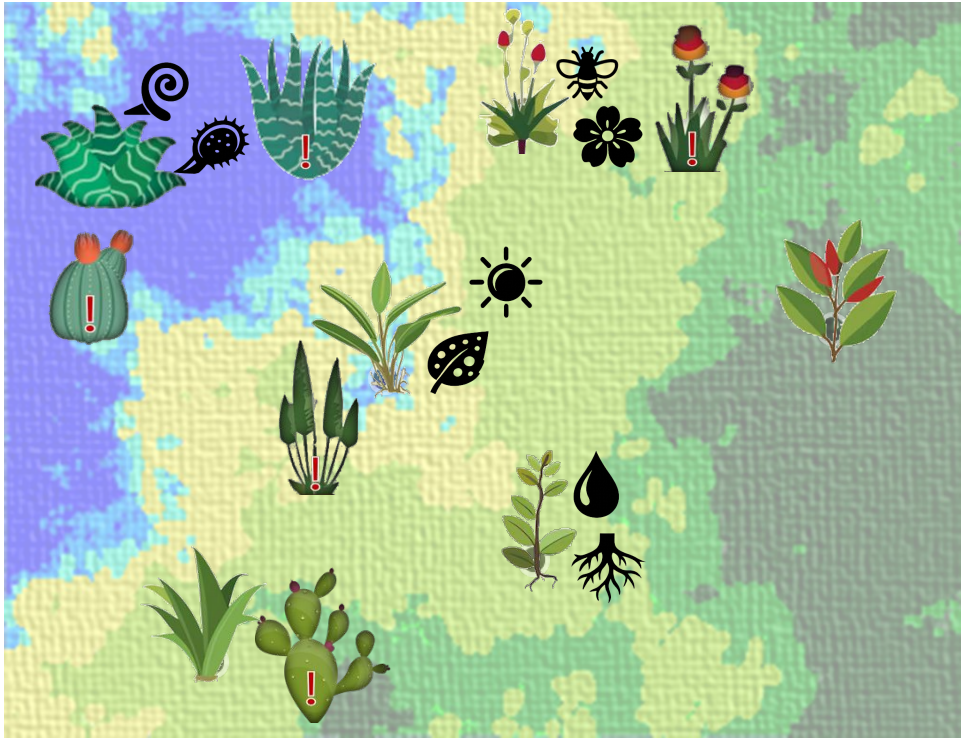


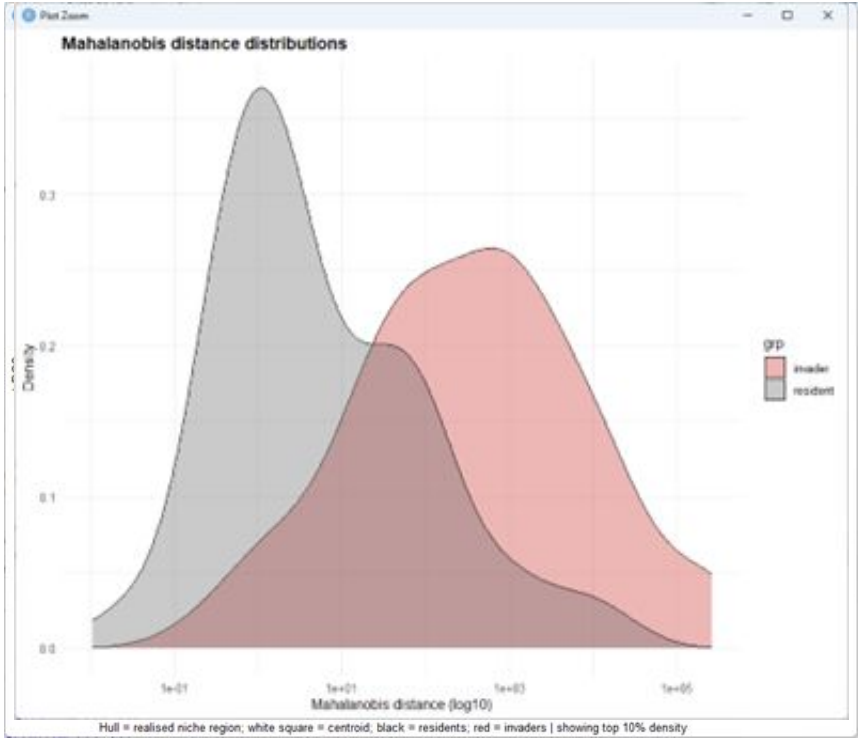


invasimapr

An R Package to assess Species Invasiveness and Site Invasibility Analyses

Shared trait-space to predict invader success



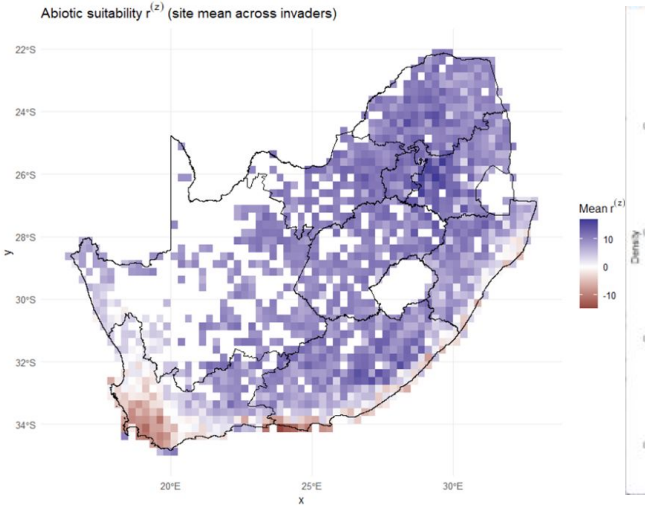


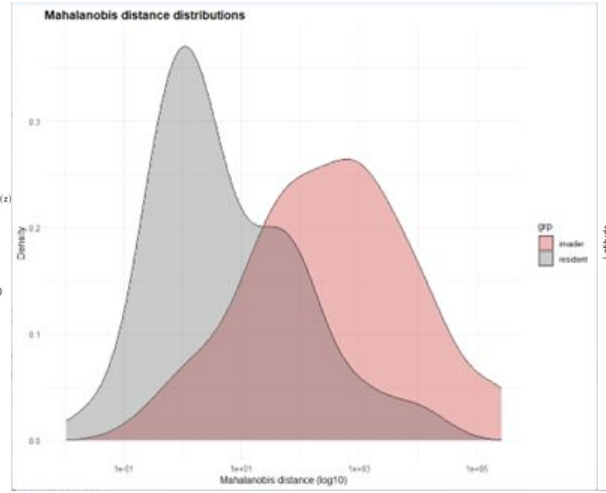
invasimapr

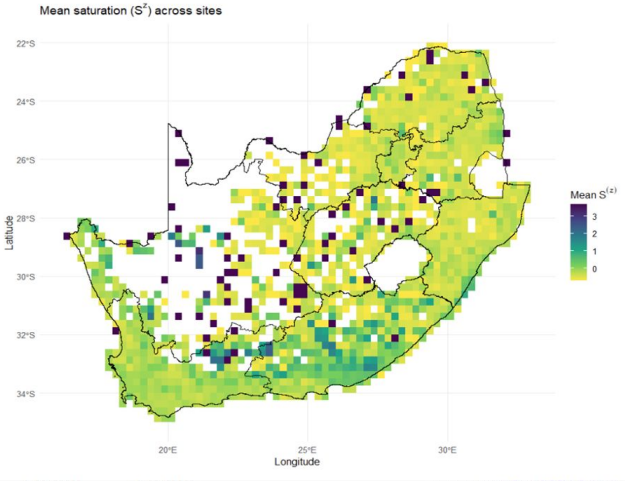
An R Package to assess Species Invasiveness and Site Invasibility Analyses

Decomposing Invasion Fitness

$$\lambda_{is} = \underbrace{\Gamma_{is}}_{\text{abiotic slope}} \underbrace{r_{is}^{(z)}}_{\text{abiotic suitability}} - \underbrace{\alpha_{is}}_{\text{crowding penalty}} \underbrace{C_{is}^{(z)}}_{\text{niche crowding}} - \underbrace{\beta_i}_{\text{saturation penalty}} \underbrace{S_{is}^{(z)}}_{\text{resident competition}} + \underbrace{\kappa}_{\text{calibration offset}}$$







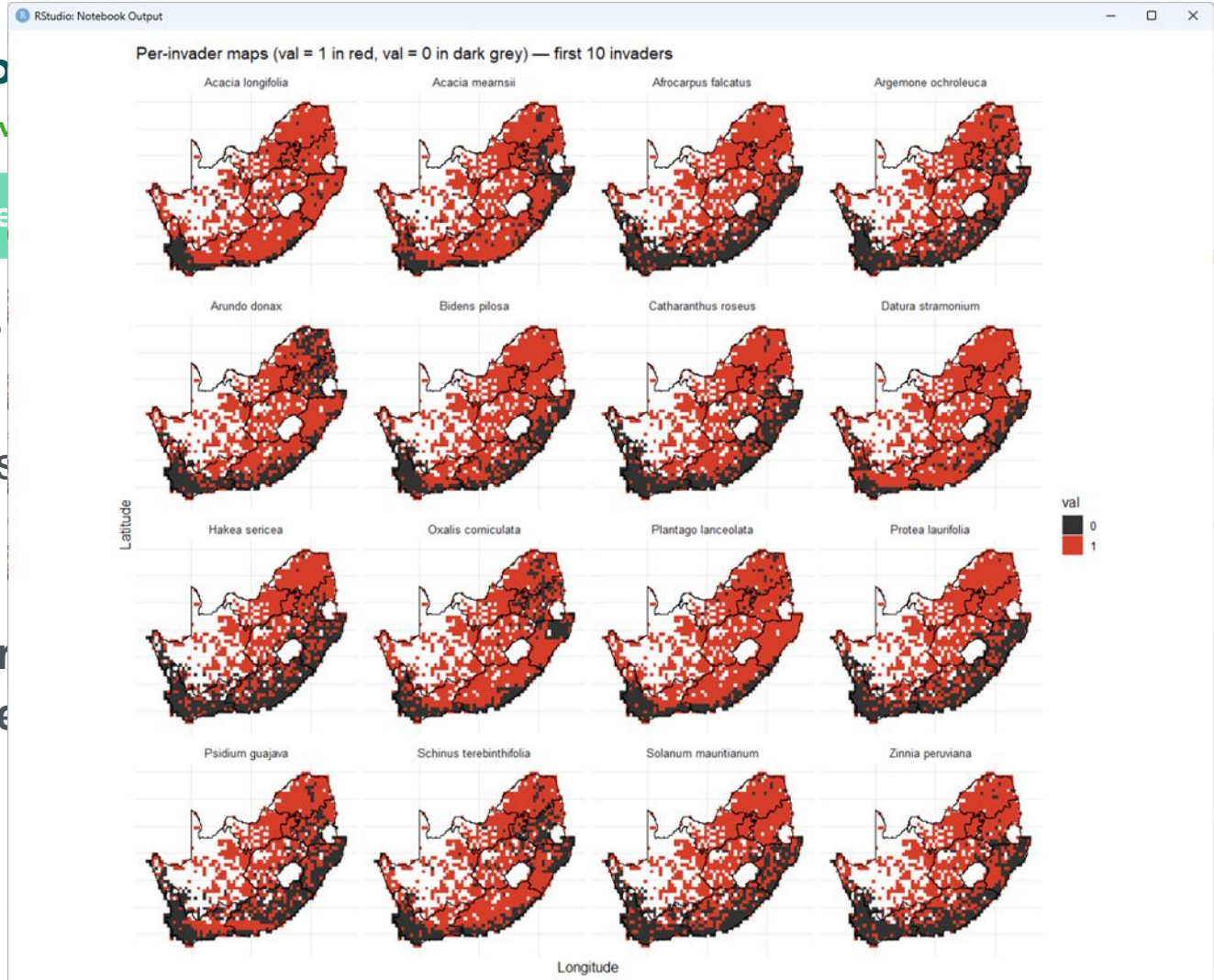
From Fitness to Estab

An R Package to assess Species Inv

Invasion Fitness, Invasivene

- **Positive λ** indicates **establishment**
- **Negative λ** indicates competition

- **Logit**/probit **transfor probability estimate**

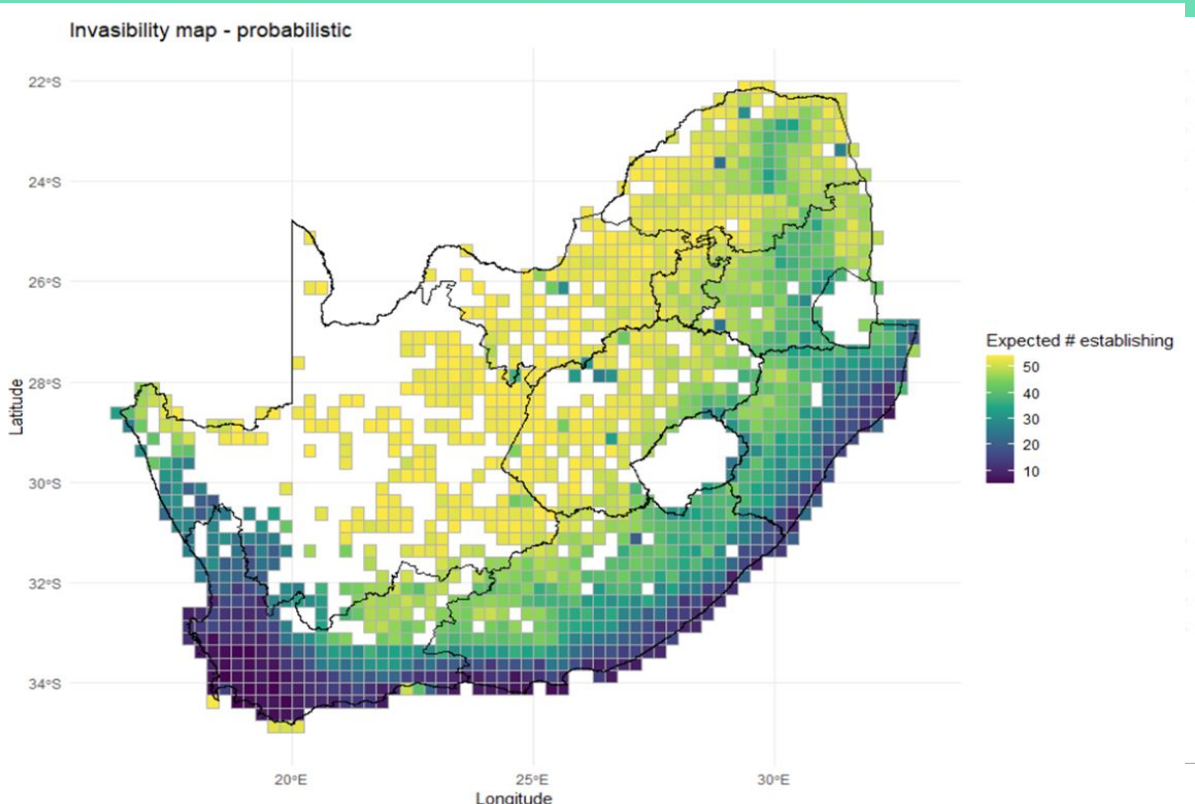


Species Invasiveness and Site Invasibiliy

An R Package to assess Species Invasiveness or Site Invasibility Analyses

Invasion Fitness, Invasiveness vs. Invasibility

- **Invasiveness:** Species/trait-level tendency to establish across sites
- **Invasibility:** site-level openness to newcomers
- Both derived from aggregated **invasion fitness** values

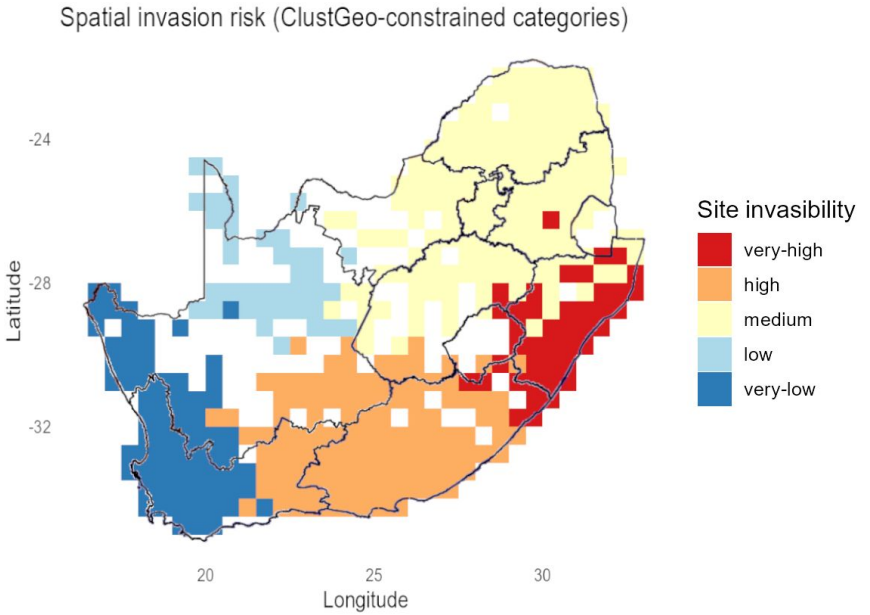


Outputs & Decision-Ready Indicators

An R Package to assess Species Invasiveness or Site Invasibility Analyses

Invasion Fitness

- Site × invader *invasion-fitness matrices*
- **Establishment** probability **maps**
- **Rankings of high-risk species/traits** and **vulnerable sites**
- Identifies **invasion hotspots** and priority regions
- Supports targeted pathway control and monitoring
- Enables transparent, comparable risk assessments



Useful references and links

Occurrence Cubes & Biological Invasions

- **b-cubed**: https://b-cubed.eu/
- **b-cubed documentation**: https://docs.b-cubed.eu/
- **`b3alien` package**: https://b3alien.readthedocs.io/en/latest/
- **`b3alien`** exemplar **workflow**: https://github.com/mtrekels/b3alien_training
- **`invasimapr` package**: https://b-cubed-eu.github.io/invasimapr

Occurrence Cubes & Biological Invasions `invasimapr` or `b3alien`

Maarten Trekels | Sandra MacFadyen

Questions?

From Biodiversity Observations to Insights

Hands-on Training

FEBRUARY TO MARCH

Programme

20 February, 15:00 CET - Species occurrence cubes
Andrew Rodrigues (GBIF) and Lina Estupinan Suarez (Martin Luther University Halle-Wittenberg)

27 February, 15:00 CET - Occurrence cubes and biological invasions
Maarten Trekels (Meise Botanic Garden) and Sandra MacFadyen (Stellenbosch University)

6 March, 15:00 CET - Indicators for national invasion reporting
Tsungai Alfred Zengeya (South African National Biodiversity Institute)

13 March, 15:00 CET - Mapping biodiversity turnover with `dissmapr`
Sandra MacFadyen (Stellenbosch University).

20 March, 15:00 CET - Making use of colorblind friendly maps
Duccio Rocchini (University of Bologna).

27 March, 15:00 CET - b3verse: an R package suite to process cubes and calculate indicators
Shawn Dove (Justus Liebig University), Ward Langeraert (Research Institute for Nature and Forest) and Jasmijn Hillaert (Research Institute for Nature and Forest).

Thank you!

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B-Cubed Newsletter

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