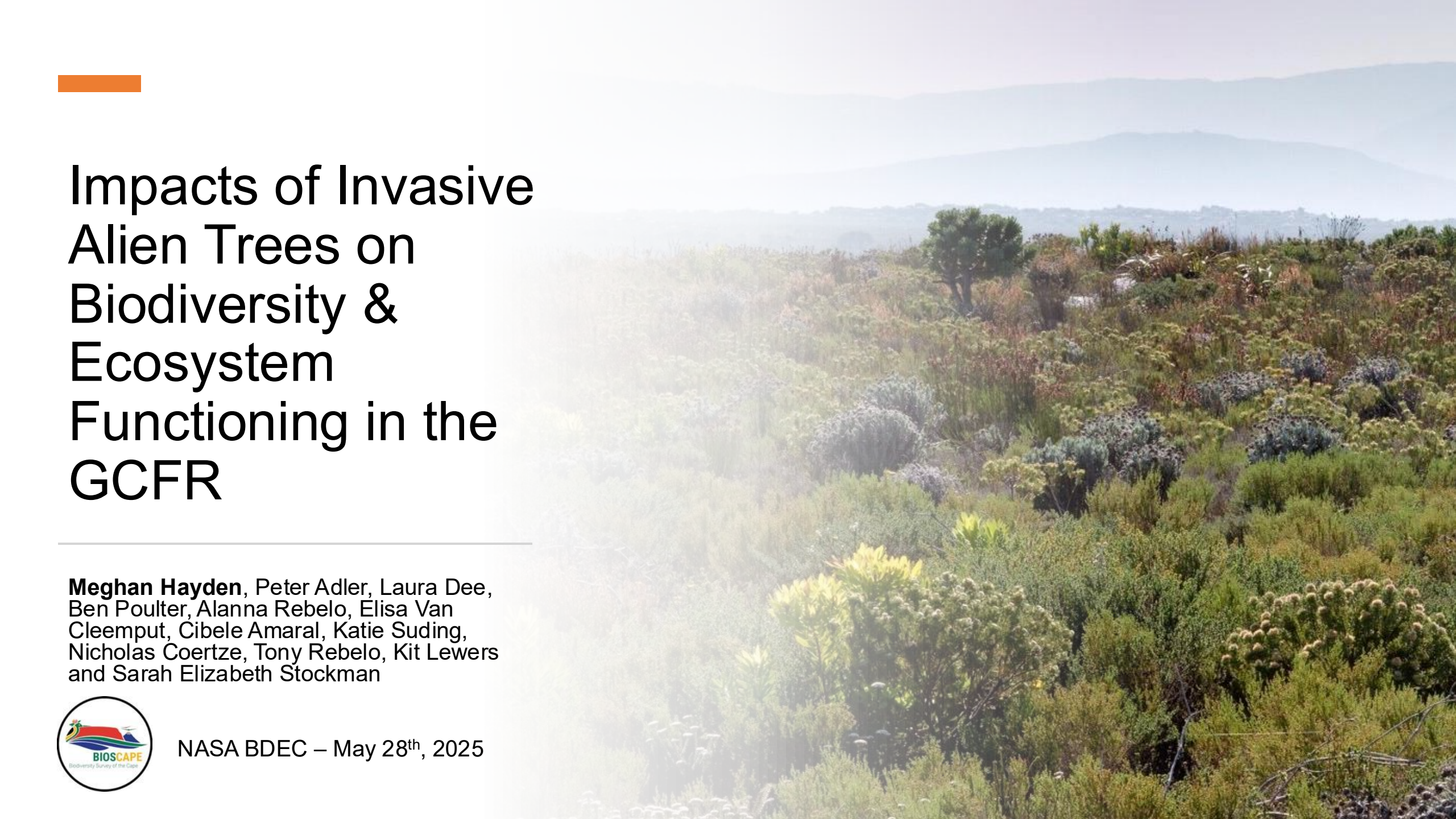
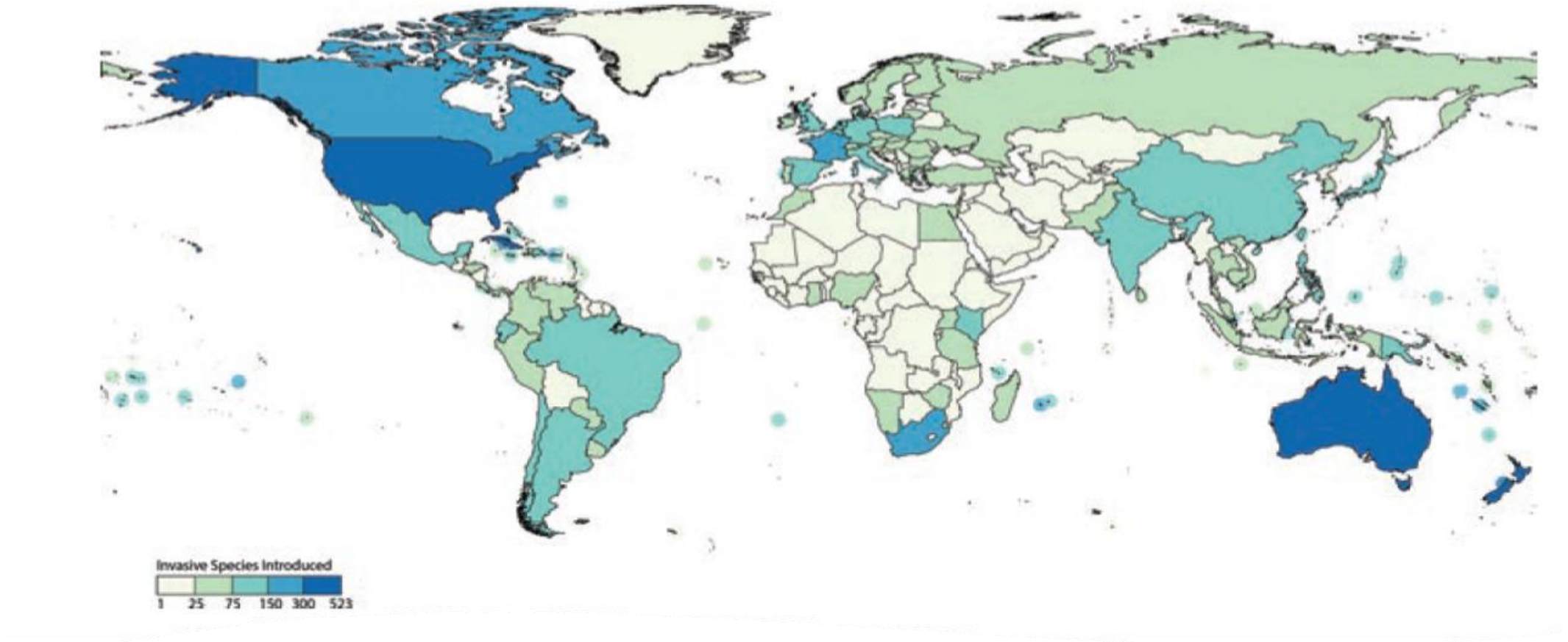
Impacts of Invasive Alien Trees on Biodiversity & Ecosystem Functioning in the GCFR

Meghan Hayden, Peter Adler, Laura Dee, Ben Poulter, Alanna Rebelo, Elisa Van Cleemput, Cibele Amaral, Katie Suding, Nicholas Coertze, Tony Rebelo, Kit Lewers and Sarah Elizabeth Stockman

NASA BDEC – May 28th, 2025



Invasive species as global change drivers

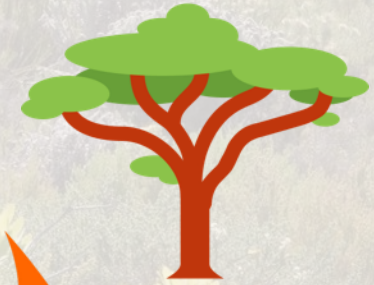


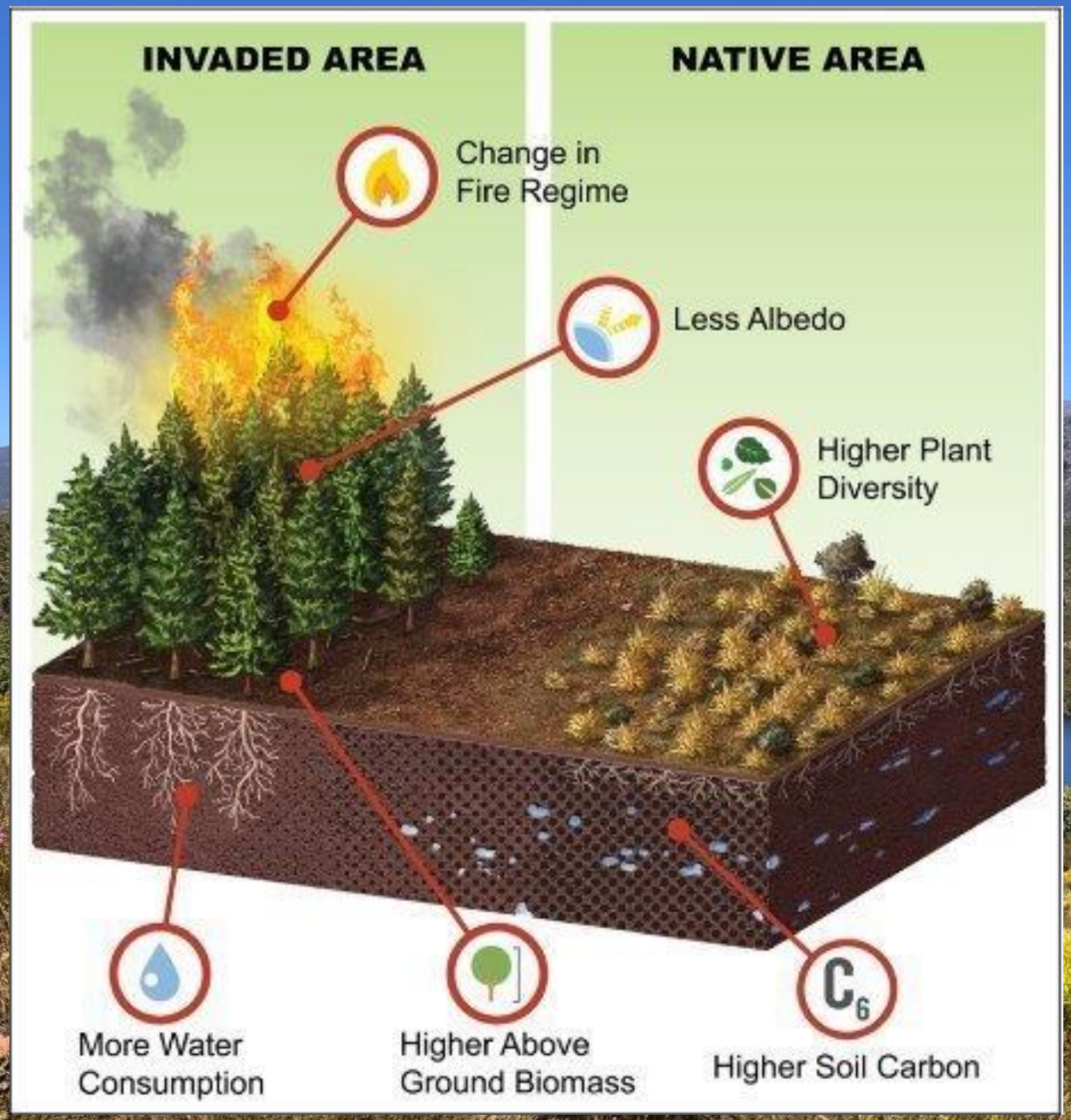
Turbelin et al., 2017

Cape Floristic Region

- Encompasses an **entire floral region** in just **90,000 km^2**.

- **9,000** plant **species**
  - **69%** are **endemic**





Nunez et al. 2021

Invasive Alien Trees (IATs)

Acacia spp.

Hakea spp.

Pinus spp.

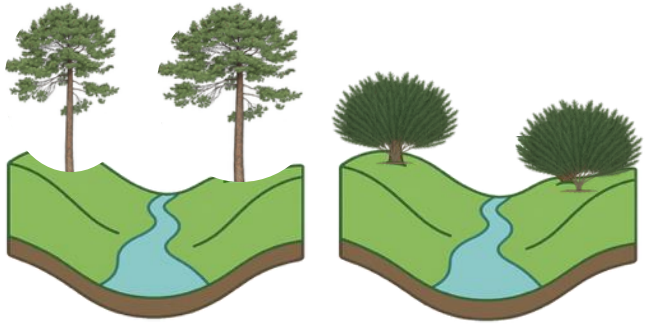
Eucalyptus spp.

Scaling invasion impacts with remote sensing & causal inference

P. pinaster *Fynbos*

Stand-level assessment of species' water use

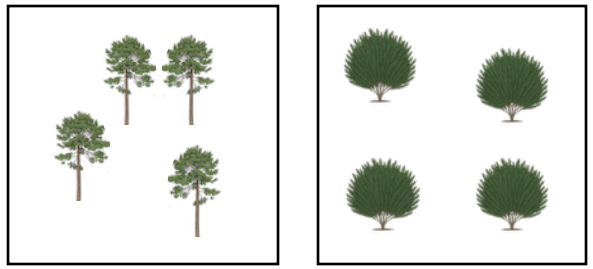
Dzikiti et al., 2014



Invaded vs uninvaded catchment

Impact of afforestation on water use in paired catchments

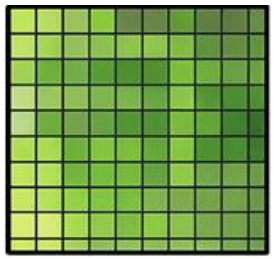
Everson et al., 2014



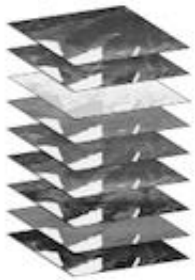
Invaded vs uninvaded pixel

Pixel-level assessment of species' water use

Meijninger & Jarmain, 2014



Invasion level



Environmental covariates

Spatial Extent

Our study: Impact of IAT on water use across a landscape

Our team and questions

1.What is the magnitude of the effect of **invasion** on **evapotranspiration**?

2. What is the magnitude of the effect of **invasion** on **canopy structure and diversity**?

3. How does the **direct effect** of invasion on ecosystem functioning compare to **indirect effects** via structure and diversity?

Our team and questions

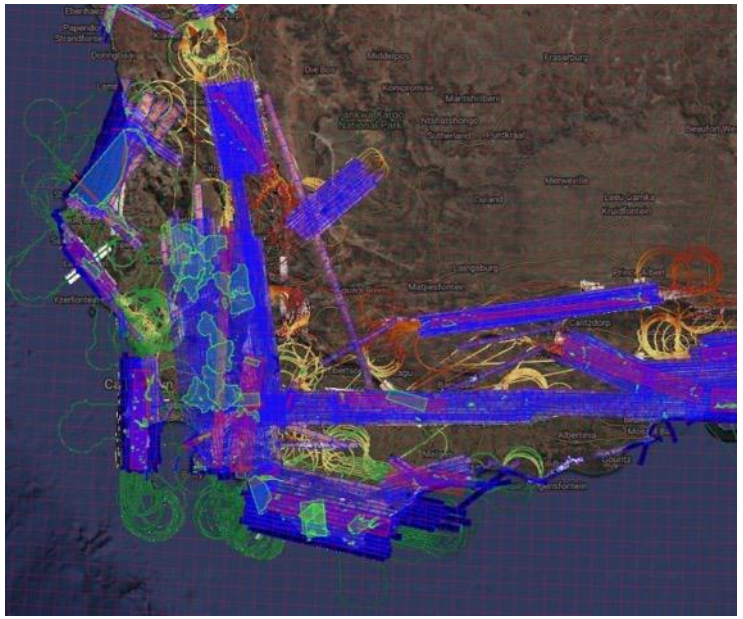
1.What is the magnitude of the effect of **invasion** on **evapotranspiration**?

2. What is the magnitude of the effect of **invasion** on **canopy structure and diversity**?

3. How does the **direct effect** of invasion on ecosystem functioning compare to **indirect effects** via structure and diversity?

Biodiversity **S**urvey of the **Cape**

NASA's first **biodiversity** field campaign incorporating airborne imaging spectroscopy, lidar, and field observations

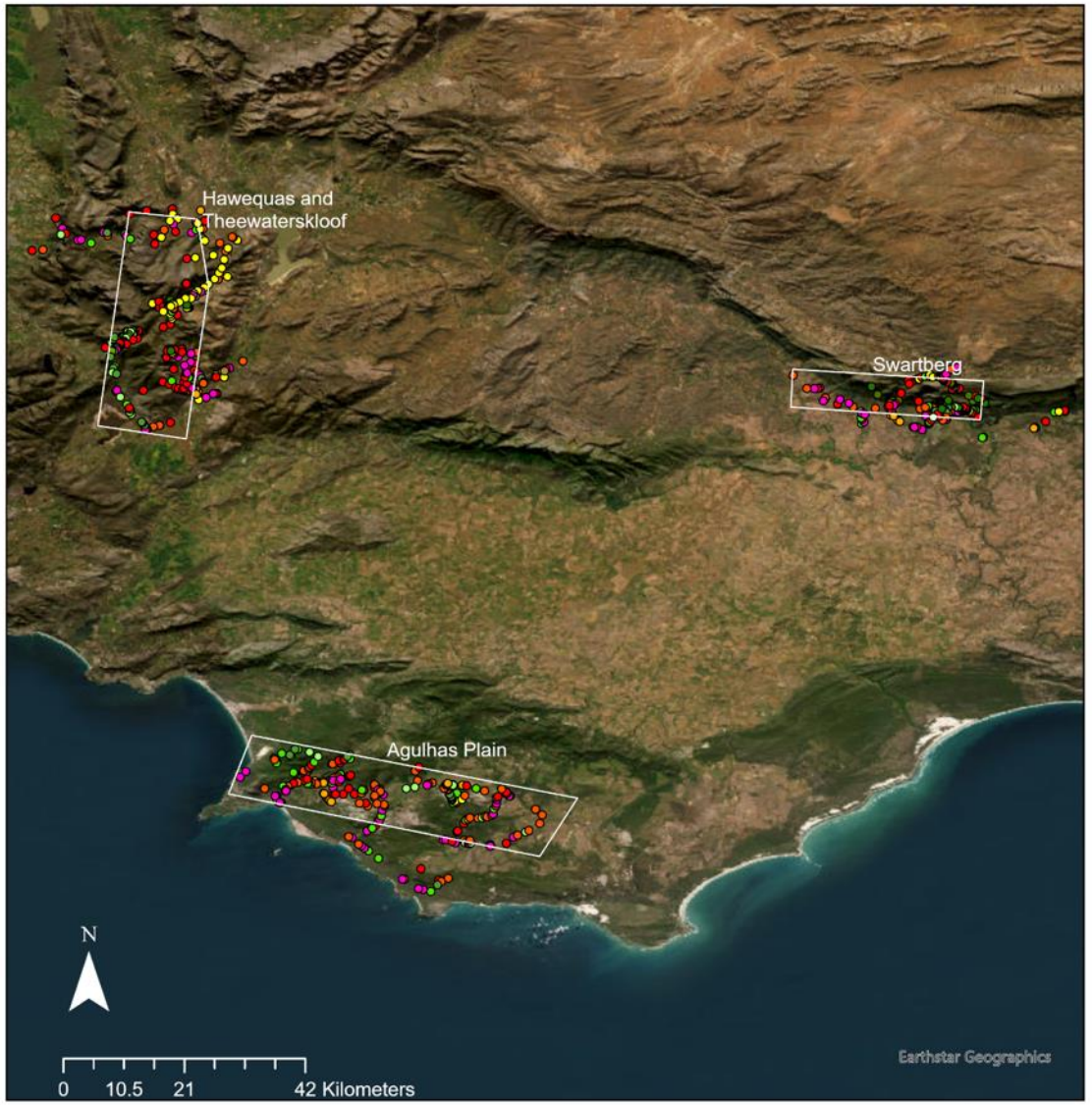


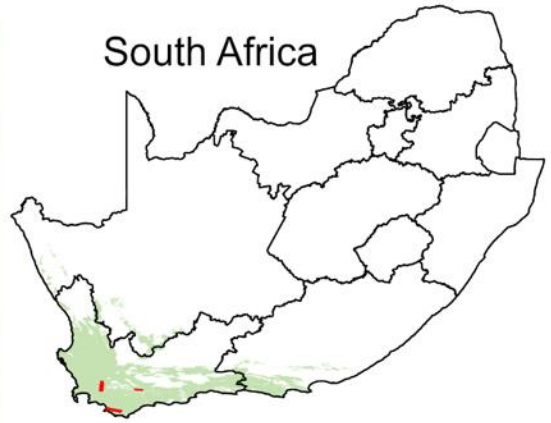
Bioscape.io

Our sites: Greater Cape Floristic Region

Dr. Alanna Rebelo and Nicholas Coertze

ARC • LNR

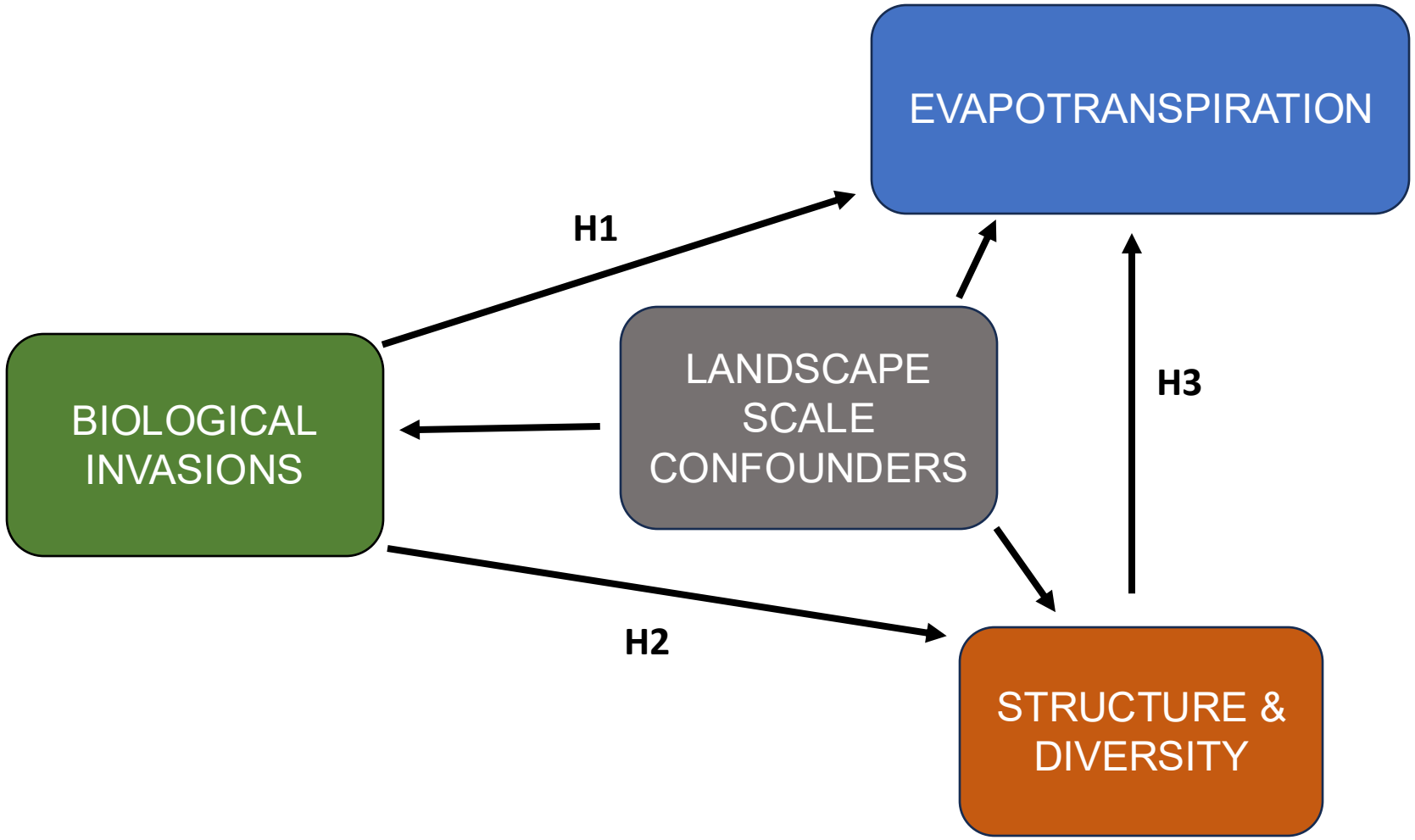




Key

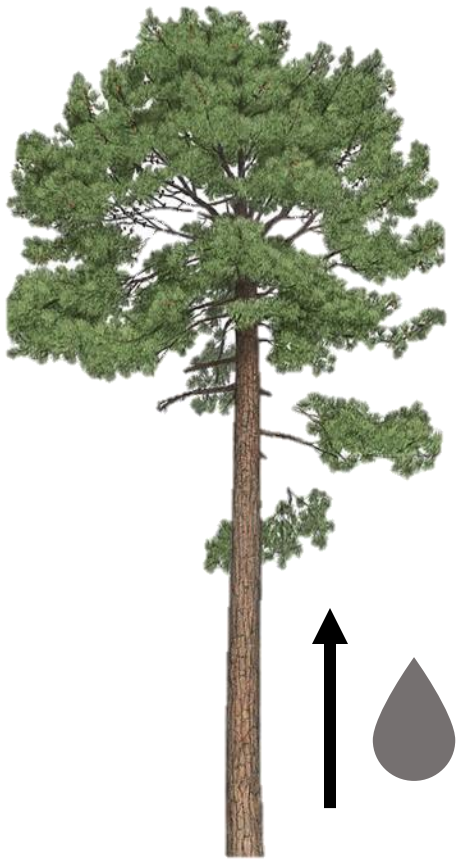
- Afromontane Forest
- Asteraceous Fynbos
- Australian Myrtle
- Bramble
- Bugweed
- Ericaceous Fynbos
- Grassy Fynbos
- Gum
- Hakea
- Other
- Pine
- Poplar
- Proteoid Fynbos
- Renosterveld
- Restioid Fynbos
- Scrub Fynbos
- Wattle

Hypotheses and steps

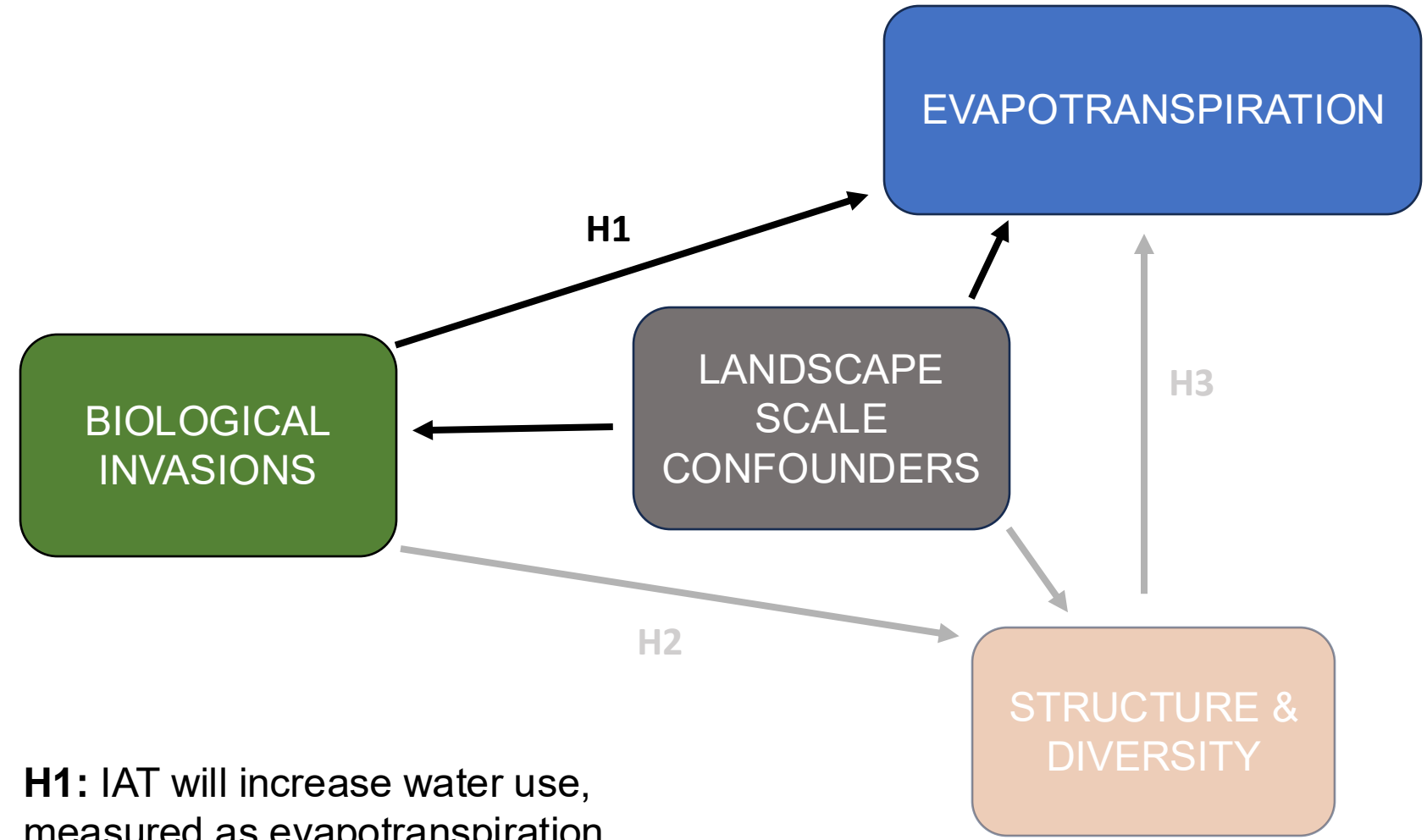


Hypotheses and steps

Pinus pinaster



H1: IAT will increase water use, measured as evapotranspiration.



Hypotheses and steps

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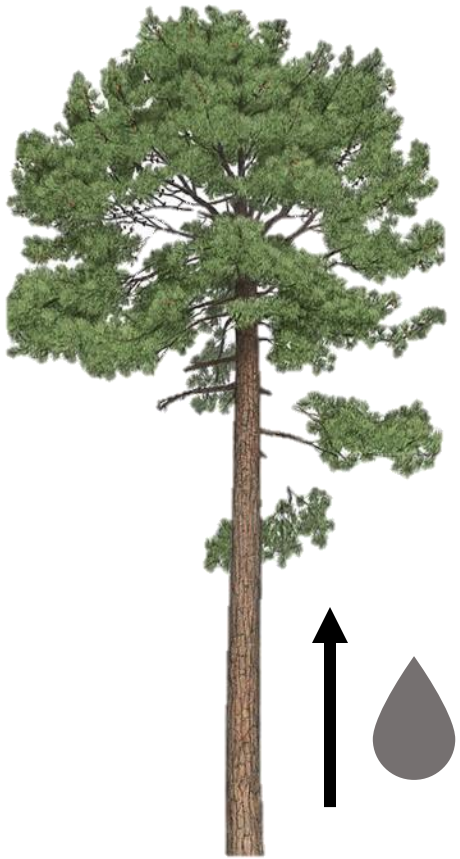
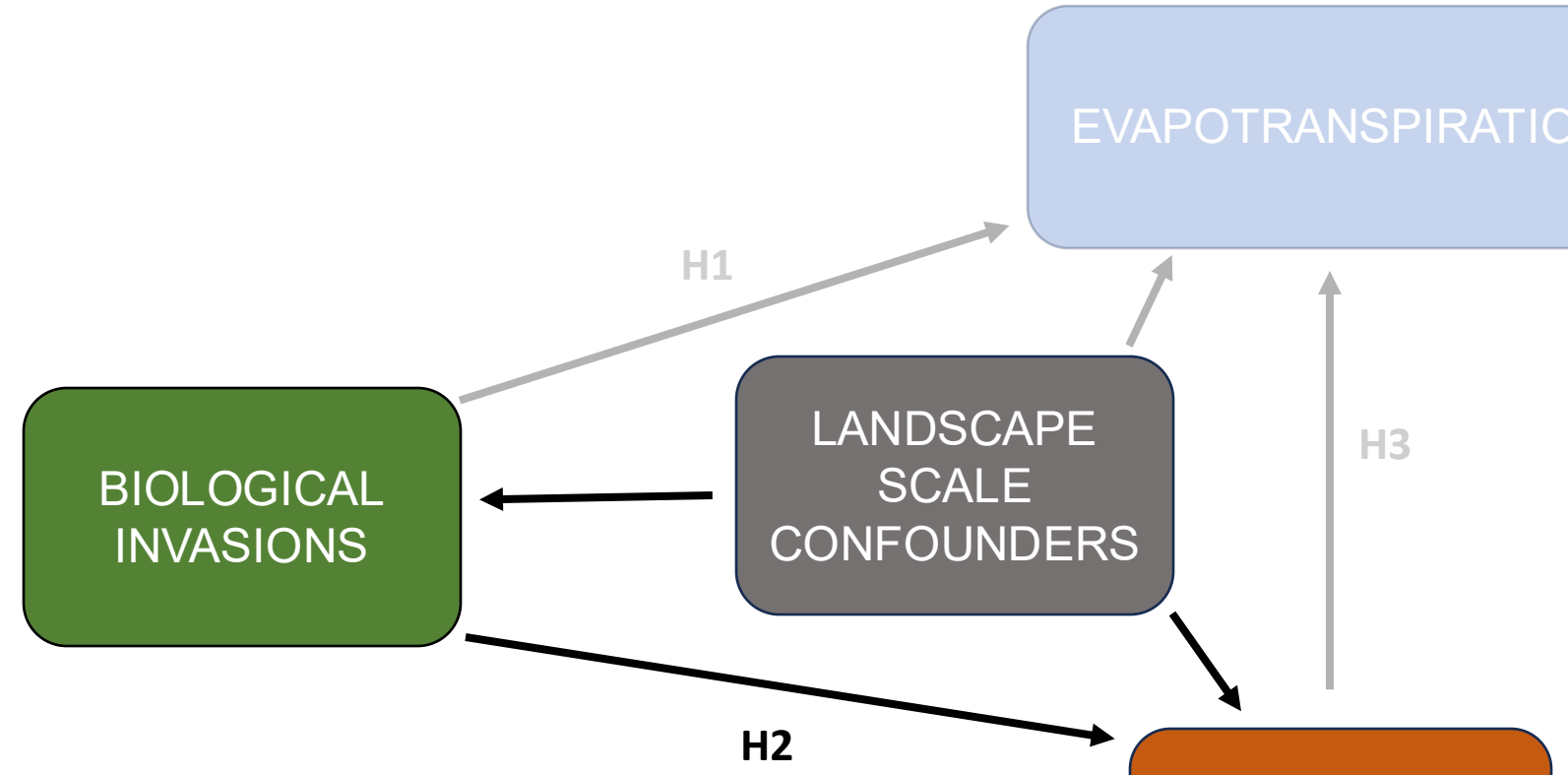
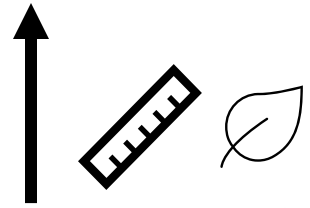
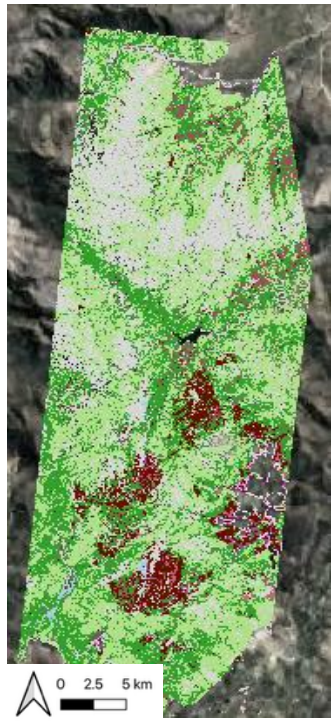




H2: IAT will increase the average height of the community and will increase diversity at low levels, but decrease diversity at high levels of invasion.



Mapping Biological Invasions



IAT

Native

Other

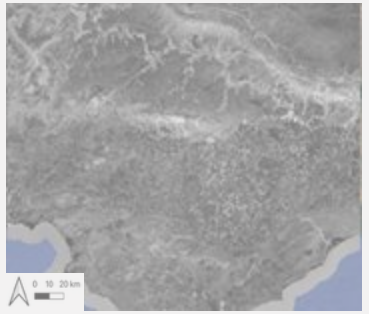
Classifier predictions (5 m) from AVIRIS-NG summarized as **percent IAT cover** at 100 by 100 m^2 region.

Fire history, climate, geology, soils, topography

BIOLOGICAL INVASIONS

LANDSCAPE SCALE CONFOUNDERS

EVAPOTRANSPIRATION

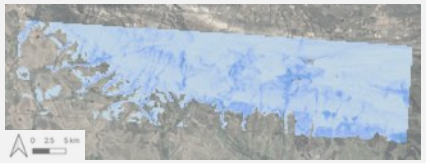


FAO's WaPOR **daily ET** at **100 by 100 m^2**

High

Low

STRUCTURE & DIVERSITY



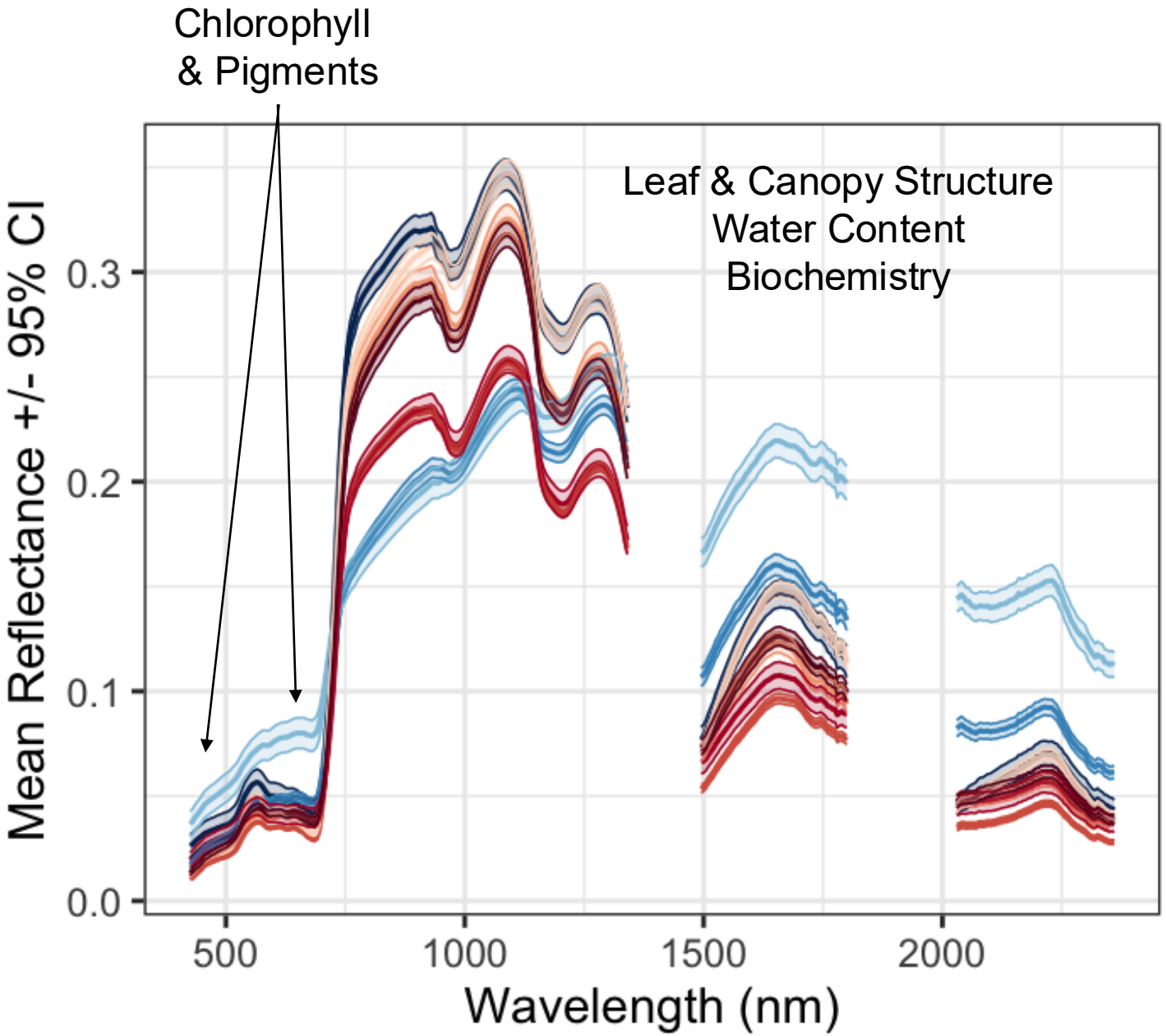
High

Low

Average **canopy height** derived from LVIS RH98.

Low High

Spectral alpha, beta and gamma diversity derived from AVIRIS-NG.



Taxa

- Afromontane Forest
- Gum
- Hakea
- High Density Fynbos
- Low Density Fynbos
- Other IAP
- Pine
- Wattle

Acacia spp.

Hakea spp.

Pinus spp.

Eucalyptus spp.

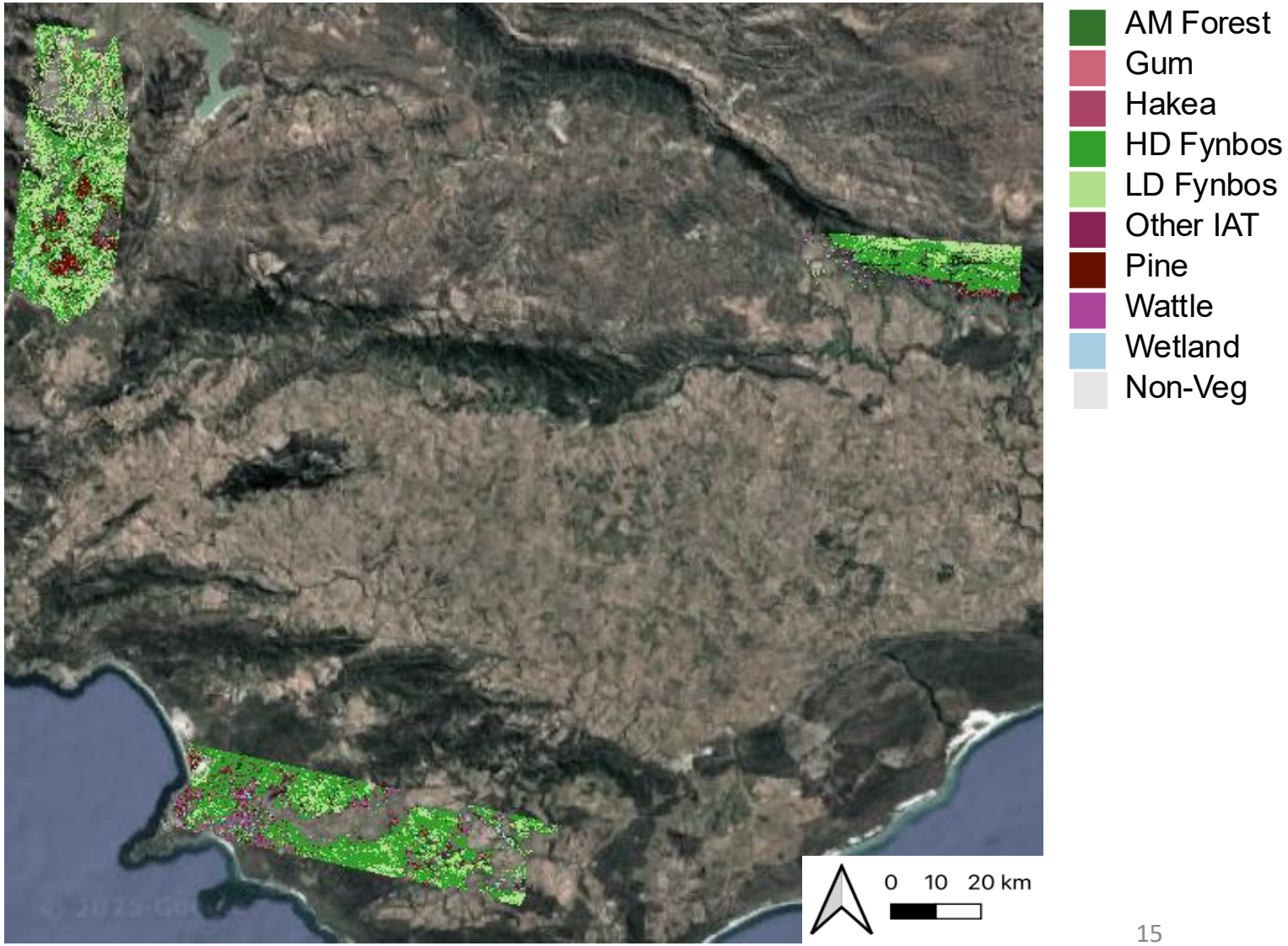
Mapping Biological Invasions

Random forest classifier trained on **5100 survey points** across the landscape.

Overall accuracy: **0.9125**
(*95% CI: 0.9101, 0.9148*)

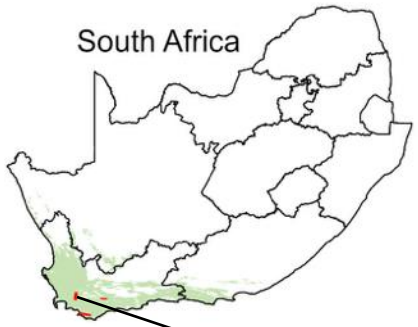
Intra-IAT accuracy: **0.9196**
(*95% CI: 0.9162, 0.9230*)

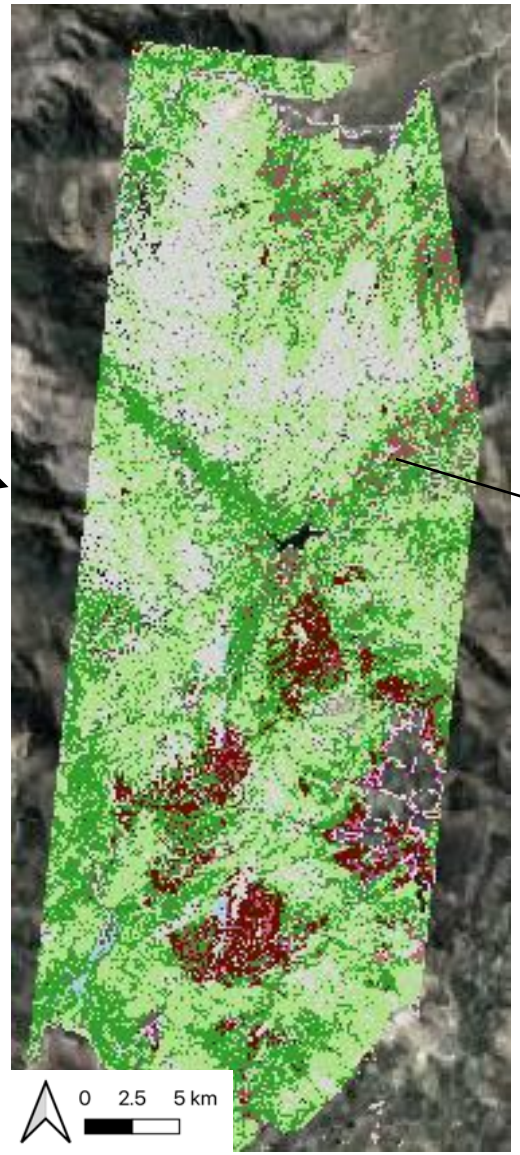
IAT/**Native** accuracy: **0.9691**
(*95% CI: 0.9678, 0.9705*)



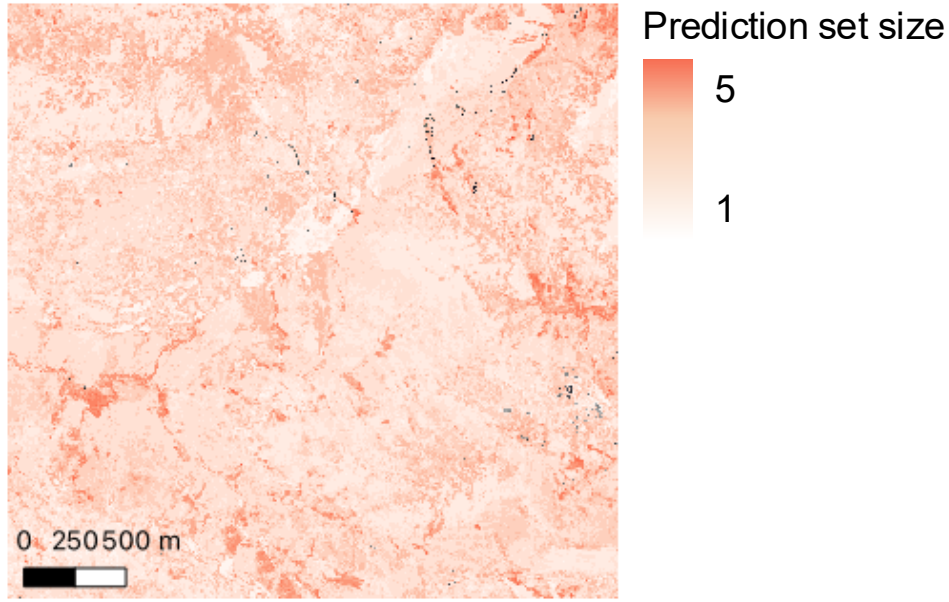
Hayden et al., in prep

Mapping Biological Invasions

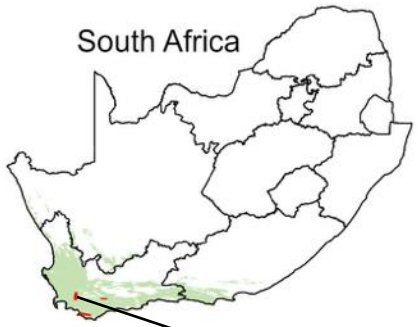


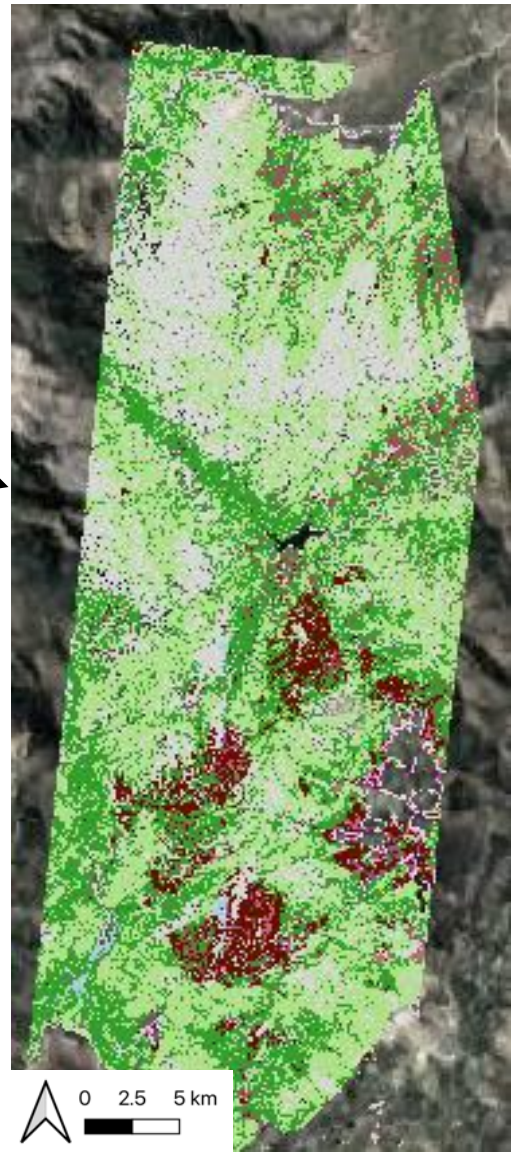


Using **conformal predictions** to generate prediction sets for each pixel allows us to test our hypotheses for multiple map realizations and assess robustness to classifier uncertainty.

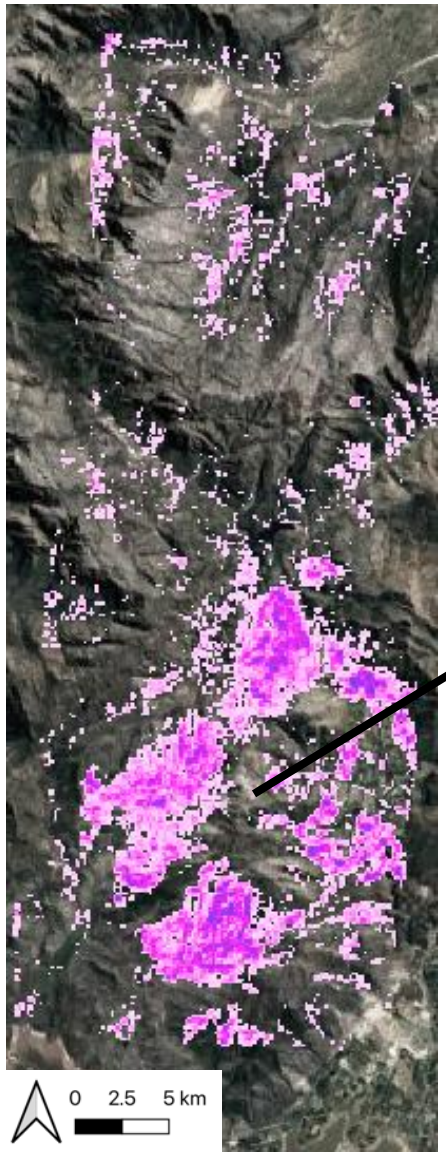


Mapping Biological Invasions



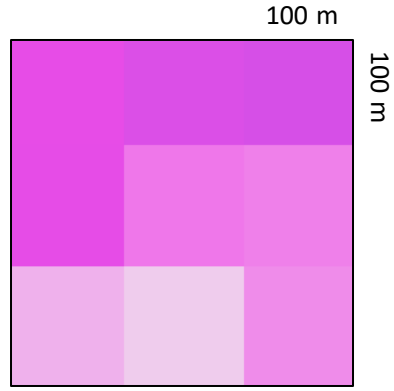


AM Forest
Gum
Hakea
HD Fynbos
LD Fynbos
Other IAT
Pine
Wattle
Wetland
Non-Veg



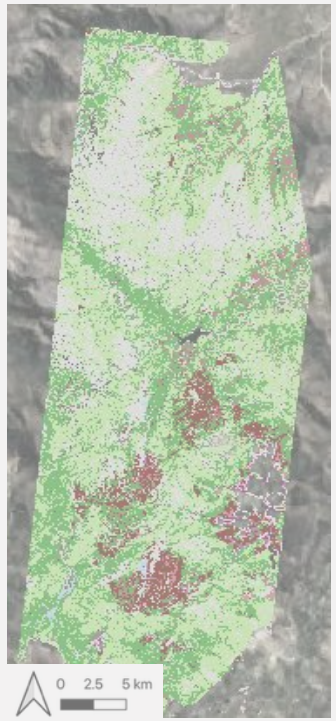
High
Low
% cover
Pinus spp.

~38,000 100 by 100 m² regions after excluding regions with <90% valid pixels (from n = 81,000).



For each region, summarized as uninvaded (< 1% cover IAT) or low, medium and high invasion.

Evapotranspiration



Classifier predictions (5 m) from AVIRIS-NG summarized as **percent IAT cover** at 100 by 100 m^2 region.

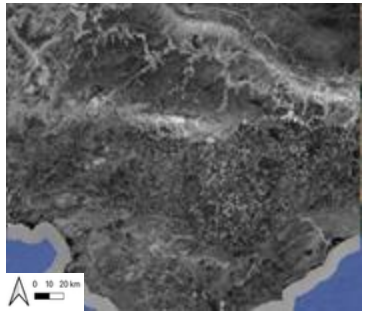
Fire history, climate, geology, soils, topography

BIOLOGICAL INVASIONS

LANDSCAPE SCALE CONFOUNDERS

EVAPOTRANSPIRATION

STRUCTURE & DIVERSITY



FAO's WaPOR **daily ET** at **100 by 100 m^2**

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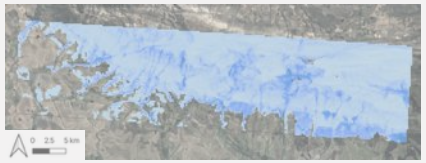
Low



High

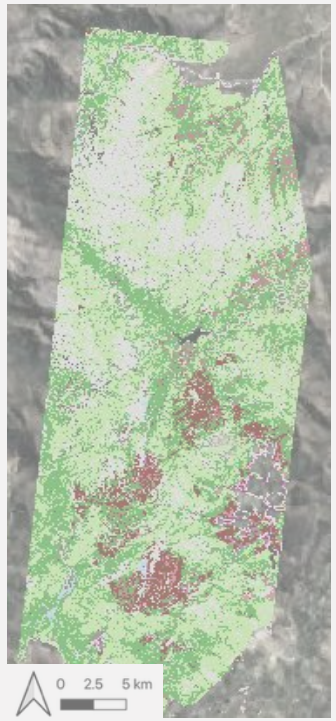
Low

Average **canopy height** derived from LVIS RH98.

Low High

Spectral alpha, beta and gamma diversity derived from AVIRIS-NG.

Canopy Structure & Diversity



IAT

Native

Other

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Fire history, climate, geology, soils, topography

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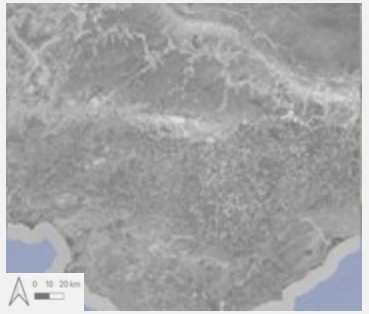

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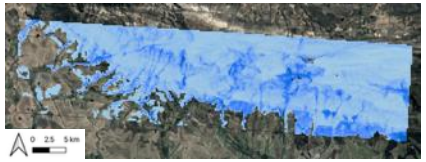

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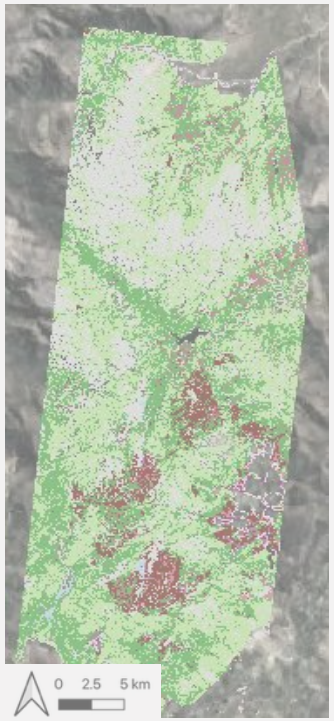
Spectral alpha, beta and gamma diversity derived from AVIRIS-NG.

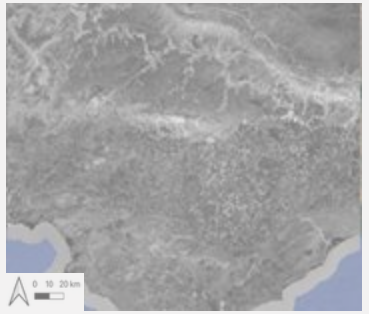
Landscape-level confounders



Classifier predictions (5 m) from AVIRIS-NG summarized as **percent IAT cover** at 100 by 100 m^2 region.

Fire history, climate, geology, soils, topography

EVAPOTRANSPIRATION



FAO's WaPOR **daily ET** at **100 by 100 m^2**

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BIOLOGICAL INVASIONS

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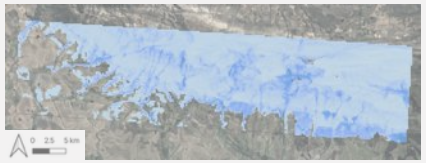


High

Low

Average **canopy height** derived from LVIS RH98.

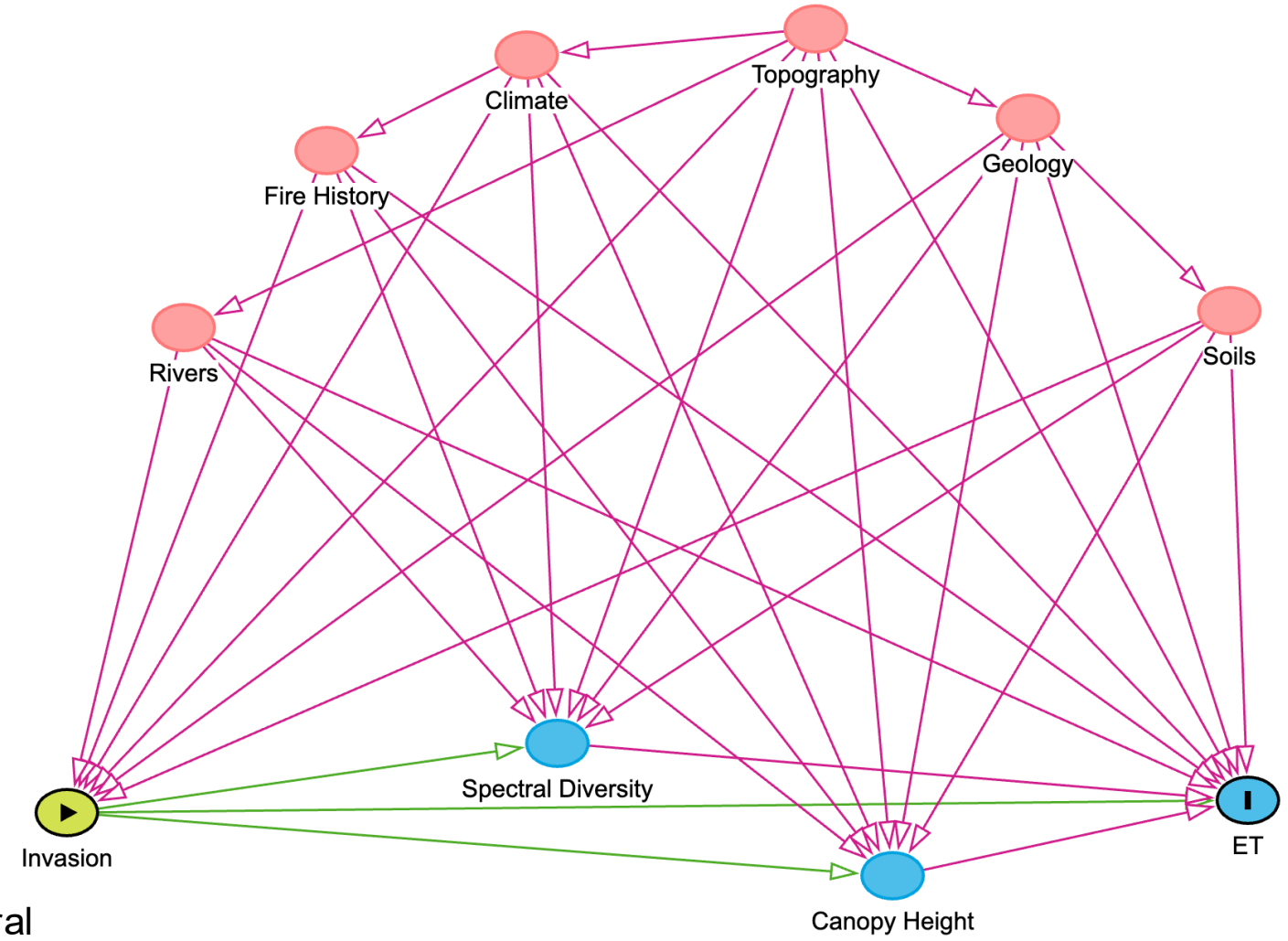
Low High

Spectral alpha, beta and gamma diversity derived from AVIRIS-NG.

Expert-developed and elicited causal diagram

Dr. Anthony Rebelo
South African National Biodiversity Institute

Dr. Alanna Rebelo
South African Agricultural Research Institute

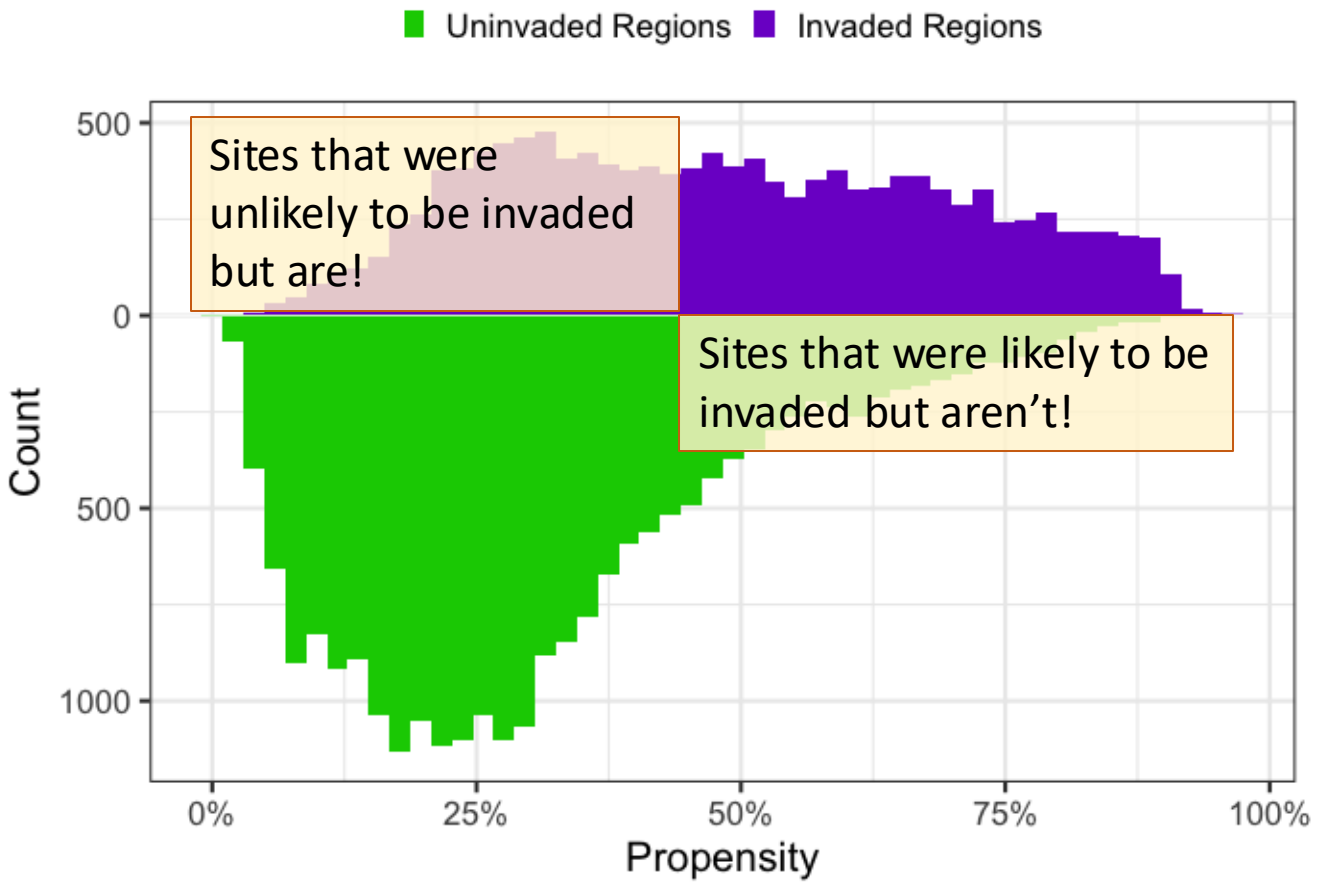


Climate: Mean annual temperature and precipitation, Minimum and maximum temperature and precipitation, Temperature range, Temperature and precipitation seasonality

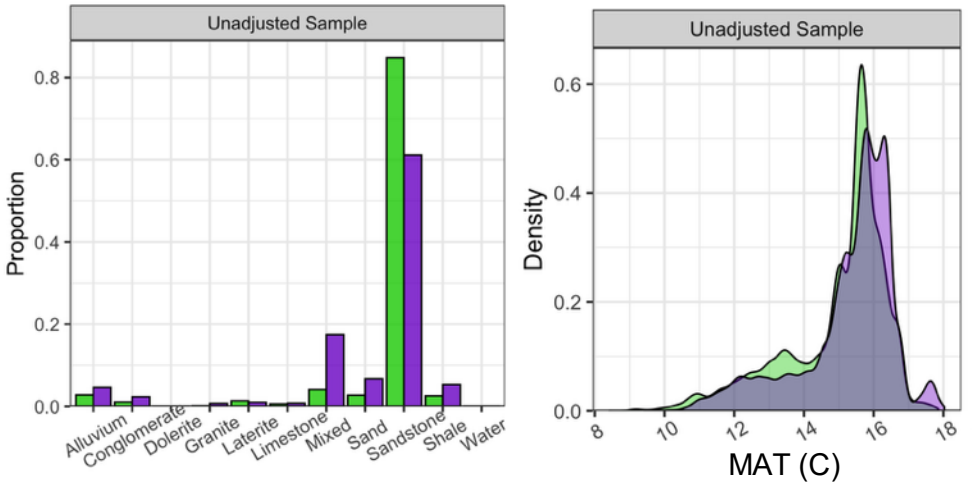
Topography: Elevation, Aspect, Landform

Soils: pH, N, P, K

Inverse Probability Weighting

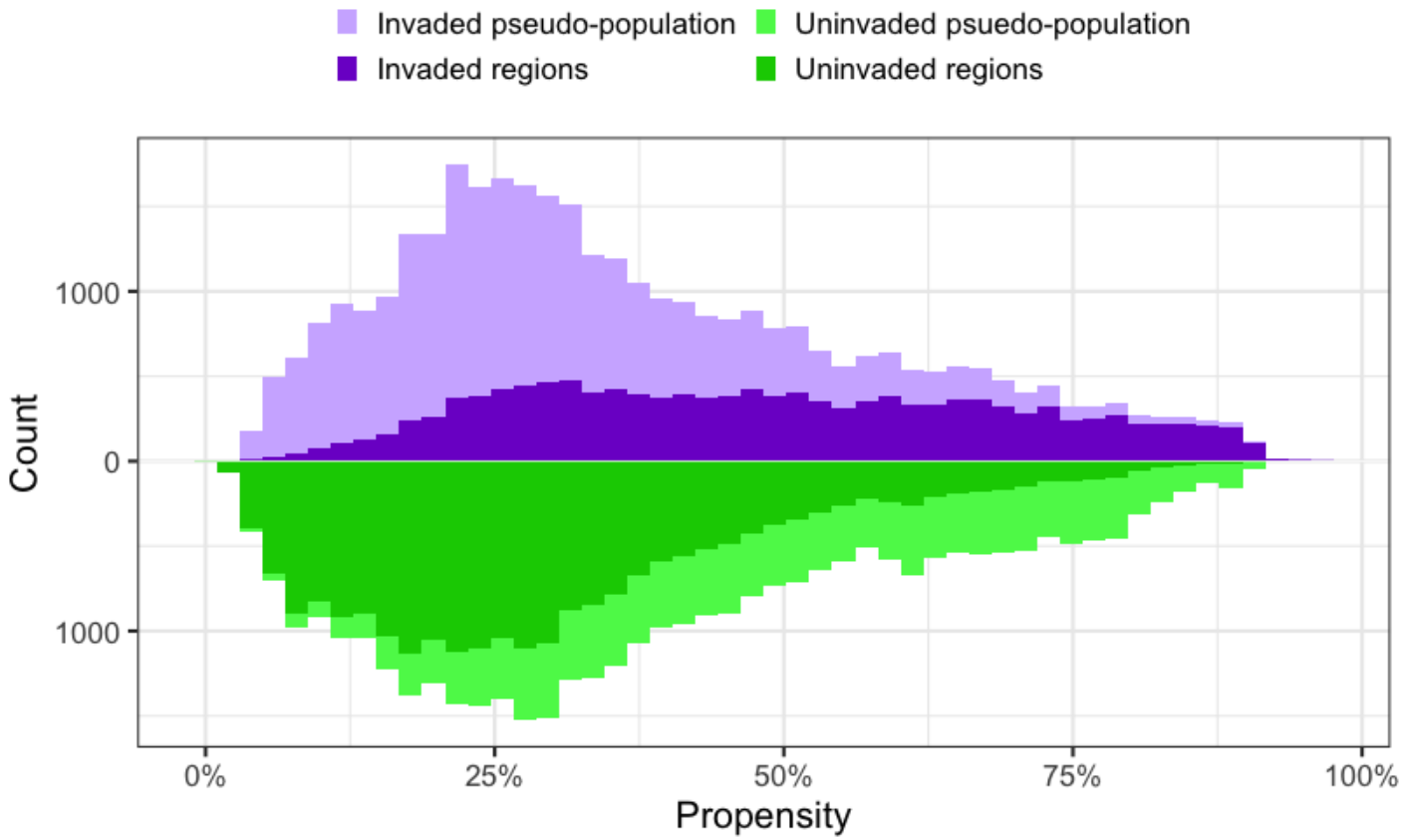


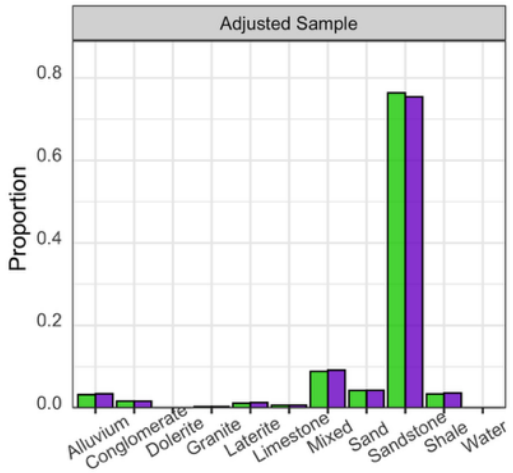
Example of selection bias →

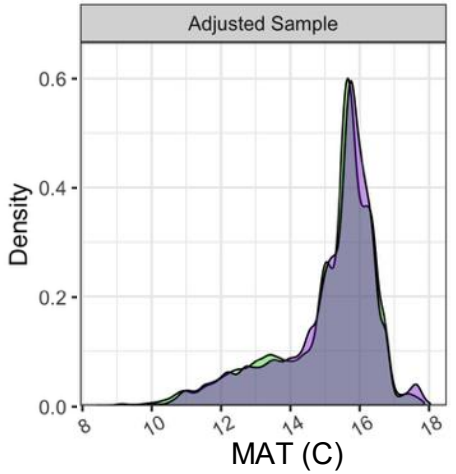


$$\text{Propensity} = \Pr(T_i=1|X_i)$$

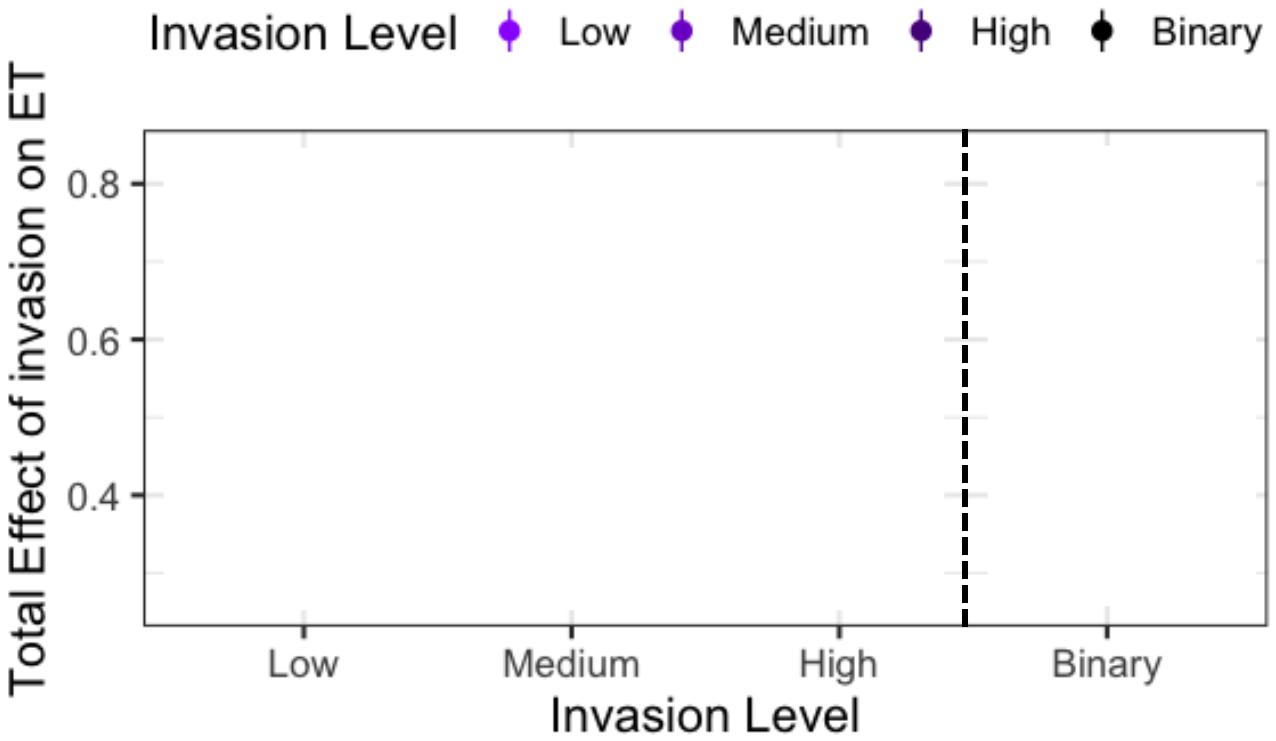
Inverse Probability Weighting







Results: IAT → ET

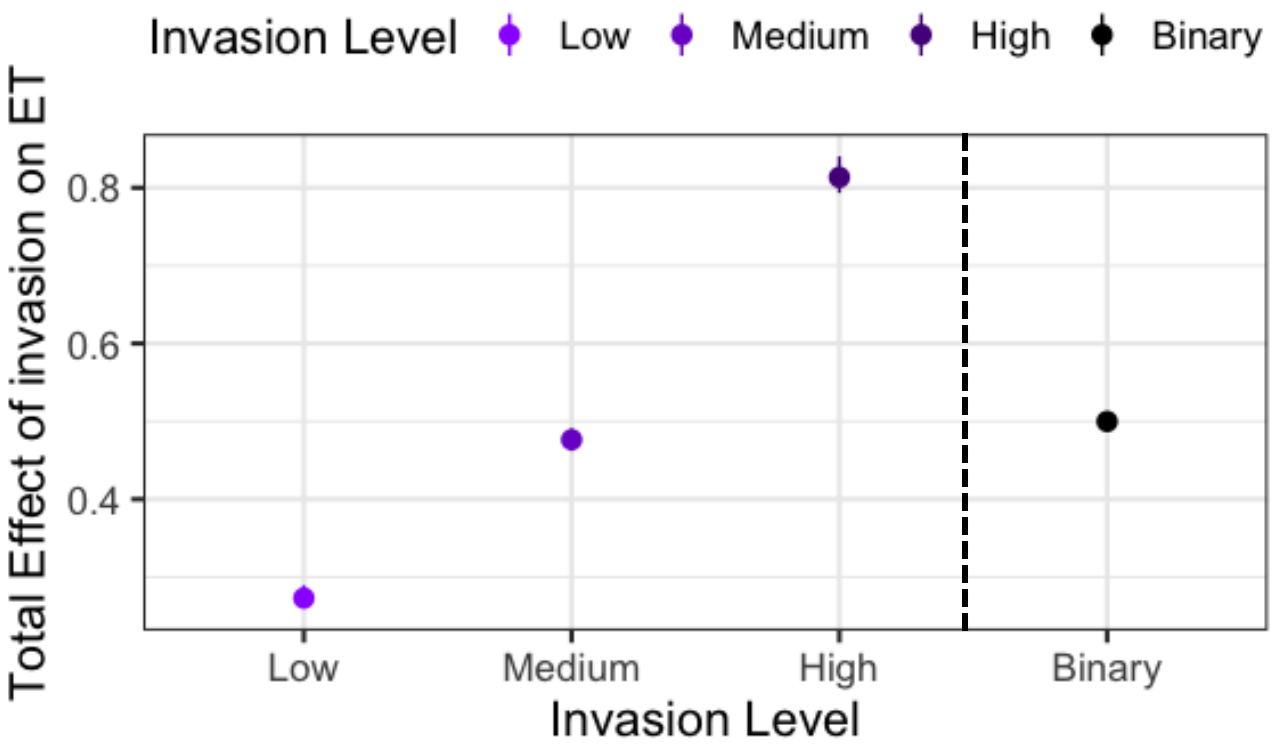


In the Fynbos biome, invasion increases ET by an average of 0.51 mm/day (**18% increase**), as low as 0.27 mm/day (**10% increase**) at low densities of IAT and up to 0.81 mm/day (**28% increase**) at high densities of IATs.

Average increase is comparable to small scale studies (e.g., IAT increase ET by ~200 mm/year; 13% increase), but we demonstrate variability with density of invasion.

Hayden et al, in prep.

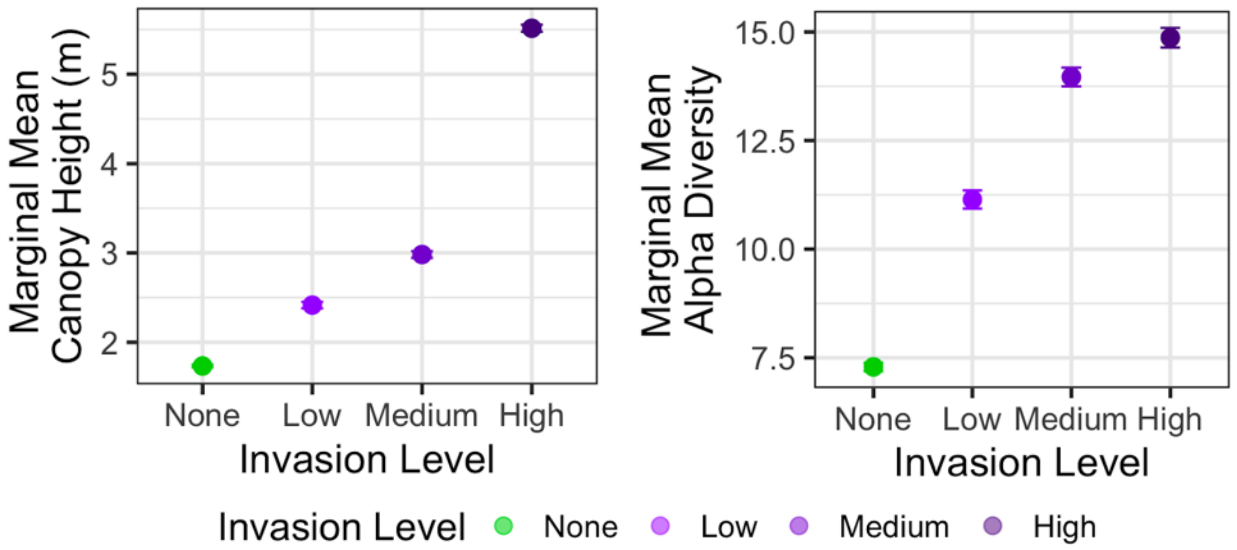
Results: IAT → ET



Tested sensitivity to unobserved confounders, robustness to model specification, spatial autocorrelation and classifier uncertainty (conformal predictions).

Hayden et al, in prep.

Results: IAT → Composition & Structure



In the Fynbos biome, invasion increases canopy height by an average of 1.73 m (**85% increase**), and up to 3.16 m (**200% increase**) at high densities of IATs.

Invasion also increases alpha, beta and gamma spectral diversity. Invasion increases alpha diversity by an average of 3.55 (**87% increase**), gamma diversity by an average of 6.21 (83% increase), and beta diversity by an average of 2.88 (78% increase).

Hayden et al, in prep.

Summary

We demonstrate how to combine remotely sensed data with approaches for causal inference, finding:

1. Invasion increases ET across the landscape by an average of 18%, but there is a three-fold difference in impacts between low- and high-density invasions.
2. Invasion alters canopy structure and diversity. Some of the effect of IAT on ET is through these indirect pathways.
3. Effects of invasion diverge when considering invaded Afromontane Forest and Wetland ecosystems.

Thank you!

Questions?

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