Stable isotopes as early indicators of high impact after plant invasion: A remote sensing perspective

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Structure of the talk

• Introduction
  • Model invader and model system

• Scales and indicators
  • Leaf & Canopy: Trait dissimilarity
  • Stand: Spatial impact on N-cycle
  • Landscape: Invasion syndrome

Mediterranean dune ecosystem in SW Portugal, NATURA2000 site Comporta/Galé
Model invader *Acacia longifolia*, Sydney Golden Wattle

Main characteristics of the invader

- Fabaceae native to SE Australia
- Tall shrub or tree
- Introduced to stabilise dunes
- Impacts on nutrient cycling and biodiversity
Model invader *Acacia longifolia*, Sydney Golden Wattle

Alien range (Global invasive species database GISD)

**GLOBAL INVASIVE SPECIES DATABASE**

- Argentina
- Brazil
- Dominican Republic
- Indonesia
- Italy
- Mauritius
- New Zealand
- Reunion
- Spain
- United States

- Australia
- Colombia
- India
- Israel
- Kenya
- Myanmar
- Portugal
- South Africa
- Sri Lanka
- Uruguay

Mediterranean dune ecosystem in SW Portugal, NATURA2000 site Comporta/Galé

**Introduction**

Leaf & Canopy: Traits

Stand: Spatial Impact

Landscape: Invasion Syndrome
Stable isotopes as early indicators of high invader impact: Remote sensing perspective

Model invader Acacia longifolia

Impact of Acacia on N cycling

- Foliar N and $\delta^{15}N$ of the native shrub increases with vicinity to the N-fixing invader
- For mapping, topographic effects need to be considered

**Invasive Acacia**
- $N_{\text{max}}$: ~3%
- $\delta^{15}N_{\text{max}}$: 0

**Native Corema**
- $N_{\text{max}}$: ~0.5%
- $\delta^{15}N_{\text{min}}$: -12

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Model invader *Acacia longifolia*

Impact of *Acacia* on water cycling

Rascher et al. (2011) Understory invasion by *Acacia longifolia* alters the water balance and carbon gain of a mediterranean pine forest. Ecosystems.
Model invader *Acacia longifolia*

Research gap

- Nutrient poor system
- Sparse cover
- Adaption to drought

- \(N_2\) fixing invader
- Dense thicket
- Water spending
Concept „Trait dissimilarity“

- Leaf and litter nitrogen (N) content, C:N ratio to assess invasive species’ impacts on N cycling
- Trait dissimilarities were better predictors than the trait values of invasive species alone
- Magnitude of impact increases with dissimilarity.

Lee et al. (2017) Invasive species’ leaf traits and dissimilarity from natives shape their impact on nitrogen cycling: a meta-analysis. New Phytologist.
Research Question

- Are *Acacia longifolia*‘s leaf traits dissimilar from native species’ traits?

Spectral signatures of selected species at canopy level

Große-Stoltenberg et al. (2016) Evaluation of continuous VNIR-SWIR spectra versus narrowband hyperspectral indices to discriminate the invasive Acacia ... . Remote Sensing.
Methods
Species, functional groups, biochemical leaf traits, field spectra

• 18 species including *Acacia longifolia*
• 8 leaf traits together with leaf and canopy hyperspectral data (n = 162-218)

-- Leaf biochemical traits
  • Carbon (C)
  • $\delta^{13}C$ (water use efficiency)
  • Nitrogen (N)
  • $\delta^{15}N$ (identification of N source)
  • Tannin (defense, decomposition)
  • Leaf Fibres (NDF, ADF, ADL, decomposition)

Results: PCA of leaf traits

- Leaf biochemical traits
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Results: PCA of leaf traits


Introduction  Leaf&Canopy: Traits  Stand: Spatial Impact  Landscape: Invasion Syndrome
Results: Prediction of traits based on spectral data

- $R^2$ slightly higher at leaf than at canopy level
- $R^2$ varies across leaf traits
- $R^2$ relatively high for $\delta^{13}C$, but relatively low for $\delta^{15}N$

Results: Prediction of traits based on spectral data

• Even though $R^2$ ranges between 0.2 and 0.8, *Acacia longifolia*’s position in the trait space can be predicted accurately using hyperspectral data at both leaf and canopy level.

Results: Prediction of traits based on spectral data

- There is potential nitrogen isotopic signatures from fresh leaf reflectance spectra.

Hellmann et al. (2015) Retrieving nitrogen isotopic signatures from fresh leaf reflectance spectra: disentangling $\delta^{15}$N from biochemical and structural leaf properties. Front Plant Sci
Conclusion

Acacia longifolia is dissimilar from native species of the same growth form particular regarding leaf N content and including both $\delta^{13}$C and $\delta^{15}$N.

This dissimilarity can be predicted using spectral data which indicates potential for mapping.
Concept „Isoscapes“

• Isotope + landscape: spatially explicit prediction of isotope ratios

• N\textsubscript{2}-fixing species typically have greater foliar N content and δ\textsuperscript{15}N signatures closer to the atmospheric value (0) than non-fixing plant species (=> origin of plant nitrogen (e.g. atmospherically derived ver. soil derived))

Research question „Isoscapes“

- Can *Acacia longifolia*’s impact on N cycling be mapped using a functional tracer?

Hellmann et al. (2017) Heterogeneous environments shape invader impacts: integrating environmental, structural and functional effects by isoscapes and remote sensing
Stable isotopes as early indicators of high invader impact: Remote sensing perspective

Methods
Native *Corema album* transects surrounding *Acacia longifolia*

- Data for 5 sites (one site shown here)
  - Map of the N-fixing *A. longifolia*
  - Transects of the native, non-fixing *Corema album*
  - Foliar $\delta^{15}N$ of *C. album* as a functional tracer of *Acacia* N-fixation
  - LiDAR data on topography and vegetation structure (environmental heterogeneity)

Hellmann et al. (2017) Heterogeneous environments shape invader impacts: integrating environmental, structural ... Scientific Reports.
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Methods
Spatial predictors derived from airborne LiDAR
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- Position of the native shrub relative to the invader
- Landform (e.g. ridge, plain, valley)
- Topographic Wetness Index (related to slope)
- Vegetation cover
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Digital Elevation Model (DEM)
Results

Impact of *A. longifolia* and topography on $\delta^{15}N$

- Important predictors (GAMM)
  - Distance to *Acacia longifolia*
  - Landform, Position relative to *A. longifolia*, Vegetation cover, Topographical Wetness Index (LiDAR)

- Model quality ($\delta^{15}N$ map)
  - Median $R^2$: 0.6; Median RMSE: 1.82‰

- Main finding
  - $^{15}N$ enrichment by *Acacia* being evident in a range of approximately 5–8 m from the canopy

Hellmann et al. (2017) Heterogeneous environments shape invader impacts. Scientific Reports.
Results

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Isoscapes linked with remote sensing can be applied to map invader impact on N cycling. They can serve as an early indicator for high impact.
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Concept „Invasion syndromes“

• Typical recurrent associations of species biology and invasion dynamics with particular invasion contexts such as invaded habitat.¹

• Sites with relatively low resource abundance and low diversity should be vulnerable to invasion by species with niche construction ability.²


Research question

How can *Acacia longifolia*’s impact on ecosystem structure and functioning be mapped at the landscape scale?

Große-Stoltenberg et al. (2018) Early detection of GPP-related regime shifts after plant invasion by integrating imaging spectroscopy with airborne LiDAR. Rem Sens Env.
Approach: Mapping the invader

- Airborne hyperspectral and LiDAR data (2m)
- 119 vegetation indices and 71 LiDAR derivatives
- Random Forest with Recursive Feature Elimination (15 VIs, 1 LiDAR derivative)
- Model accuracy: Sensitivity 0.79; PPV 0.81

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Große-Stoltenberg et al. (2018) Early detection of GPP-related regime shifts ... RSE
Approach: Estimation of productivity

- Near-Infrared Vegetation Index (NIRV) (Badgley et al. 2017)
- New vegetation index that relates to productivity (Gross Primary Production (GPP))
- Valid across ecosystems and vegetation types even if vegetation cover is low
- calibrated against multi-year monthly averages of eddy-covariance data from 105 FLUXNET sites
- \[ N_{IRV} = NDVI \times N_T; \quad NDVI = (R_{800} - R_{680}) / (R_{800} + R_{680}); \quad N_T : \text{NIR reflectance} \]

Results: Map of *Acacia longifolia* and NIR\textsubscript{v} index (productivity)

Große-Stoltenberg et al. (2018) Early detection of GPP-related regime shifts after plant invasion by integrating imaging spectroscopy with airborne LiDAR. Rem Sens Env.
Results: Cover *Acacia longifolia*, NIR\textsubscript{v} index, and GPP

- Productivity (NIR\textsubscript{v}-based GPP) increases with invader cover.
- *Acacia longifolia*, an invader with niche construction ability that changes both nitrogen and water cycling, induces a regime shift from dune to forest type ecosystem.

Große-Stoltenberg et al. (2018) Early detection of GPP-related regime shifts after plant invasion by integrating imaging spectroscopy with airborne LiDAR. Rem Sens Env.
Invader induced modifications of productivity (GPP) can be mapped even at early stages of invasion.

The NIRV index could be a remote sensing “model metric” to track this typical invasion pattern (“syndrome”).
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Acknowledgements
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- Christine Hellmann (University Freiburg)
- Jan Thiele (Thünen Institute)
- Jens Oldeland (University Hamburg)
- Christiane Werner (University Freiburg)
- And all the student helpers!!!
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Literature

- Hellmann C.; Große-Stoltenberg A.; Thiele J.; Oldeland J.; Werner C. (2017): Heterogeneous environments shape invader impacts: integrating environmental, structural and functional effects by isoscapes and remote sensing. Scientific Reports 7: 4118. doi:10.1038/s41598-017-04480-4