ADAPT FOR GRAZING
Grazing4AgroEcology
CLIMATE FARM DEMO

# Aridity thresholds; a challenge to resilience in the most arid lands.

**Miguel Berdugo**
Universidad Complutense de Madrid

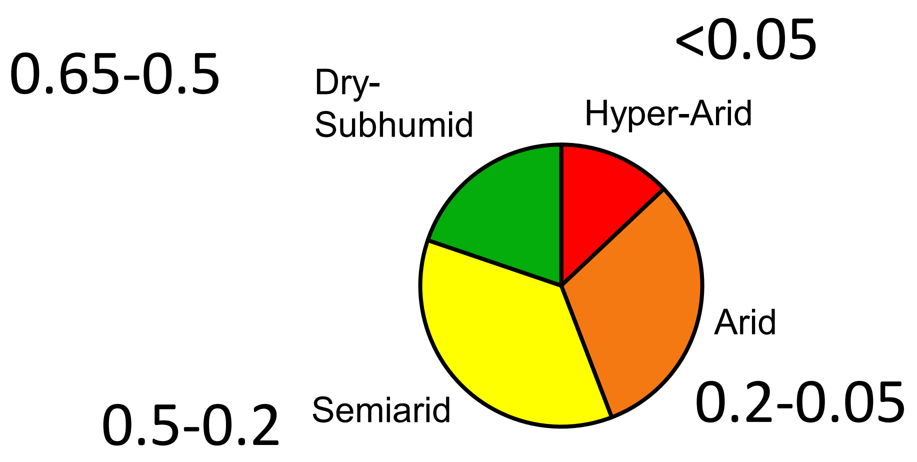
ce3c centre for ecology, evolution and environmental changes
Ciências ULisboa
Funded by the European Union
PRR
REPÚBLICA PORTUGUESA
Financiado pela União Europeia NextGenerationEU
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Commission . Neither the European Union nor the European Commission can be held responsible for them.

# Drylands

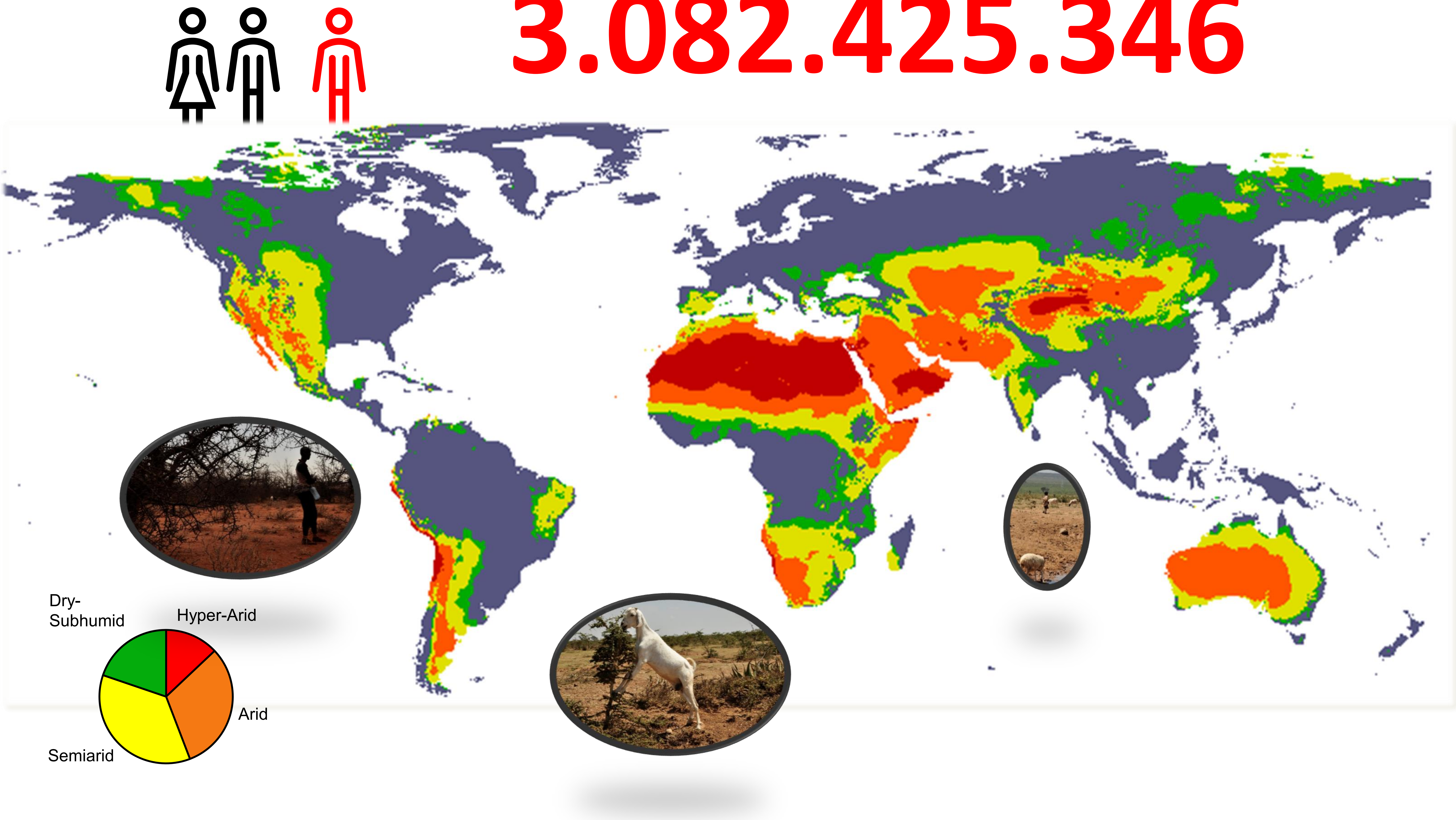
**Sites where it does not rain enough**

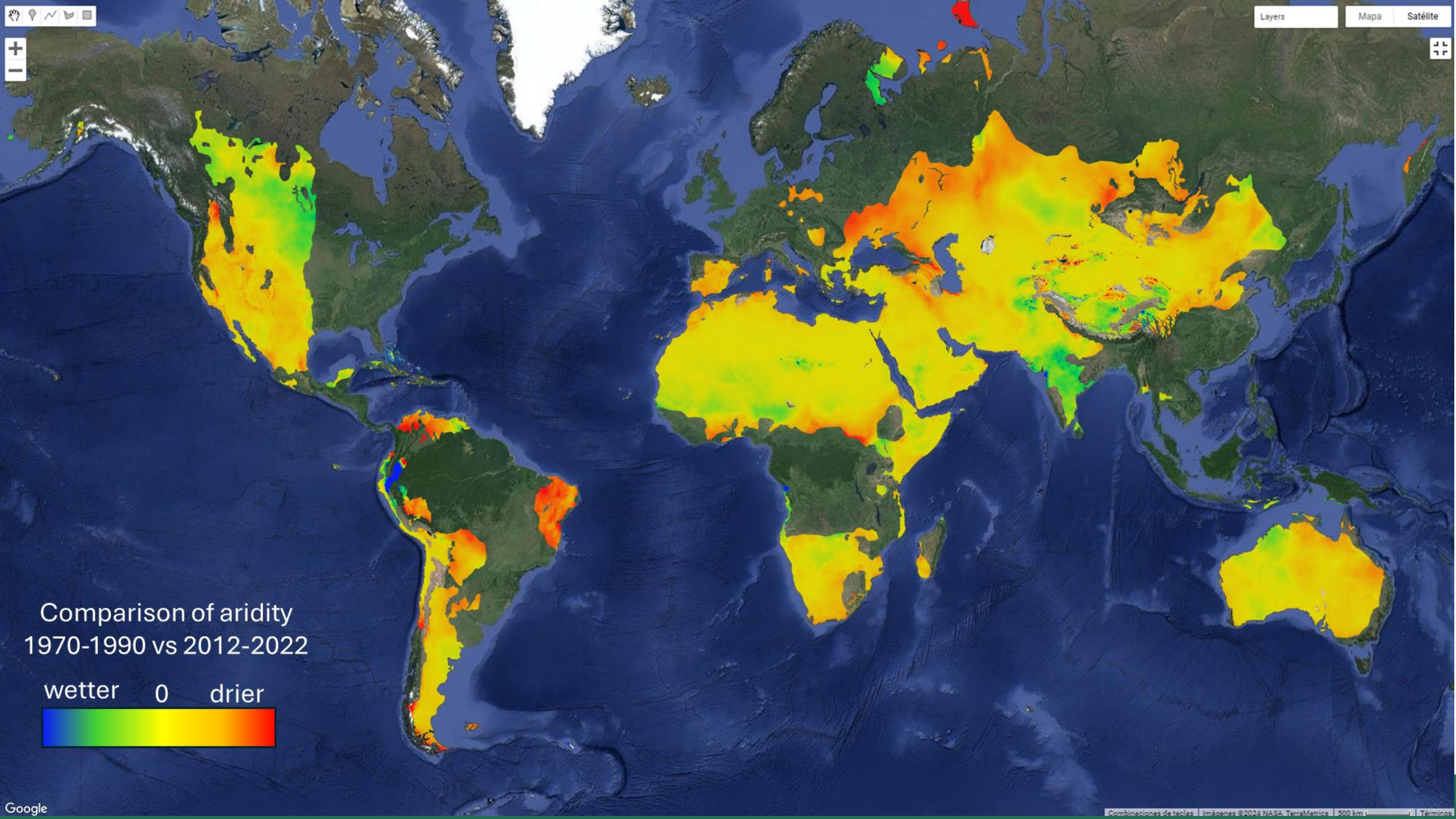
**Aridity Index:**

$$\frac{\text{Annual Precipitation}}{\text{Annual Potential Evapotranspiration}} < 0.65$$

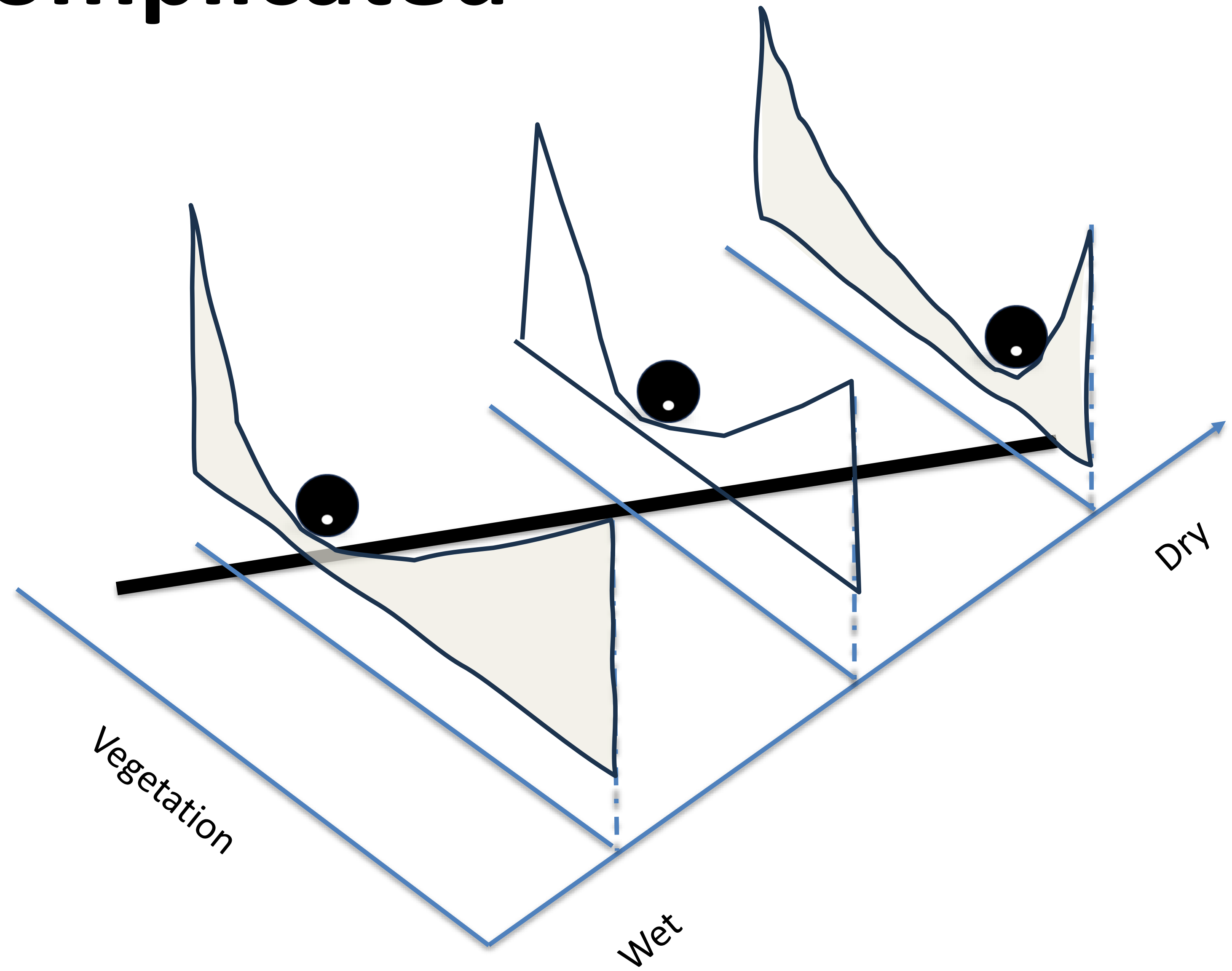


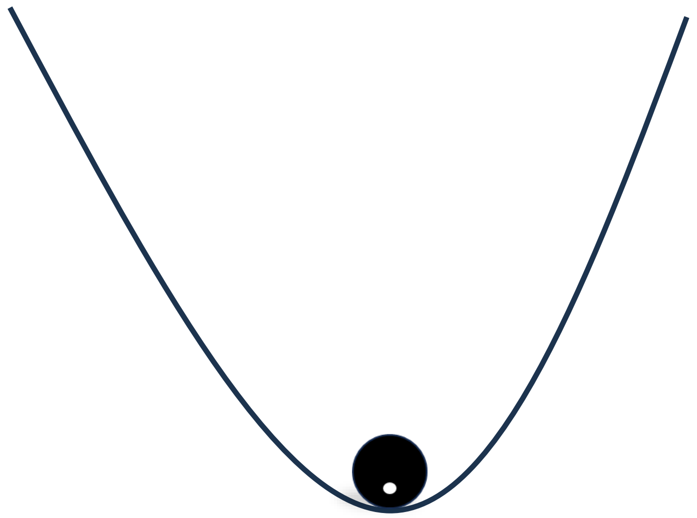

# 3.082.425.346

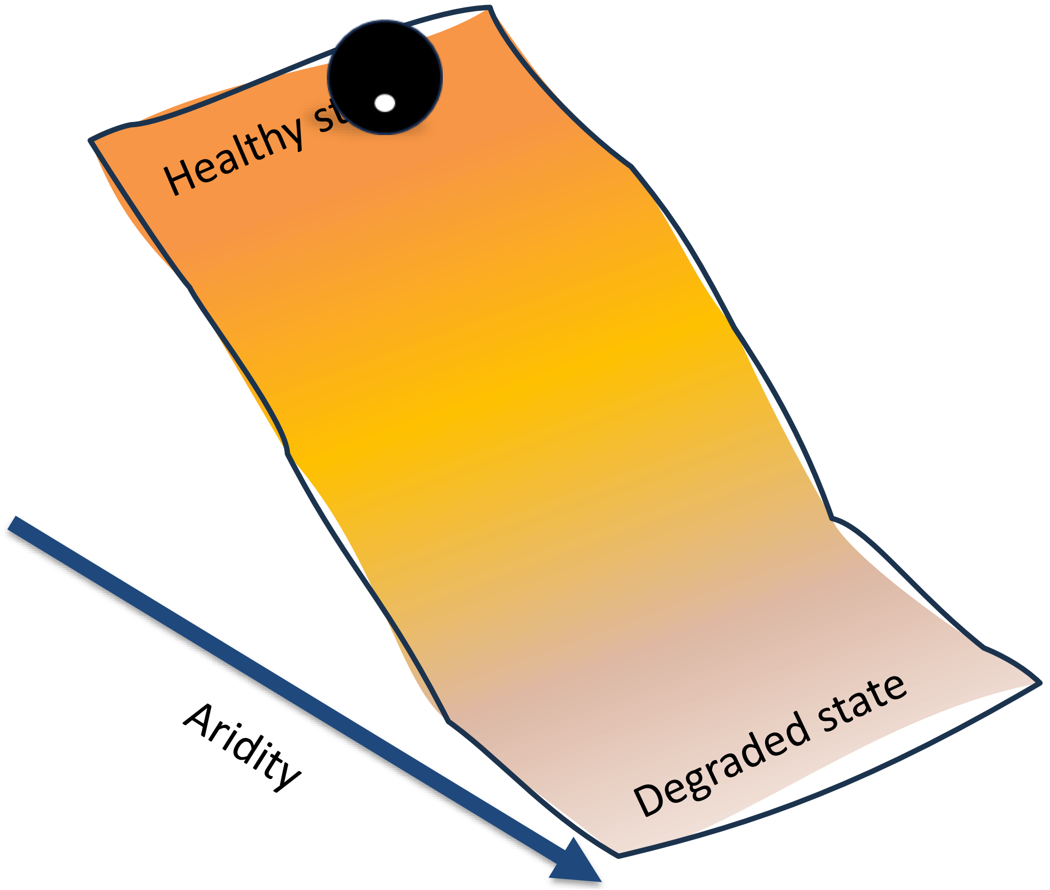



Comparison of aridity
1970-1990 vs 2012-2022
wetter
0
drier
Layers
Mapa
Satélite
Google

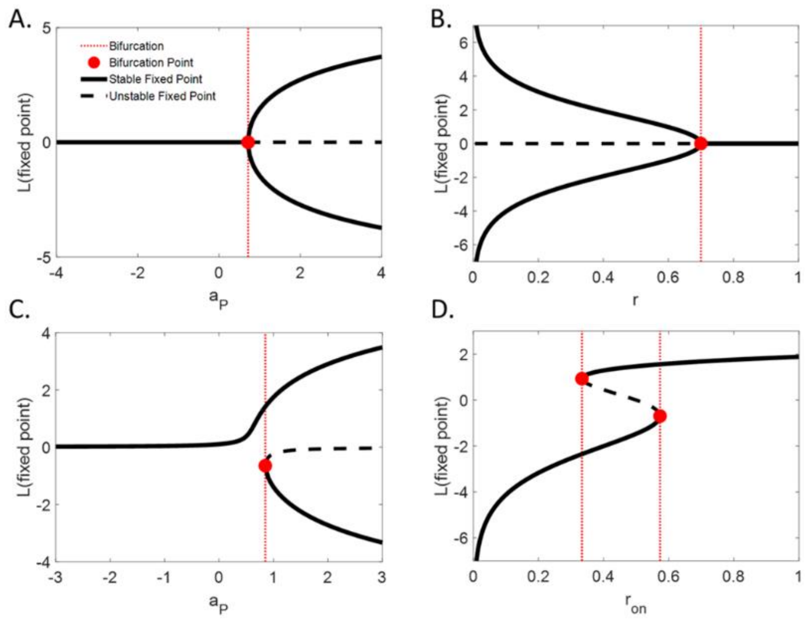
# When things are complex...
# then it gets complicated

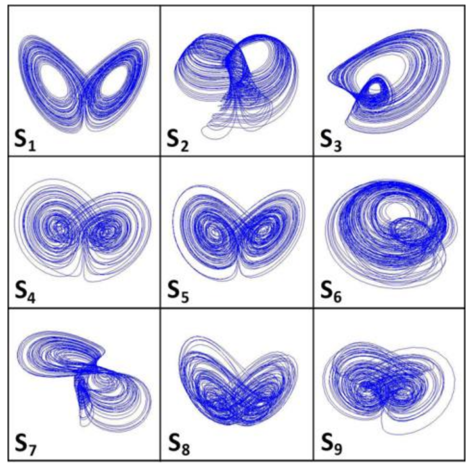


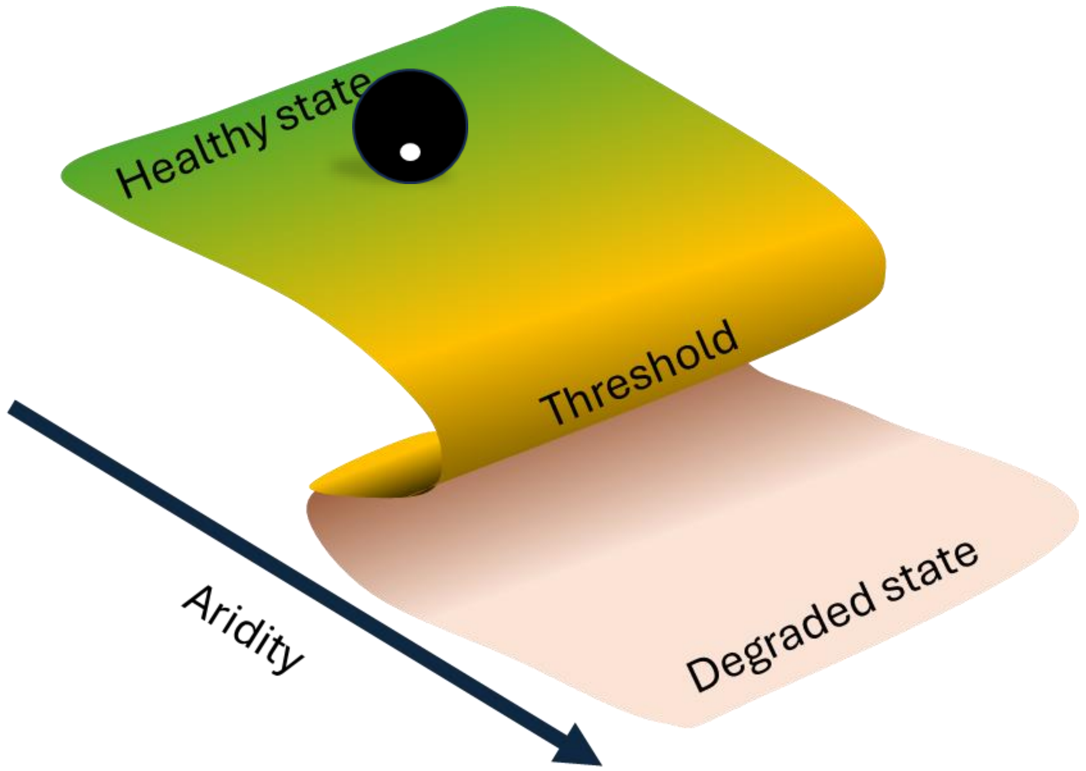



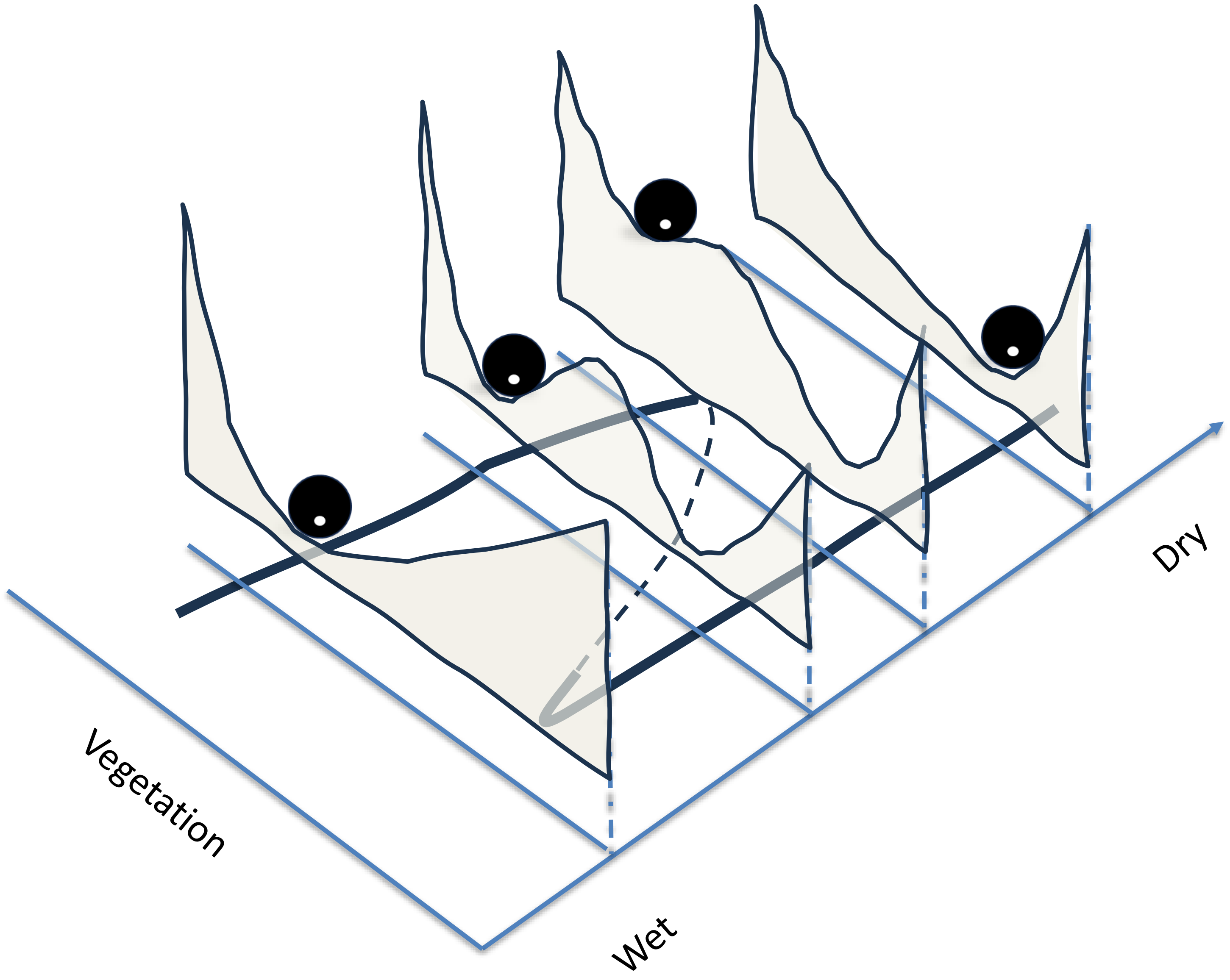


# When things are complex…
# then it gets complicated



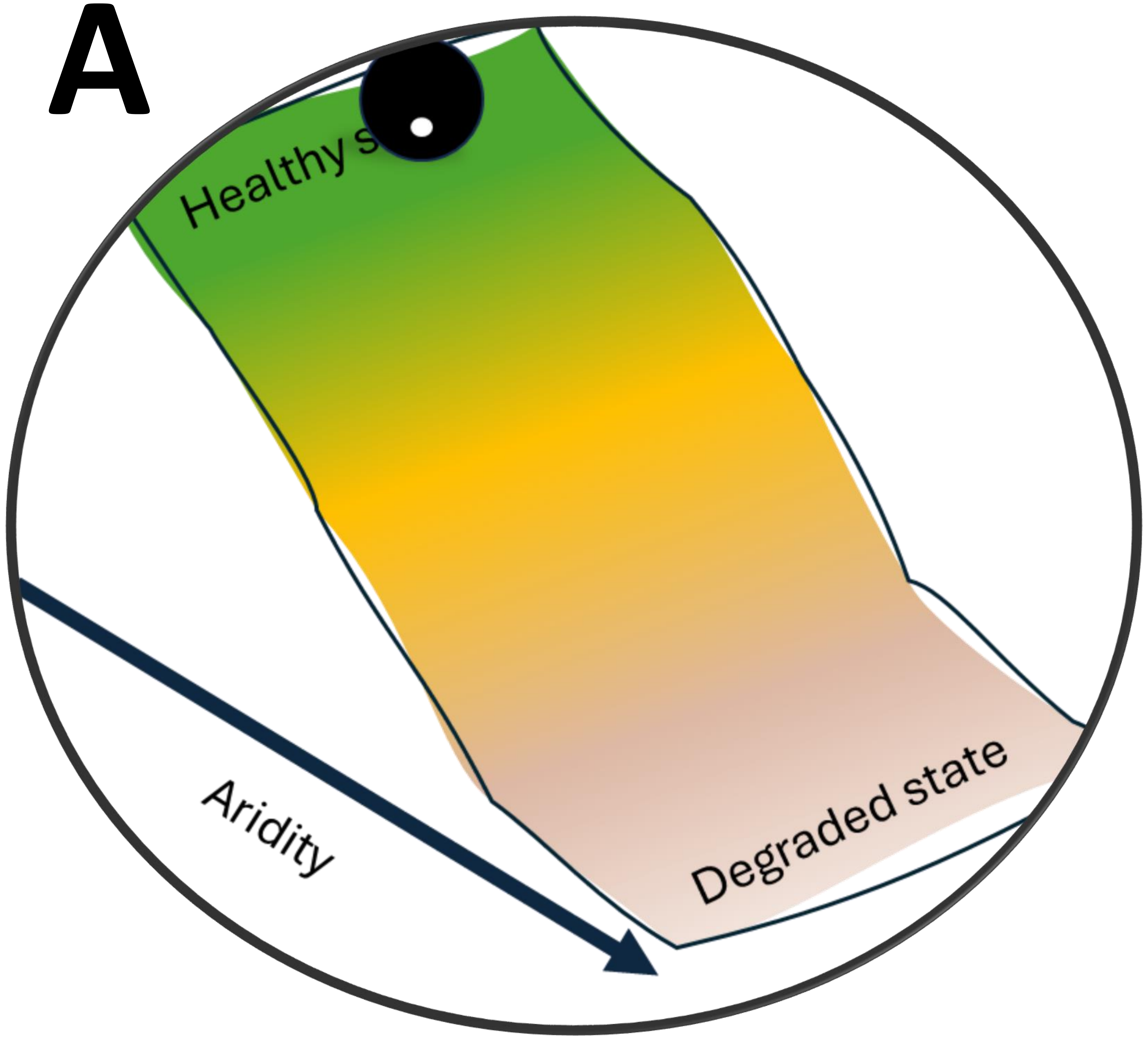



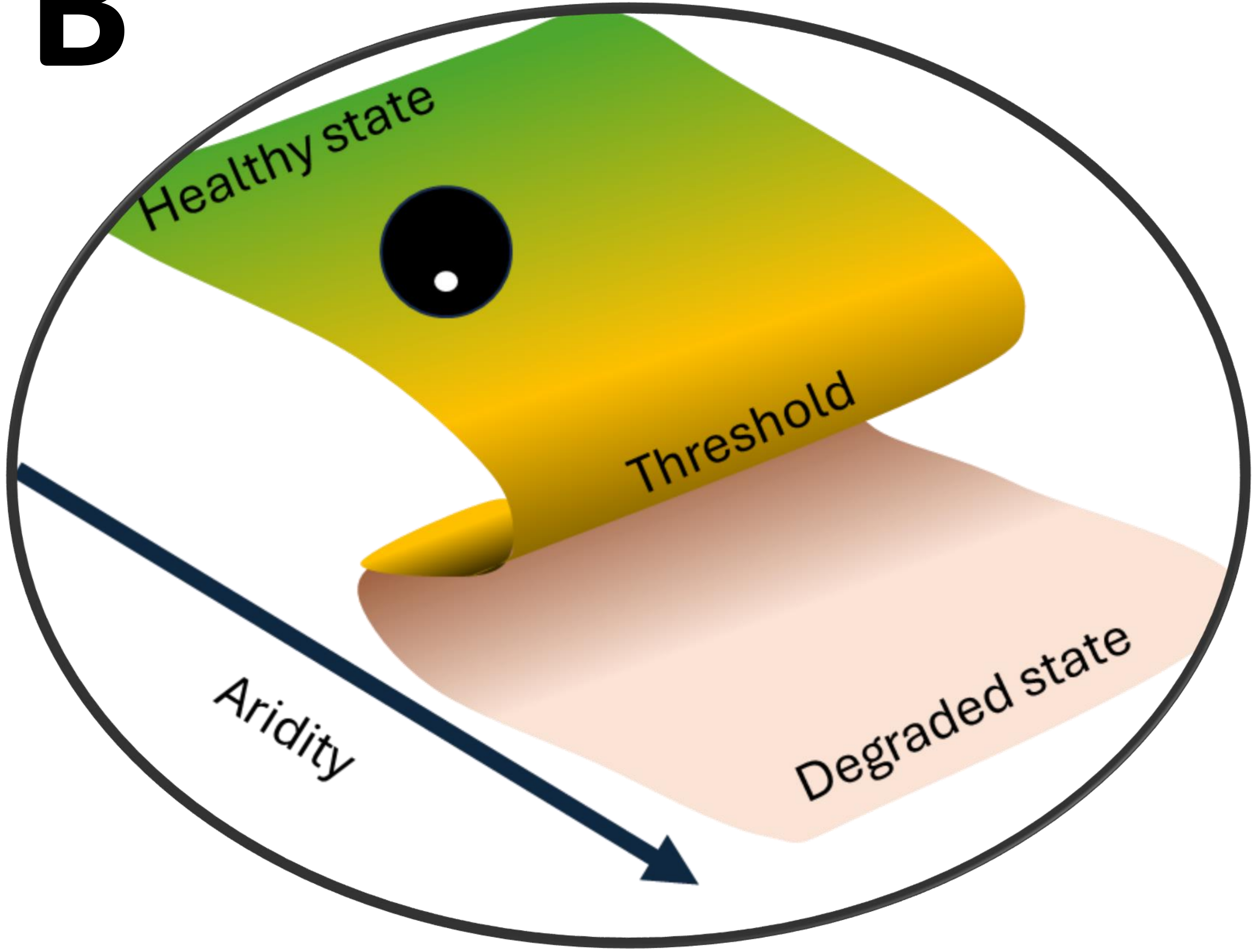



# How are drylands?

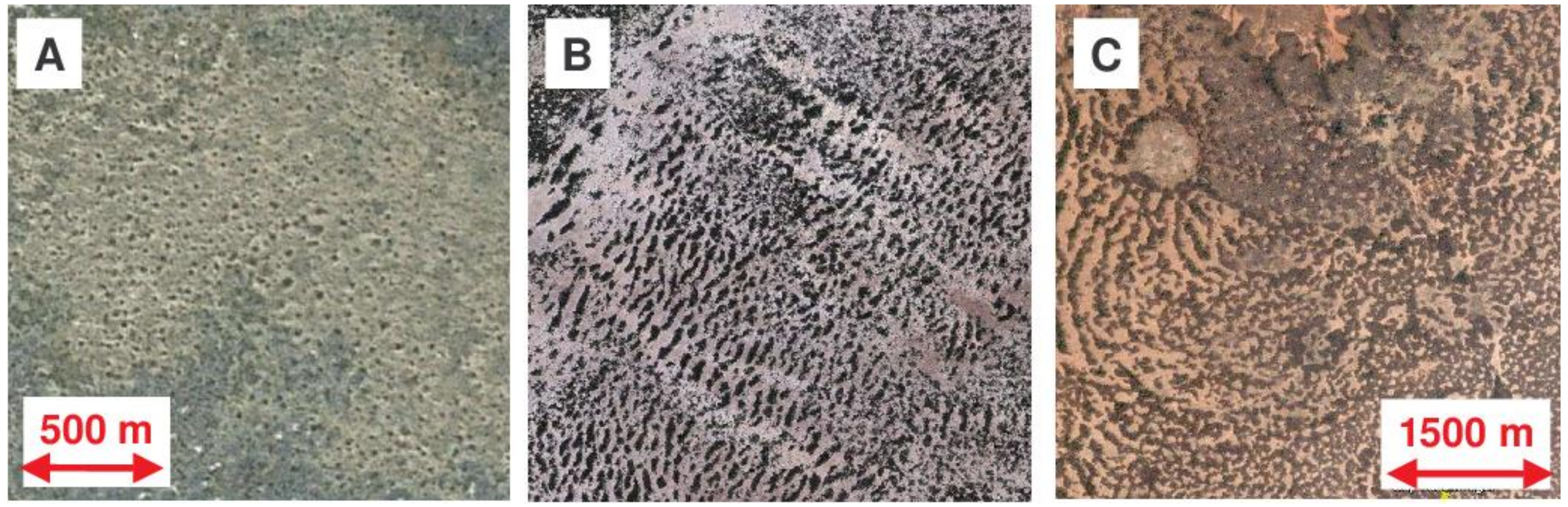
A

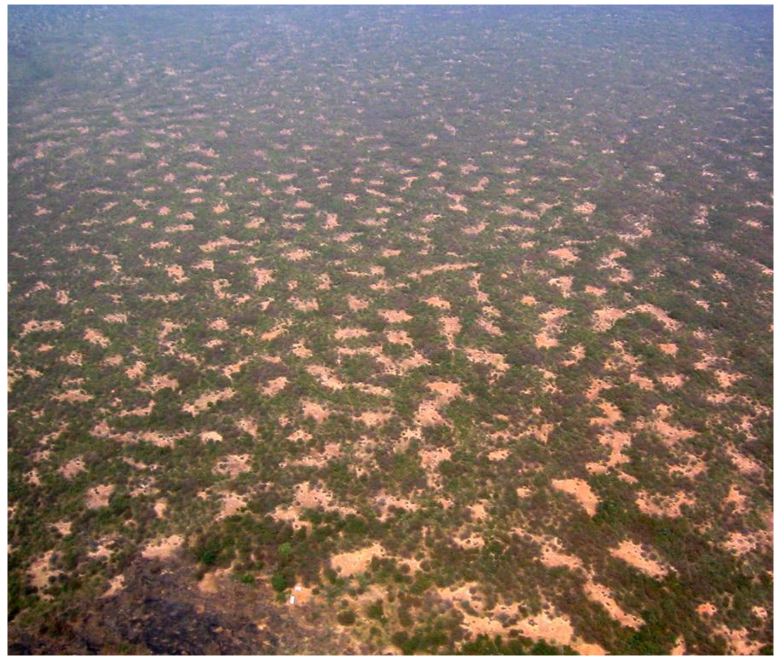


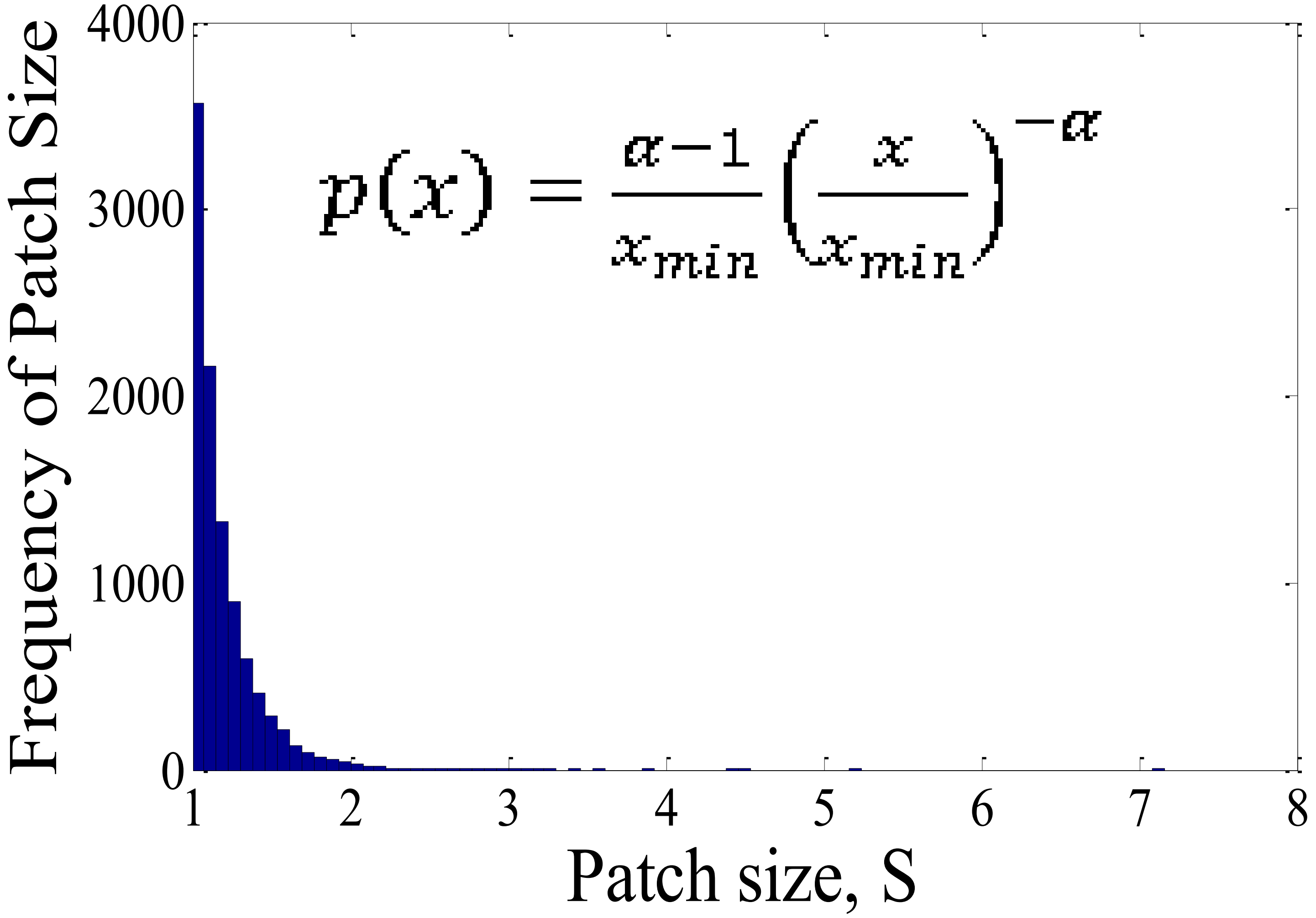

B



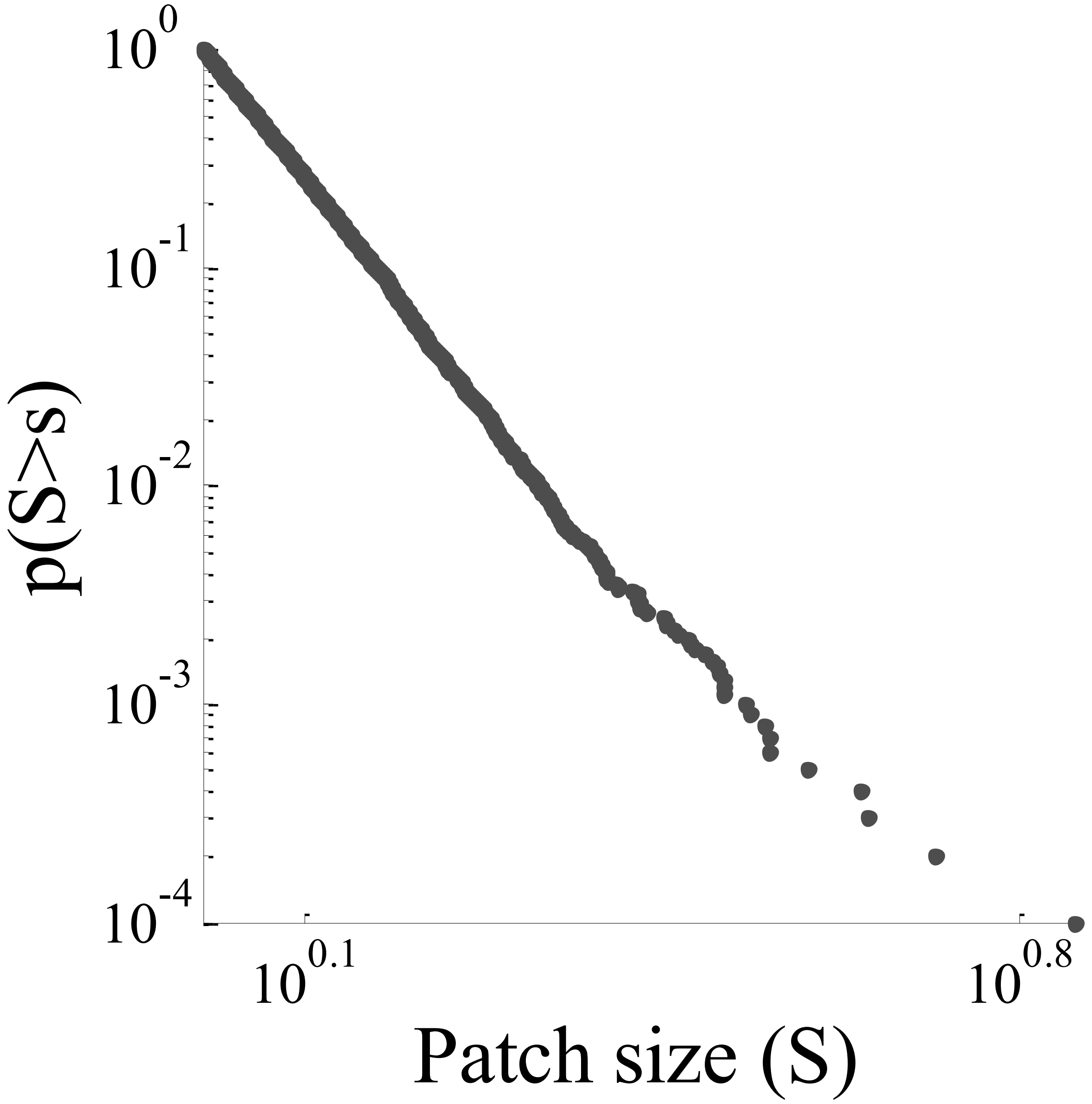
# A tale about spatial distributions (apparently)





Frequency of Patch Size
4000
3000
2000
1000
0
$p(x) = \frac{\alpha-1}{x_{min}}\left(\frac{x}{x_{min}}\right)^{-\alpha}$
1 2 3 4 5 6 7 8
Patch size, S

$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
p(S>s)
$10^{0.1}$
$10^{0.8}$
Patch size (S)

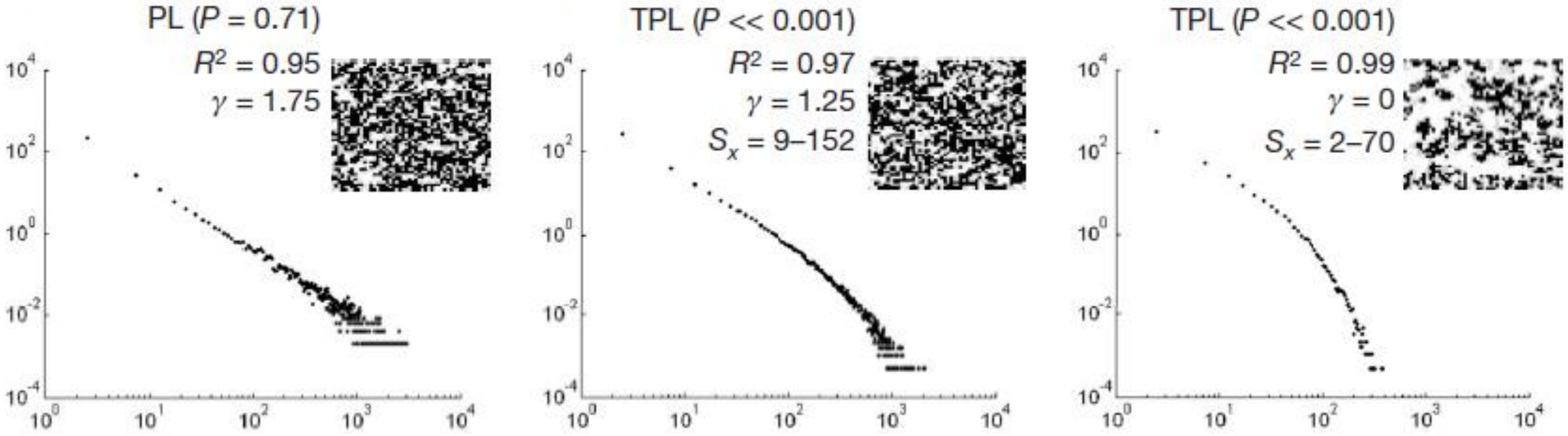
# Cover or PSDs?; that is the question.

*Ecology*, 90(7), 2009, pp. 1729–1735


Is the patch size distribution of vegetation a suitable indicator of desertification processes?

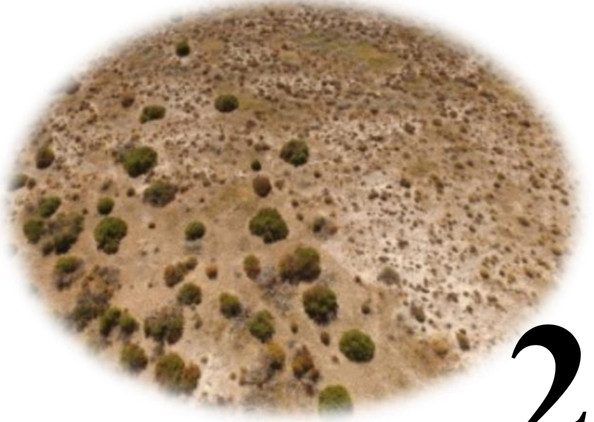
Fernando T. Maestre[1] and Adrián Escudero

log patch number




log p

*Increasing pressure*




# 236 sites

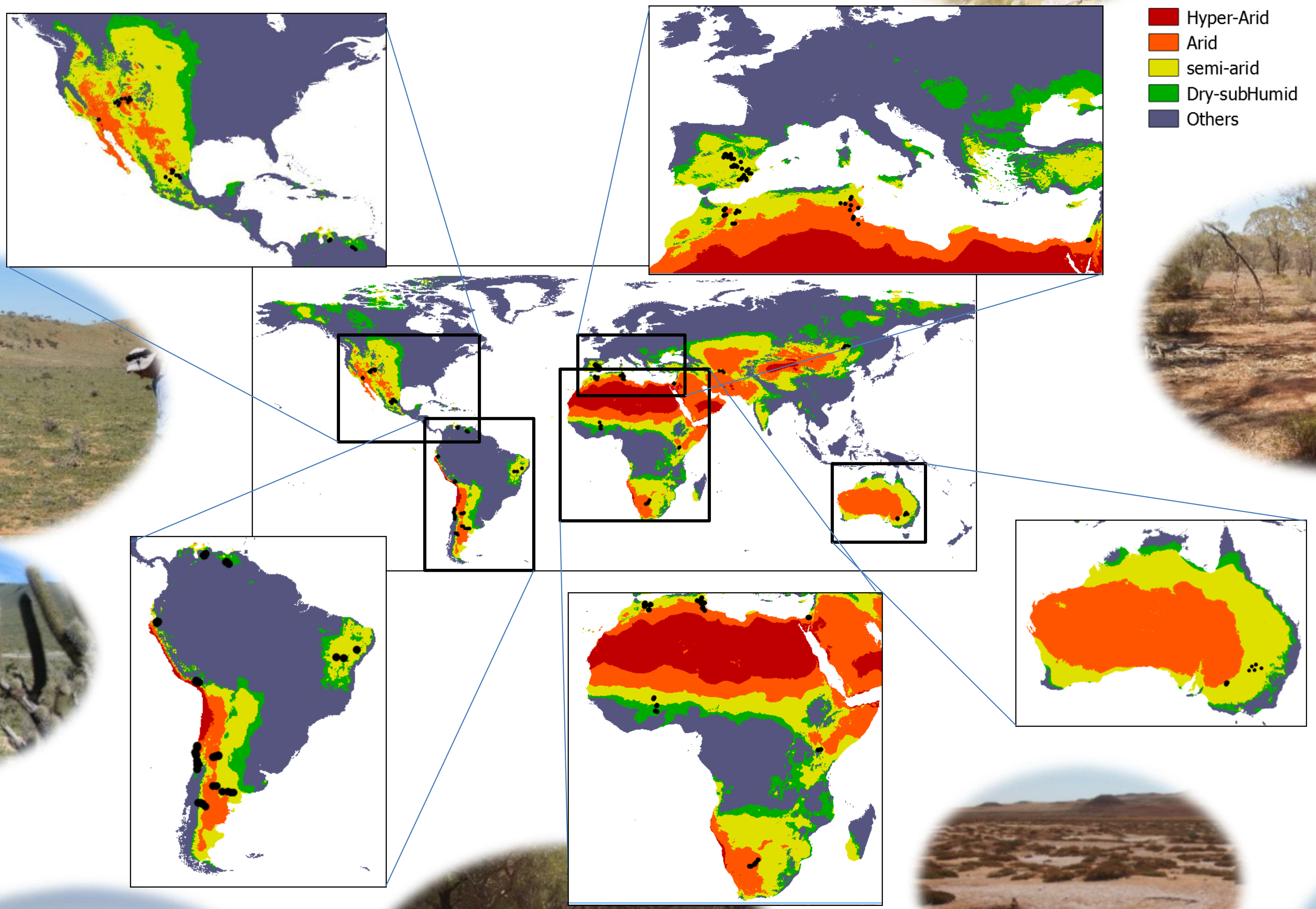




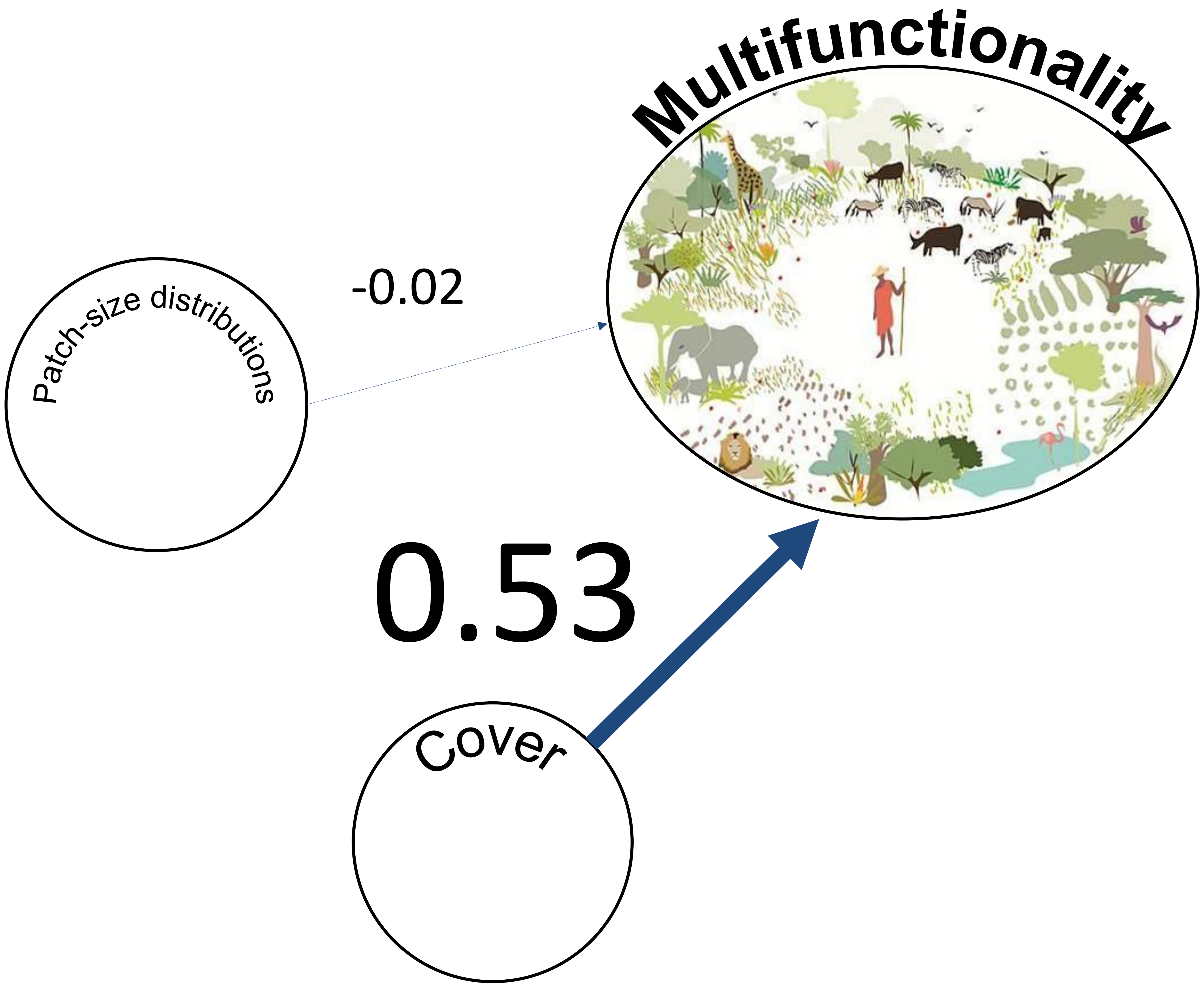




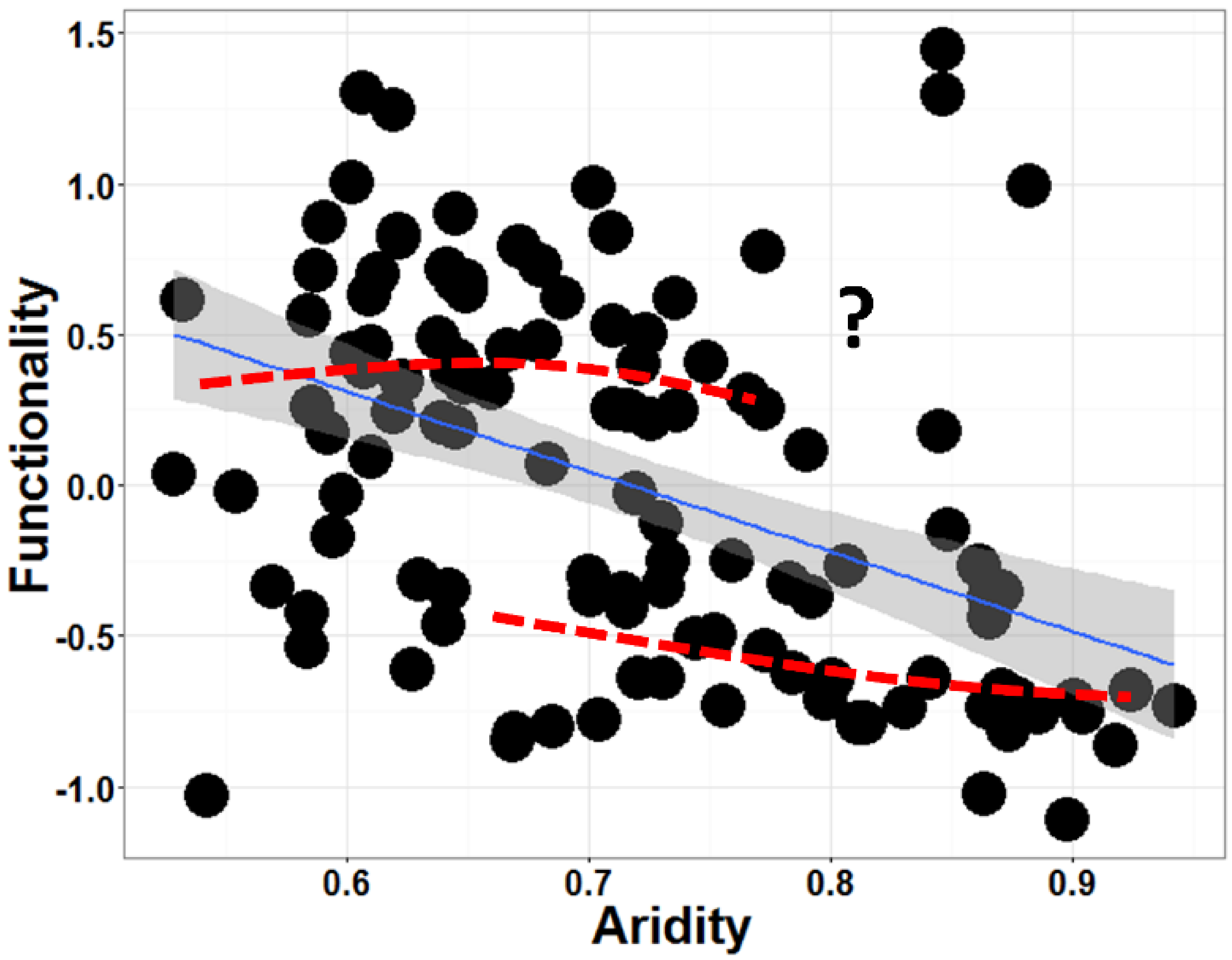


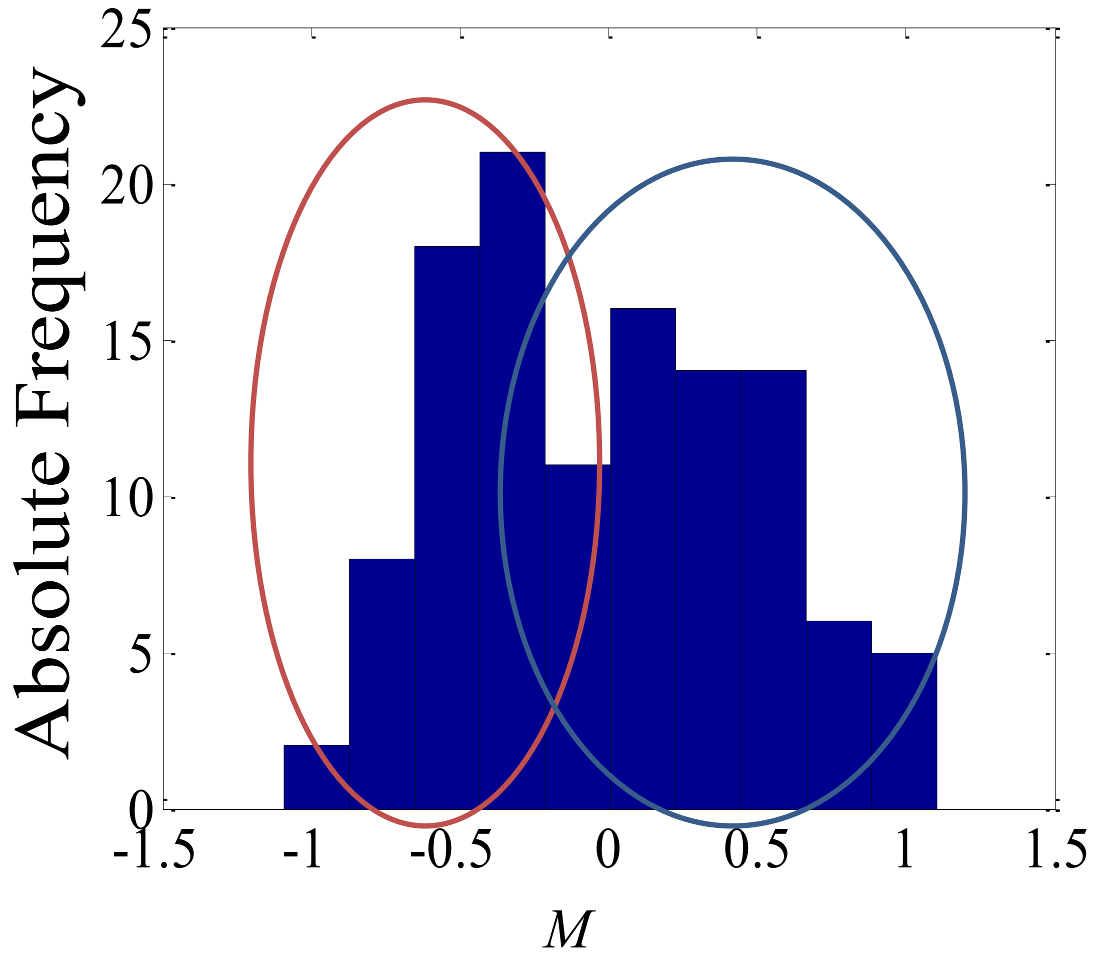


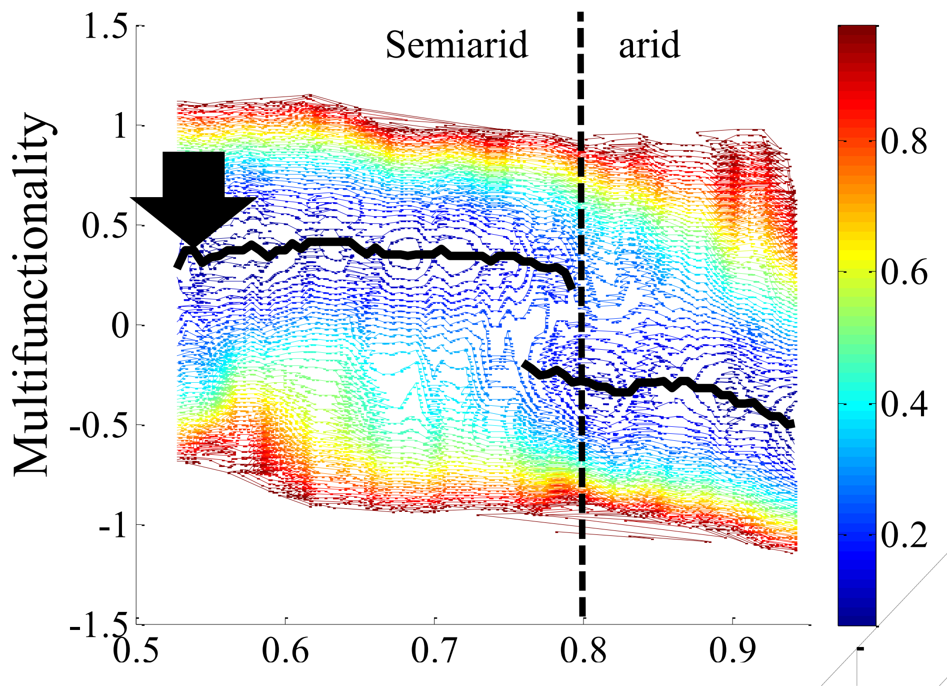

Photo credits: MB, DE, SK, MG, FM, JG


Multifunctionality
-0.02
Patch-size distributions
0.53
Cover

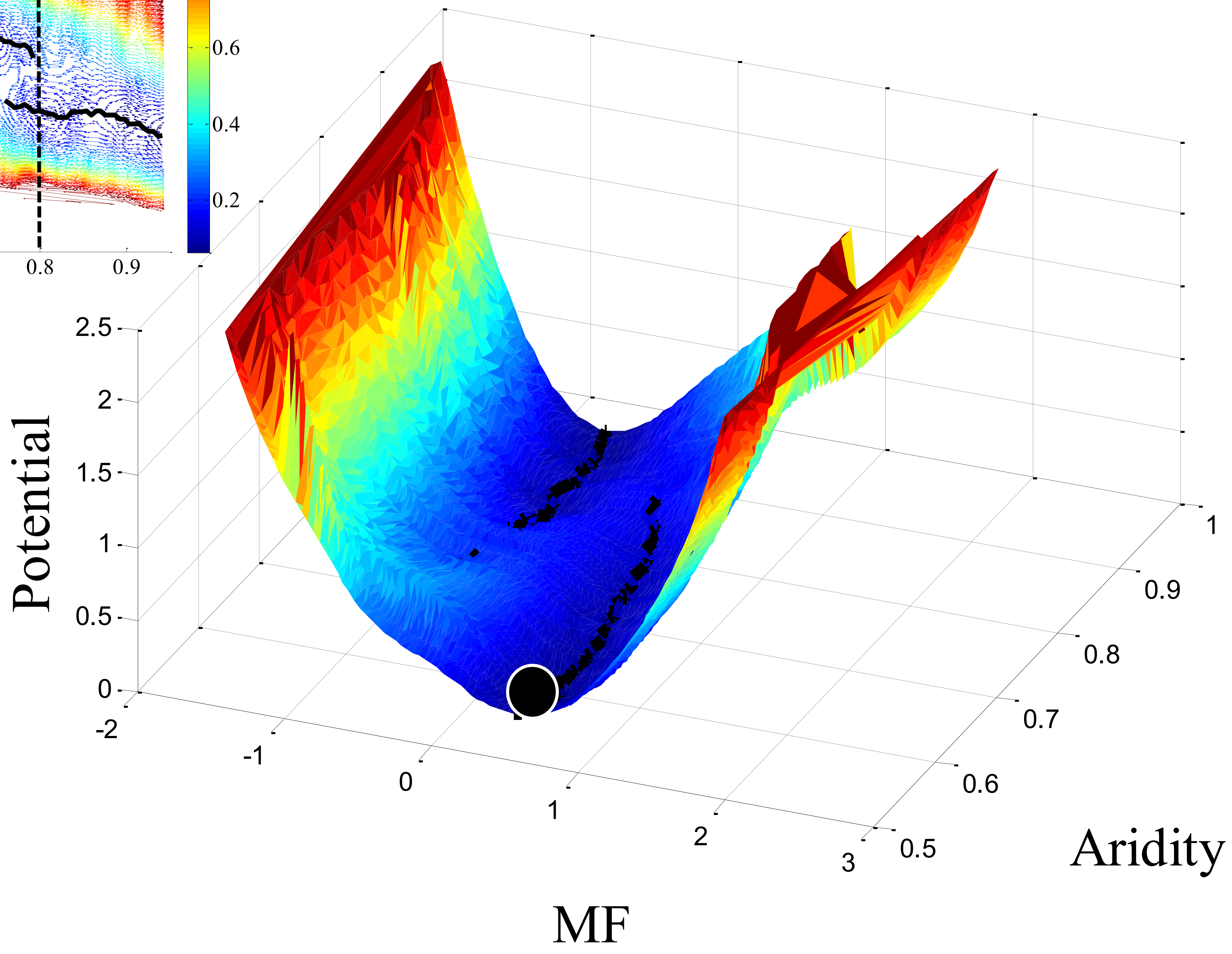
# *The importance of looking at the plot*



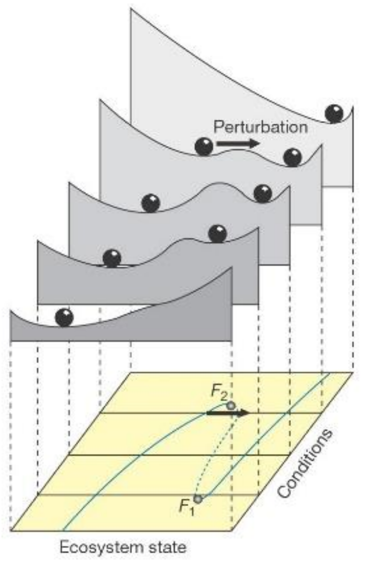





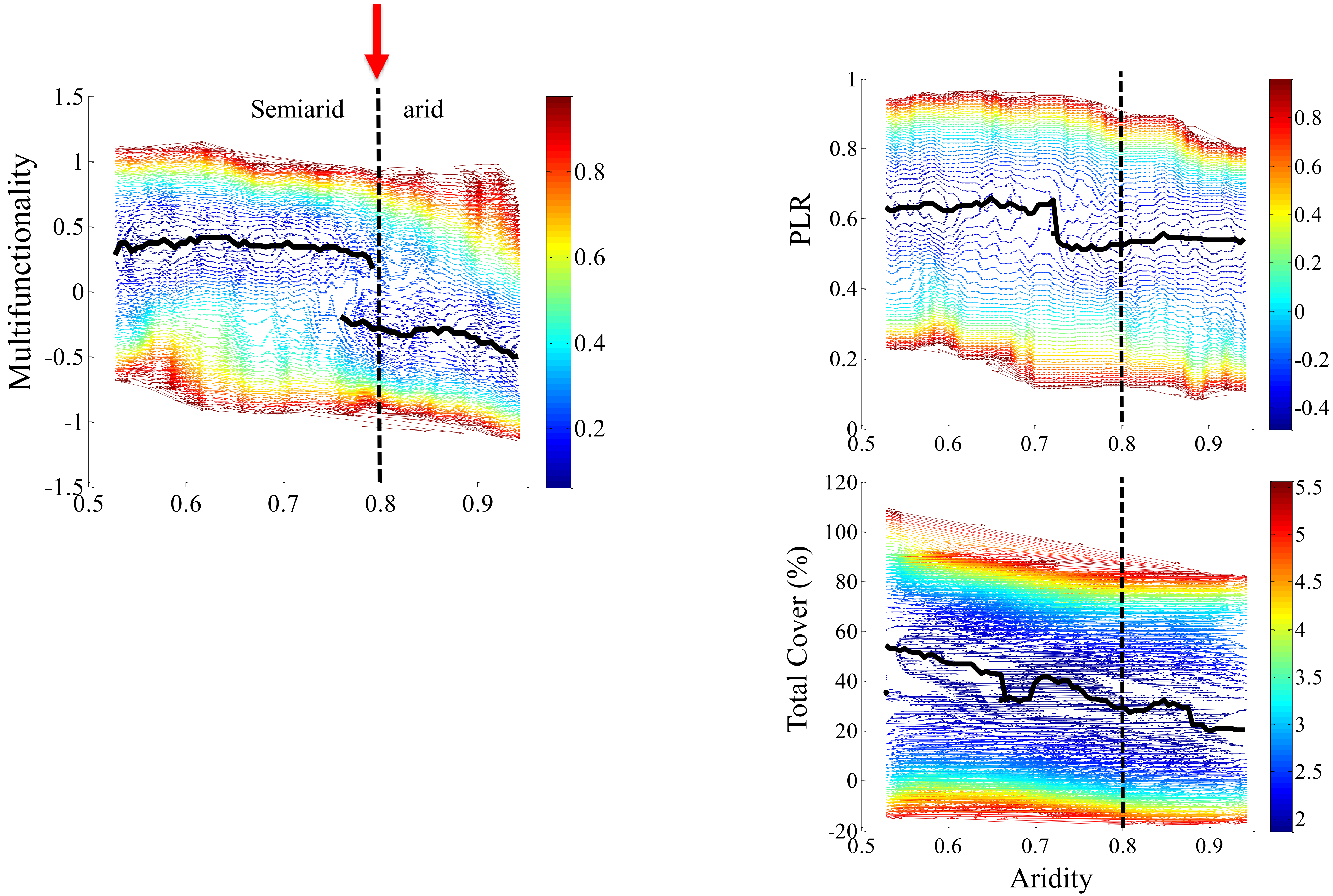
Semiarid
arid
Multifunctionality
1.5
1
0.5
0
-0.5
-1
-1.5
0.5
0.6
0.7
0.8
0.9
0.8
0.6
0.4
0.2

Potential
2.5
2
1.5
1
0.5
0
-2
-1
0
1
2
3
MF
0.5
0.6
0.7
0.8
0.9
1
Aridity

Perturbation
Conditions
Ecosystem state

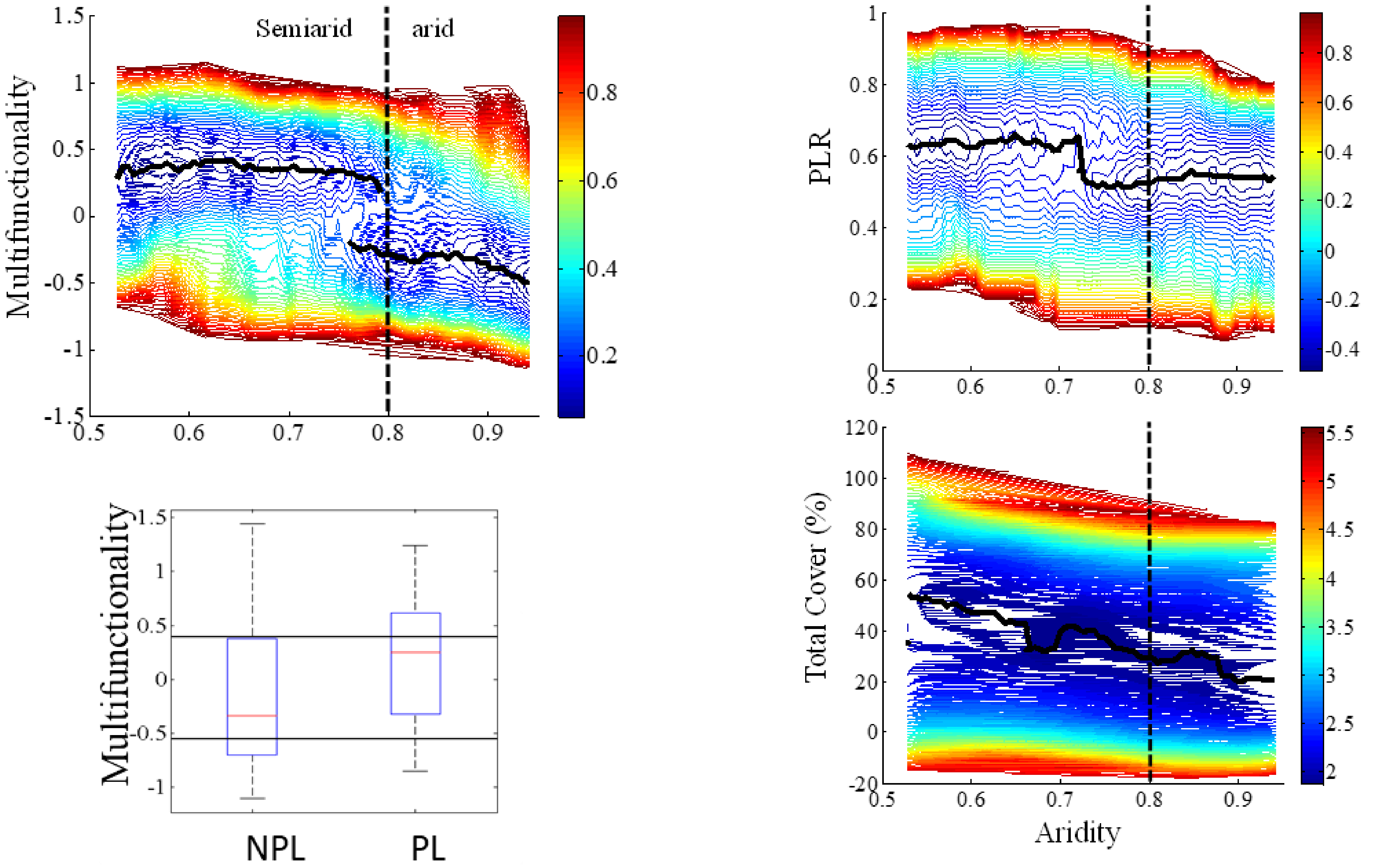


Semiarid
arid
Multifunctionality
PLR
Total Cover (%)
Aridity

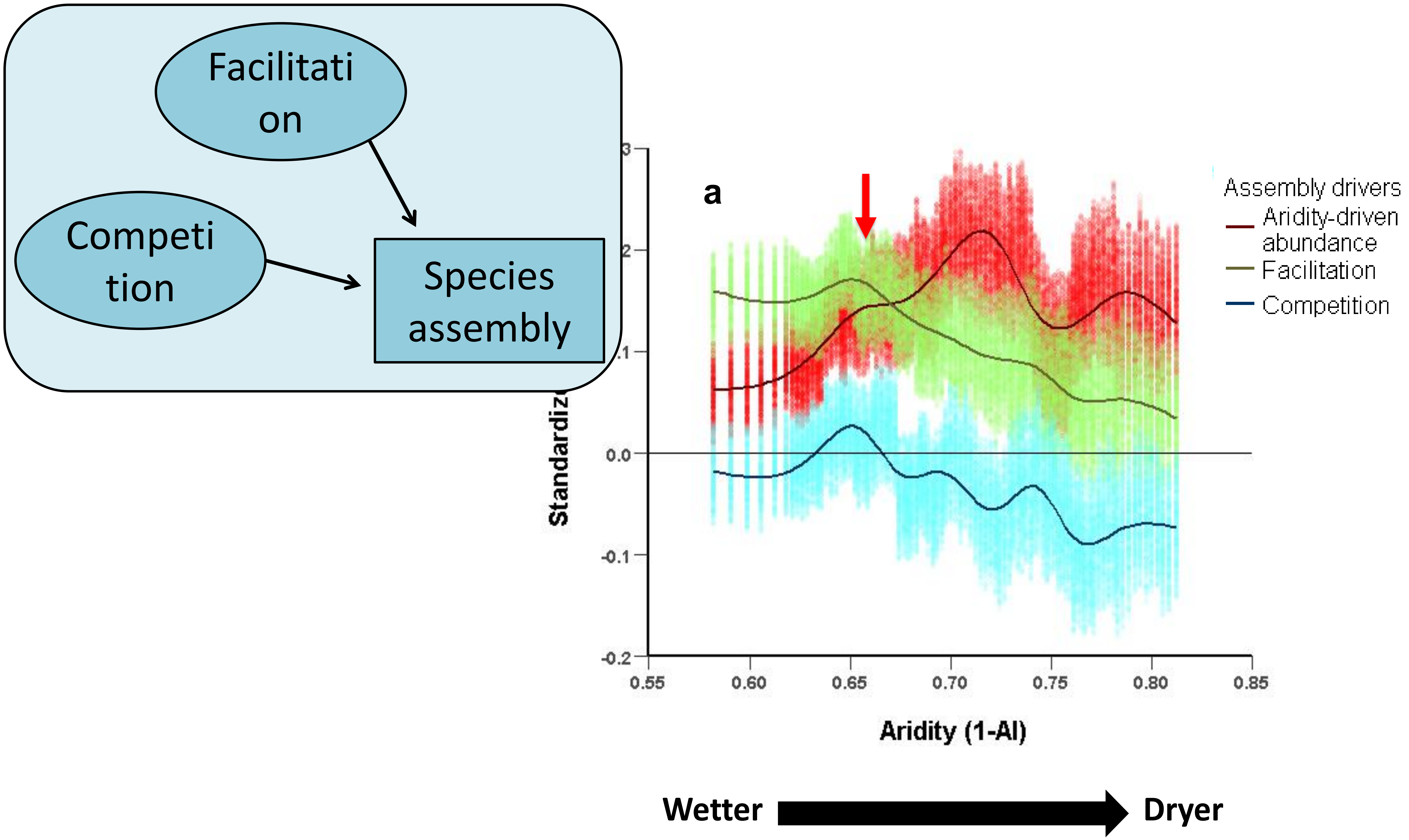
nature ecology & evolution

# Plant spatial patterns identify alternative ecosystem multifunctionality states in global drylands

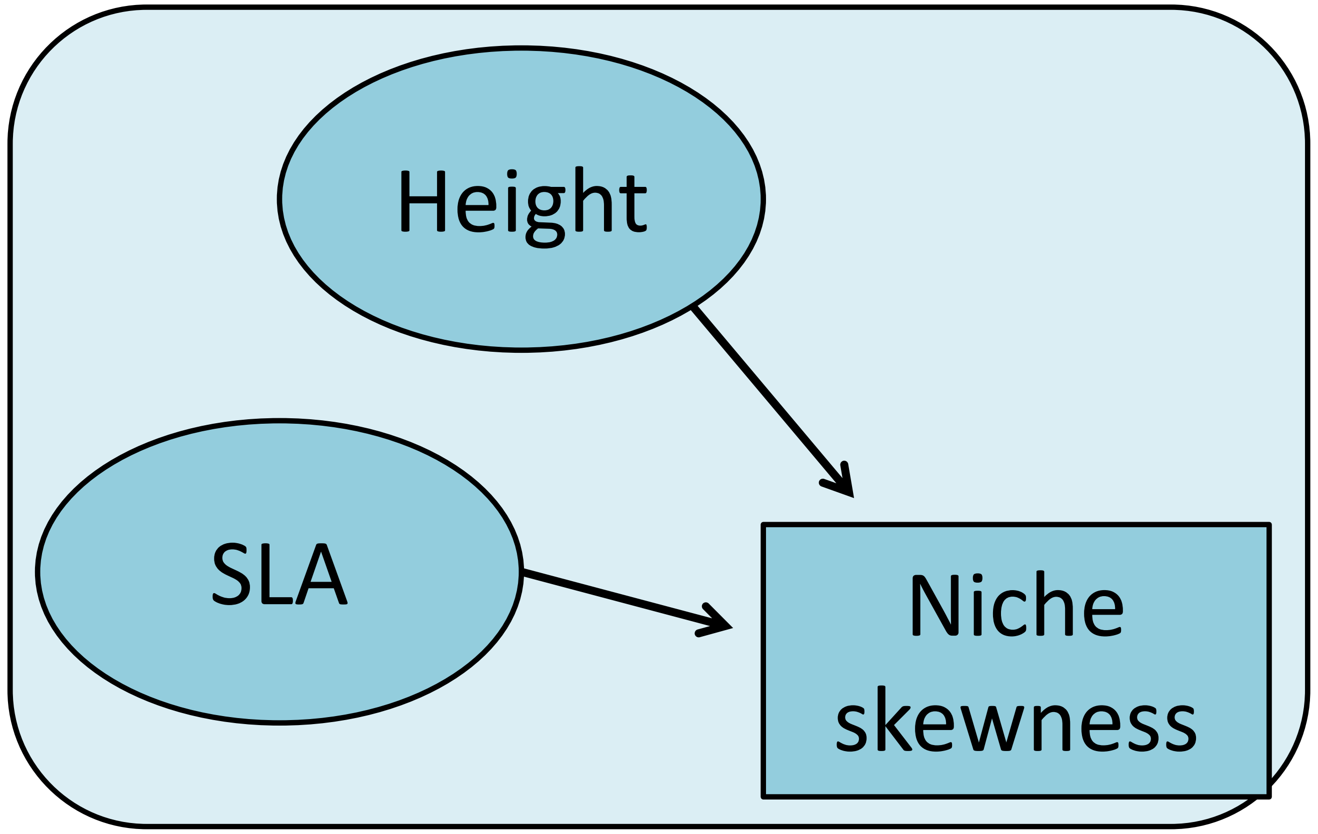
Miguel Berdugo, Sonia Kéfi, Santiago Soliveres and Fernando T. Maestre

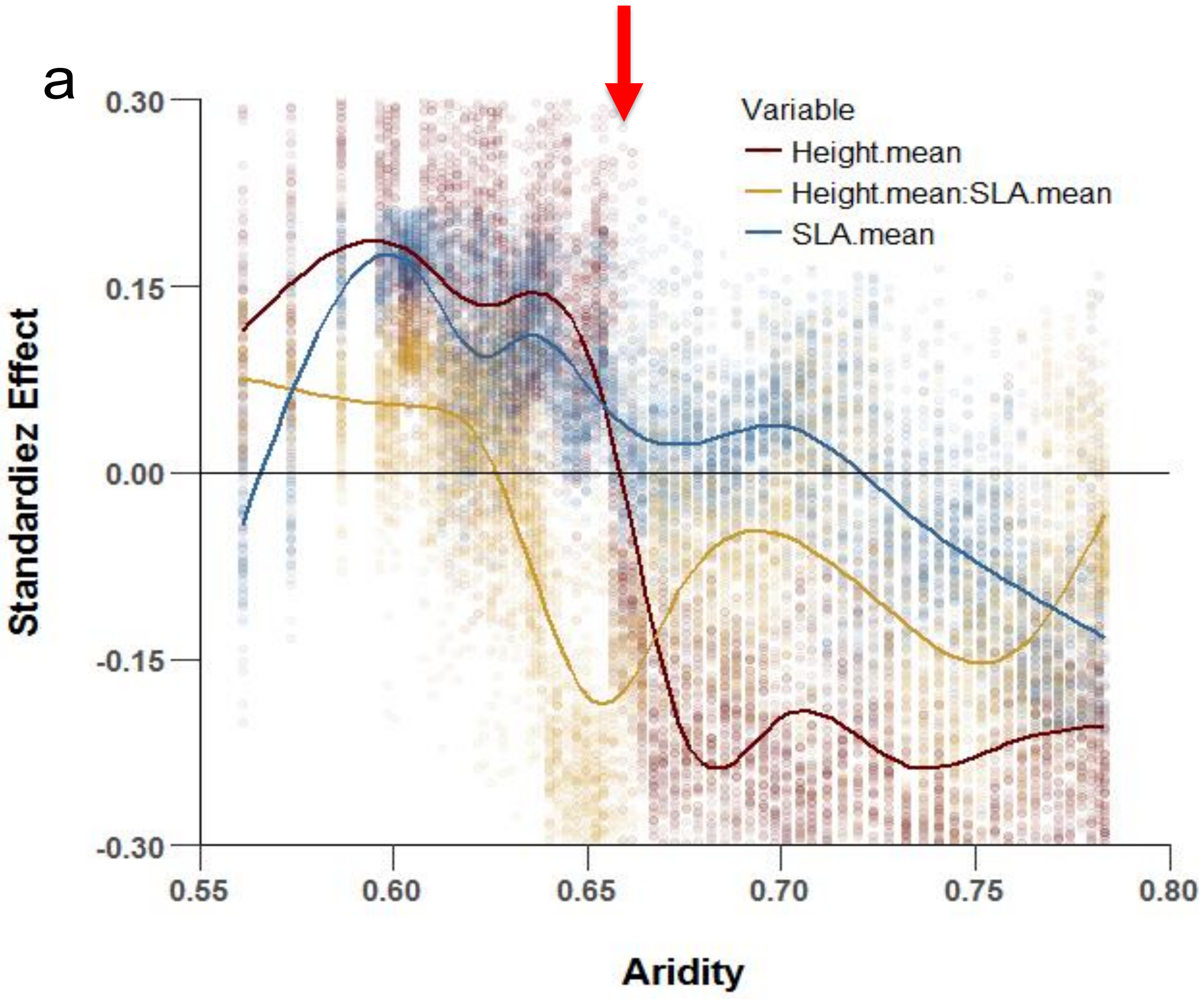




Only plant spatial arrangements can identify two functionality states in drylands, that change at aridity values of 0.7-0.8 into an unfertile state



Facilitati on
Competi tion
Species assembly
a
Standardiz
3
2
1
0.0
-0.1
-0.2
0.55
0.60
0.65
0.70
0.75
0.80
0.85
Aridity (1-AI)
Assembly drivers
Aridity-driven abundance
Facilitation
Competition
Wetter
Dryer


Height
SLA
Niche skewness


a
Variable
Height.mean
Height.mean:SLA.mean
SLA.mean
Standardiez Effect
Aridity
0.30
0.15
0.00
-0.15
-0.30
0.55
0.60
0.65
0.70
0.75
0.80

Las respuestas de los ecosistemas de las tierras áridas (sitios con un grave déficit de aportes de agua) a cambios ambientales es muy posible que sean no lineales o abruptas. Esto es de gran trascendencia dado que un ecosistema puede perder funcionalidad o mostrar cambios repentinos en su composición de una forma inesperada e irreversible con el cambio climático. En esta tesis analizamos una base de datos de ecosistemas de tierras áridas a escala global, a fin de describir y comprender los cambios bruscos y los umbrales de aridez que desencadenan este tipo de respuestas no lineales en ecosistemas áridos de todo el mundo.
Nuestros resultados sugieren la existencia de un umbral de aridez muy conservado que afecta tanto a la funcionalidad como a la estructura del ecosistema produciendo pérdidas drásticas de fertilidad del suelo asociadas a cambios bruscos en la estructura espacial, la composición de las comunidades y la importancia relativa de las interacciones planta-planta. Los resultados de esta tesis sientan las bases para el estudio de estos umbrales, el entendimiento de sus consecuencias y el desarrollo de herramientas que puedan anticipar su llegada en ecosistemas reales.

Created by Gan Khoon Lay from the Noun Project

UMBRALES CLIMÁTICOS EN LA ESTRUCTURA Y FUNCIONAMIENTO DE LAS ZONAS ÁRIDAS A ESCALA GLOBAL

MIGUEL BERDUGO

2017

TESIS DOCTORAL

# UMBRALES CLIMÁTICOS EN LA ESTRUCTURA Y FUNCIONAMIENTO DE LAS ZONAS ÁRIDAS A ESCALA GLOBAL

MIGUEL BERDUGO

Departamento de Biología Geología, Física y Química Inorgánica

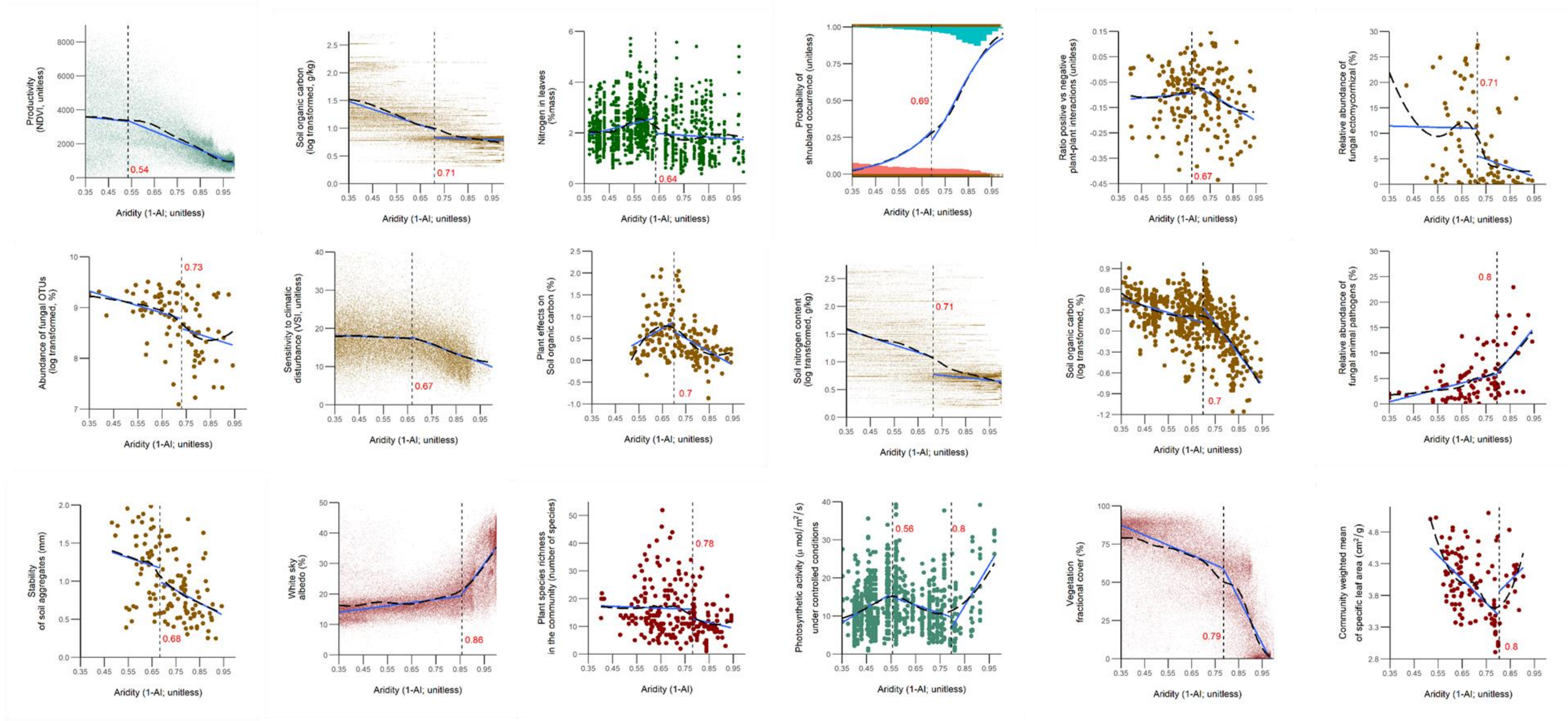
Universidad Rey Juan Carlos

2017

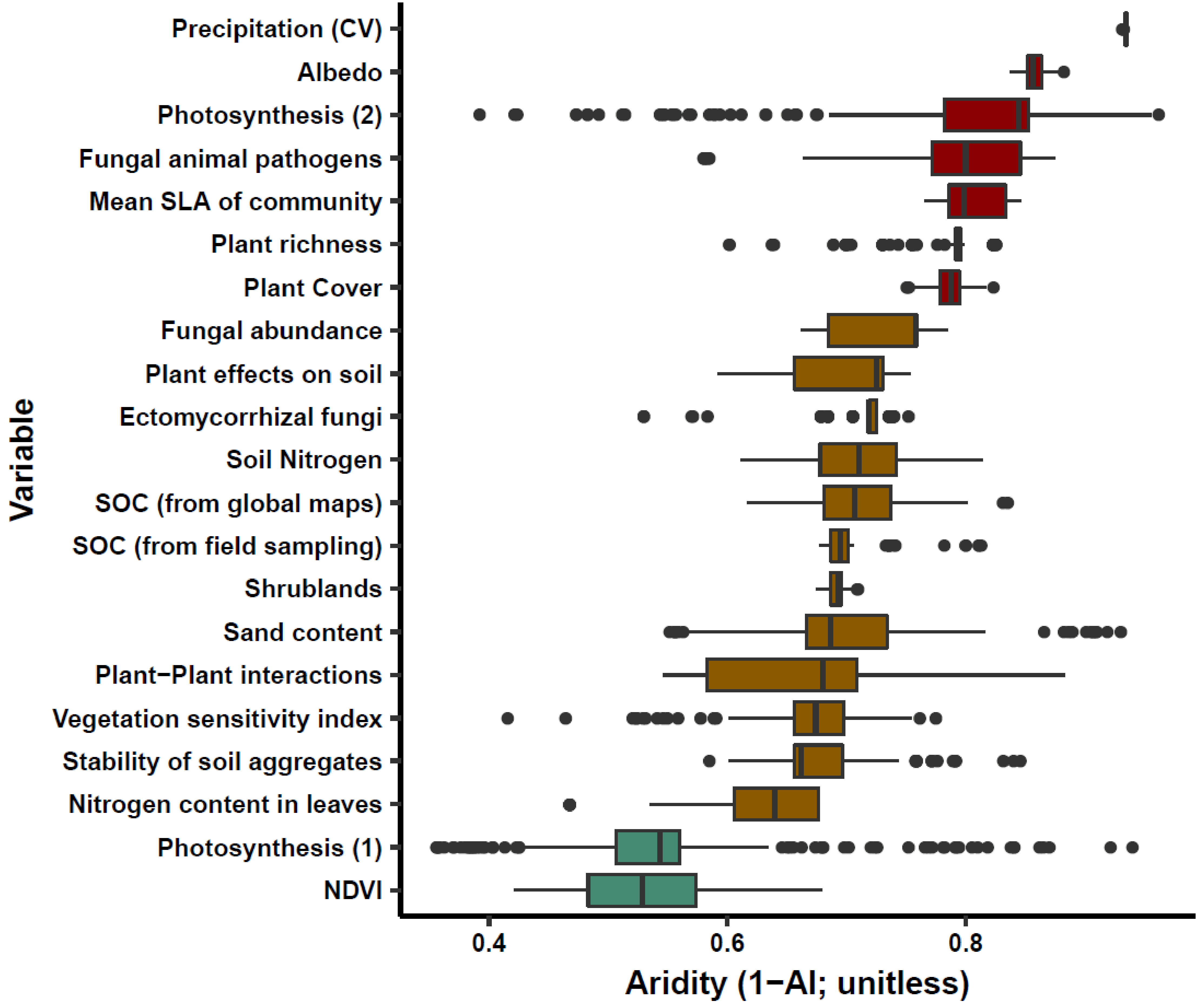
Universidad Rey Juan Carlos

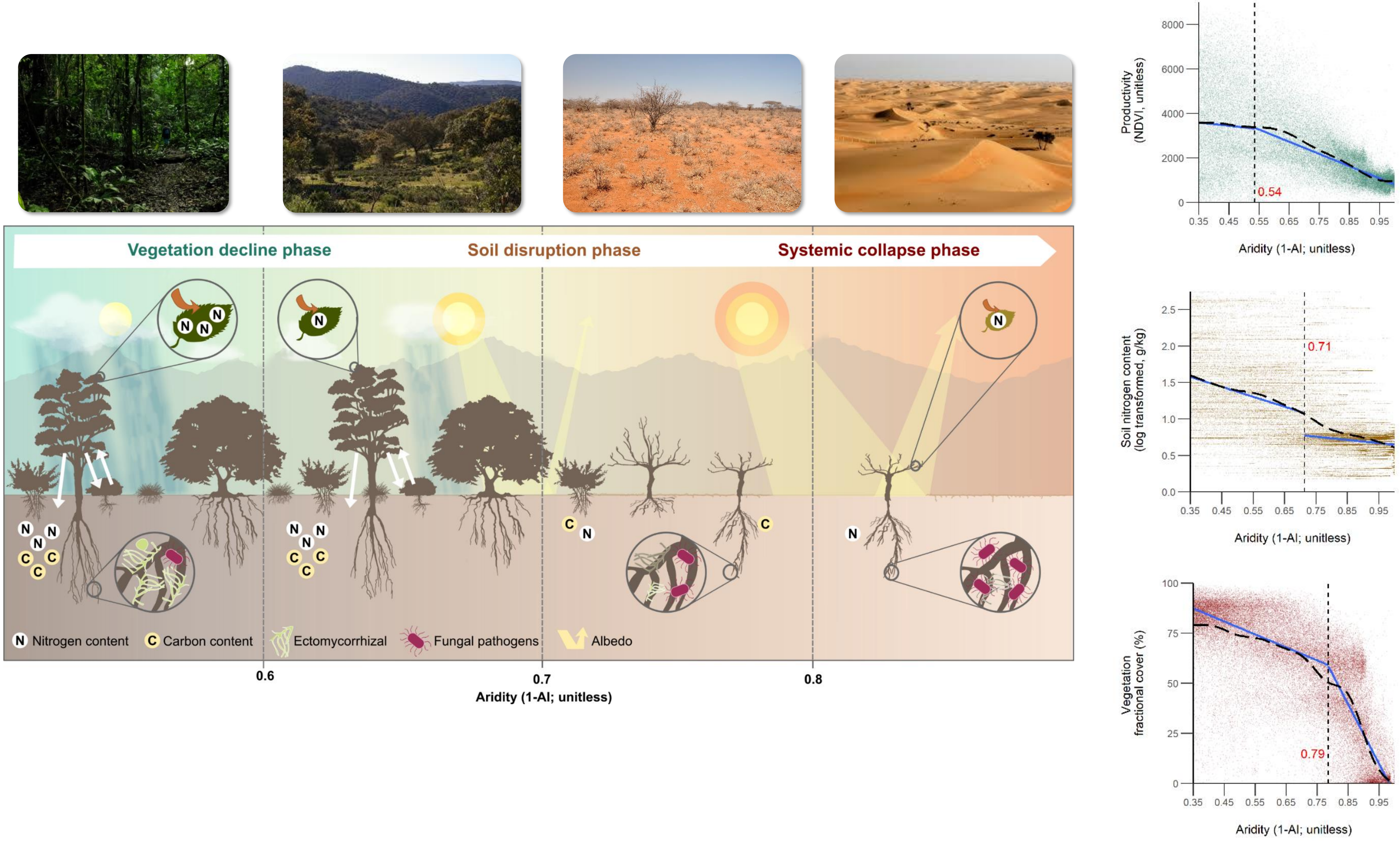
DRYLAND ECOLOGY AND GLOBAL CHANGE LAB

# Let’s test them all



# 3 clear phases



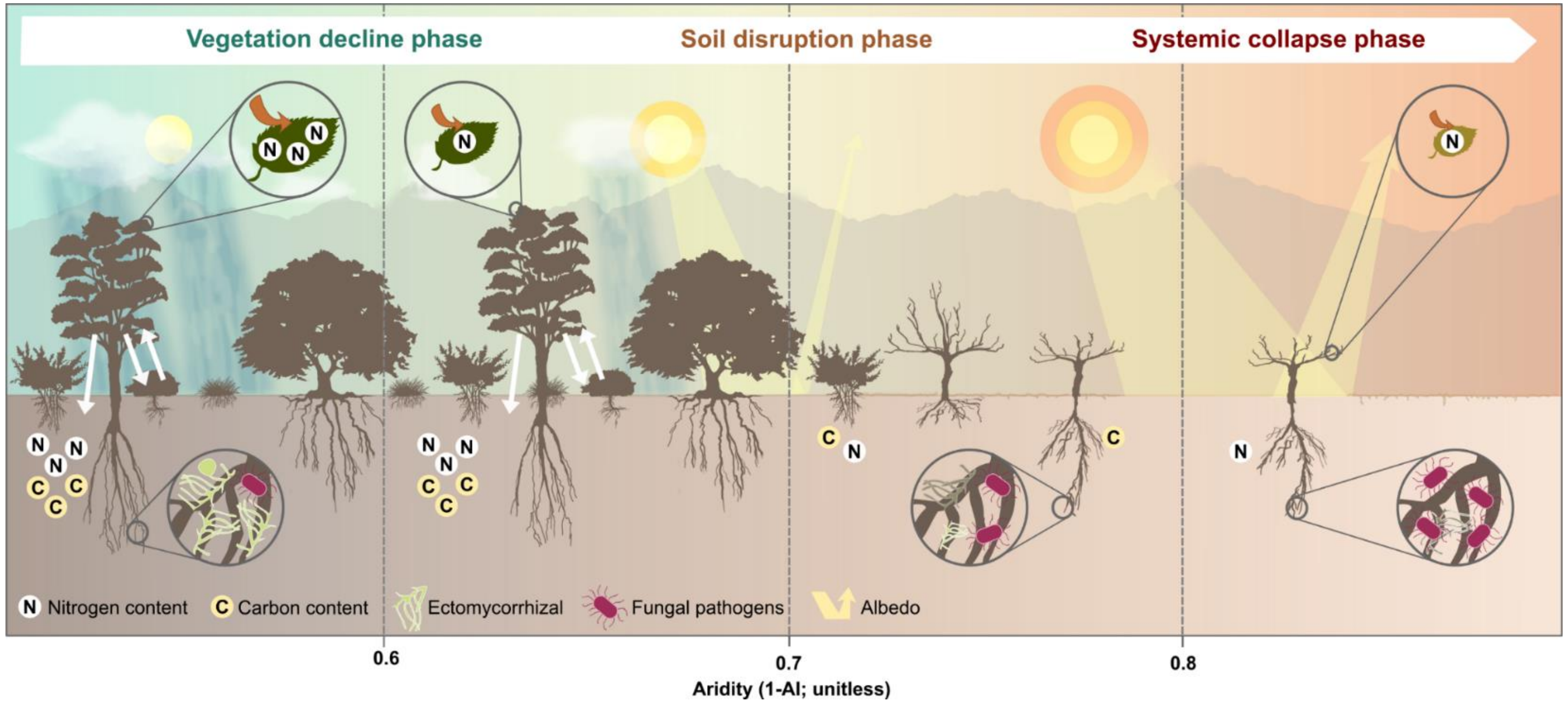


Vegetation decline phase
Soil disruption phase
Systemic collapse phase
Nitrogen content
Carbon content
Ectomycorrhizal
Fungal pathogens
Albedo
0.6
0.7
0.8
Aridity (1-AI; unitless)
Productivity (NDVI, unitless)
8000
6000
4000
2000
0
0.54
0.35 0.45 0.55 0.65 0.75 0.85 0.95
Aridity (1-AI; unitless)
Soil nitrogen content (log transformed, g/kg)
2.5
2.0
1.5
1.0
0.5
0.0
0.71
0.35 0.45 0.55 0.65 0.75 0.85 0.95
Aridity (1-AI; unitless)
Vegetation fractional cover (%)
100
75
50
25
0
0.79
0.35 0.45 0.55 0.65 0.75 0.85 0.95
Aridity (1-AI; unitless)

Science

# Global ecosystem thresholds driven by aridity

Miguel Berdugo, Manuel Delgado-Baquerizo, Santiago Soliveres, Rocío Hernández-Clemente, Yanchuang Zhao, Juan J. Gaitán, Nicolas Gross, Hugo Saiz, Vincent Maire, Anika Lehmann, Matthias C. Rillig, Ricard V. Solé & Fernando T. Maestre

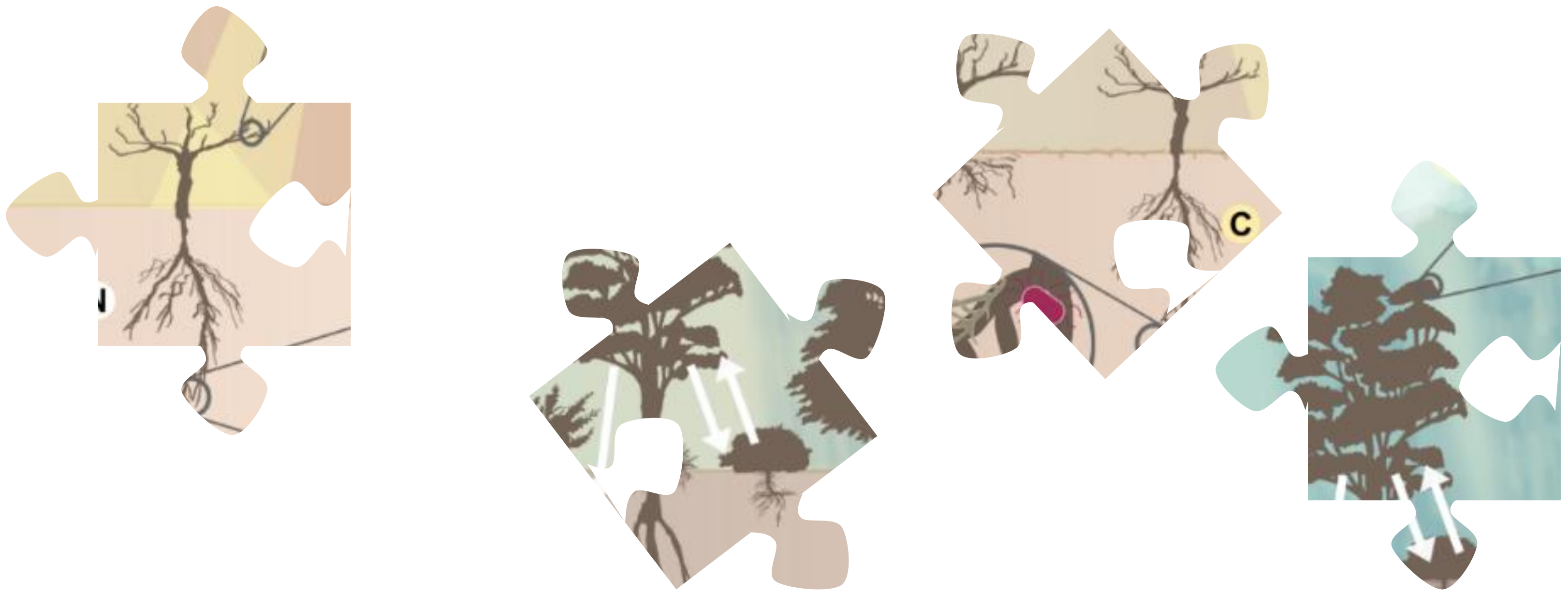


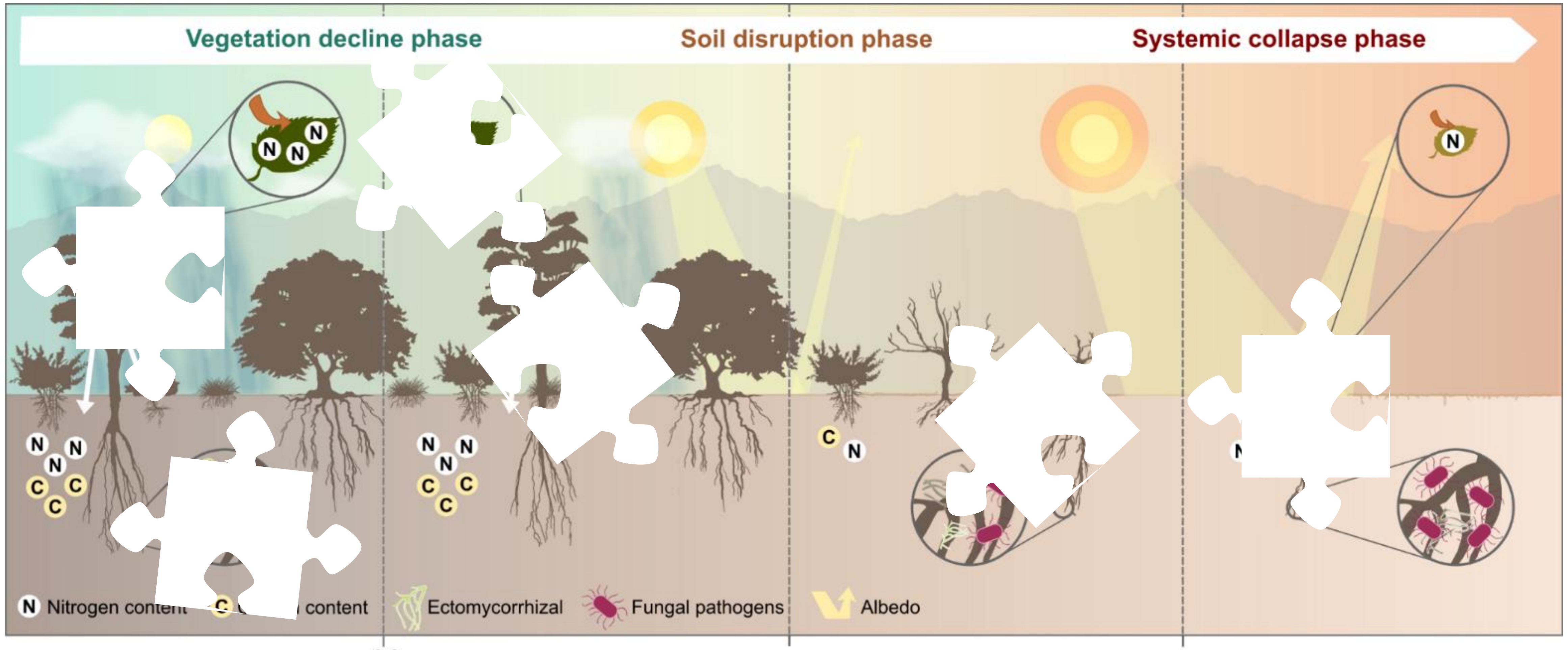

There are three consecutive thresholds of aridity in global drylands producing changes that transform the system in an abrupt or nonlinear way

Functional Ecology
BRITISH ECOLOGICAL SOCIETY

# Ecological mechanisms underlying aridity thresholds in global drylands

Miguel Berdugo, Blai Vidiella, Ricard V. Solé & Fernando T. Maestre



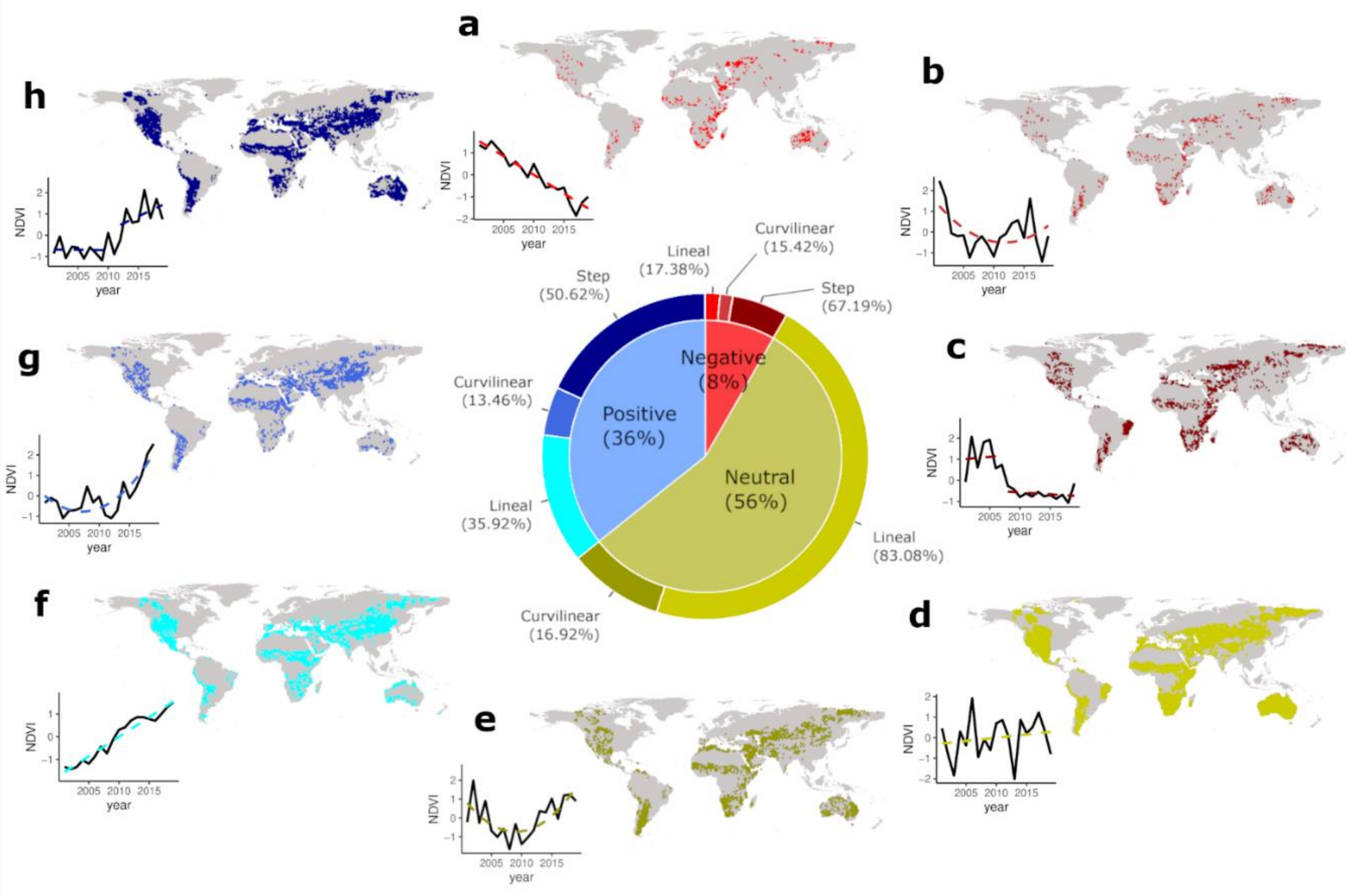




Different mechanisms may operate in each of the aridity thresholds found involving feedback processes across ecosystem components that may explain abruptness and point into some key modulators of abrupt changes for future research

PNAS

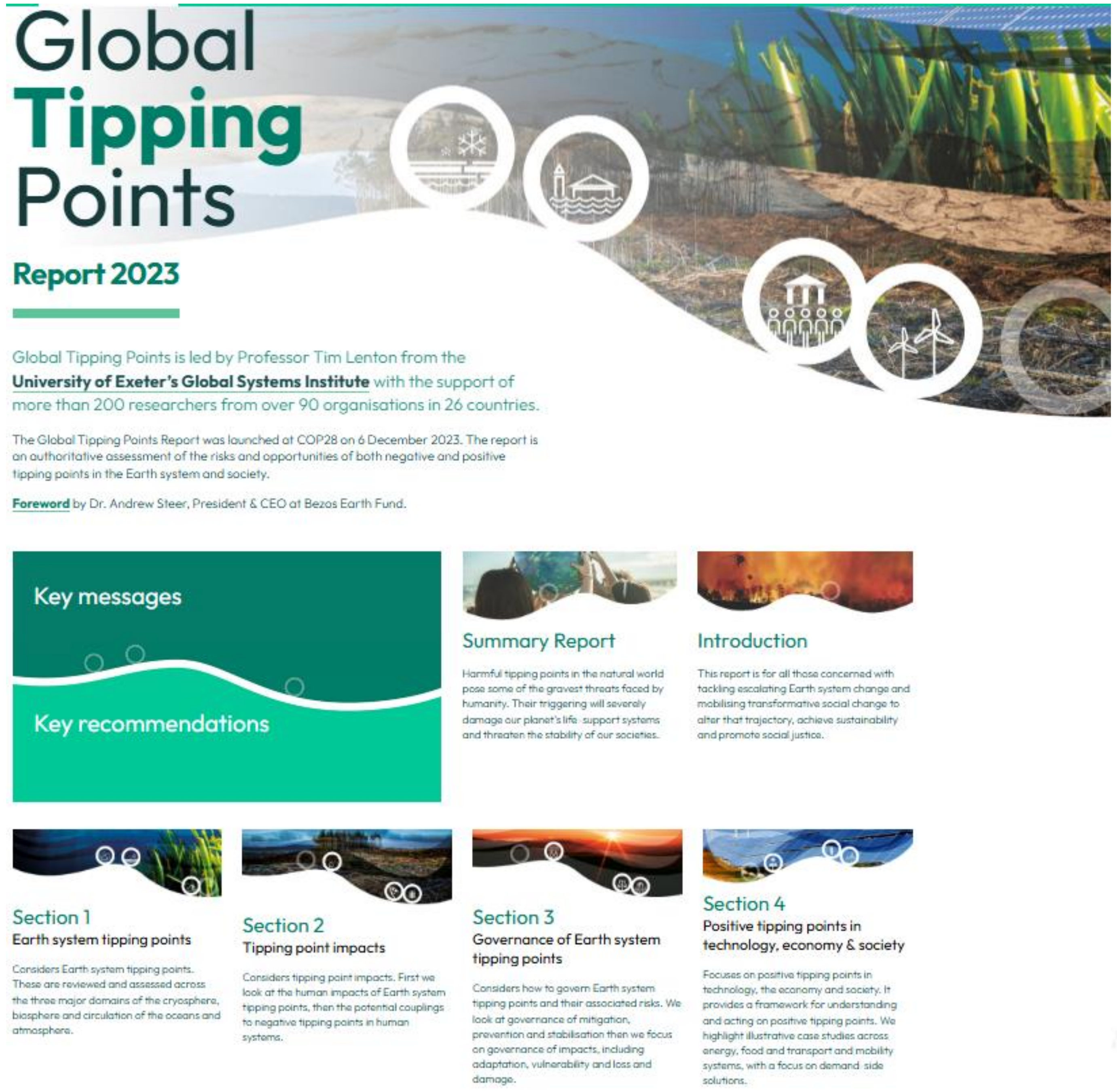
# Prevalence and drivers of abrupt vegetation shifts in global drylands

Miguel Berdugo, Juan J. Gaitan, Manuel Delgado-Baquerizo, Thomas W. Crowther, and Vasilis Dakos


Abrupt losses of vegetation are more common than previously through, and they concentrate around aridity thresholds, providing dynamical evidence of threshold existence

GLOBAL TIPPING POINTS



# Global Tipping Points

## Report 2023

Global Tipping Points is led by Professor Tim Lenton from the **University of Exeter's Global Systems Institute** with the support of more than 200 researchers from over 90 organisations in 26 countries.

The Global Tipping Points Report was launched at COP28 on 6 December 2023. The report is an authoritative assessment of the risks and opportunities of both negative and positive tipping points in the Earth system and society.

**Foreword** by Dr. Andrew Steer, President & CEO at Bezos Earth Fund.

Key messages

Key recommendations

### Summary Report

Harmful tipping points in the natural world pose some of the gravest threats faced by humanity. Their triggering will severely damage our planet's life support systems and threaten the stability of our societies.

### Introduction

This report is for all those concerned with tackling escalating Earth system change and mobilising transformative social change to alter that trajectory, achieve sustainability and promote social justice.

### Section 1
Earth system tipping points

Considers Earth system tipping points. These are reviewed and assessed across the three major domains of the cryosphere, biosphere and circulation of the oceans and atmosphere.

### Section 2
Tipping point impacts

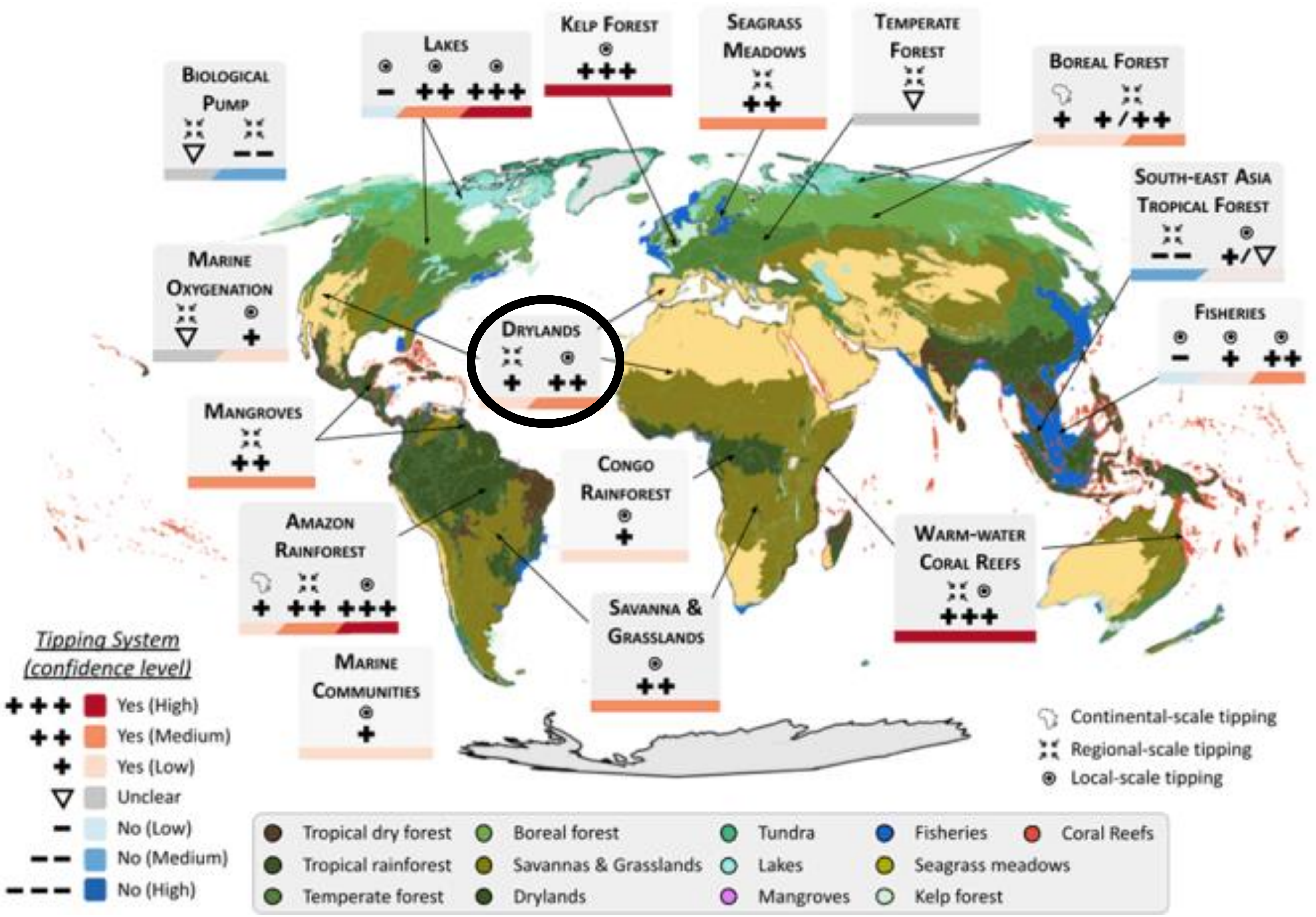
Considers tipping point impacts. First we look at the human impacts of Earth system tipping points, then the potential couplings to negative tipping points in human systems.

### Section 3
Governance of Earth system tipping points

Considers how to govern Earth system tipping points and their associated risks. We look at governance of mitigation, prevention and stabilisation then we focus on governance of impacts, including adaptation, vulnerability and loss and damage.

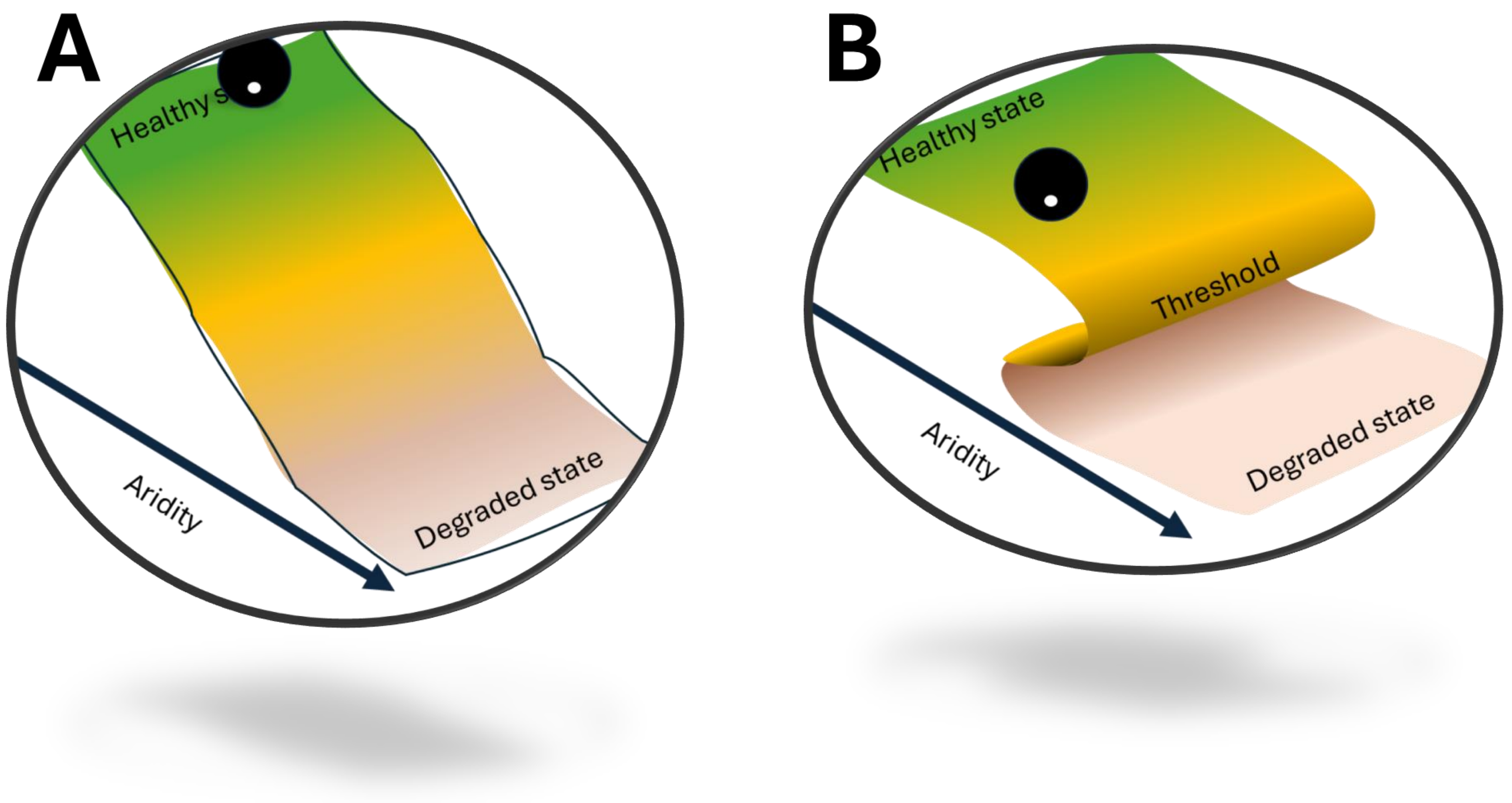
### Section 4
Positive tipping points in technology, economy & society

Focuses on positive tipping points in technology, the economy and society. It provides a framework for understanding and acting on positive tipping points. We highlight illustrative case studies across energy, food and transport and mobility systems, with a focus on demand side solutions.




https://global-tipping-points.org/

**How are drylands?**

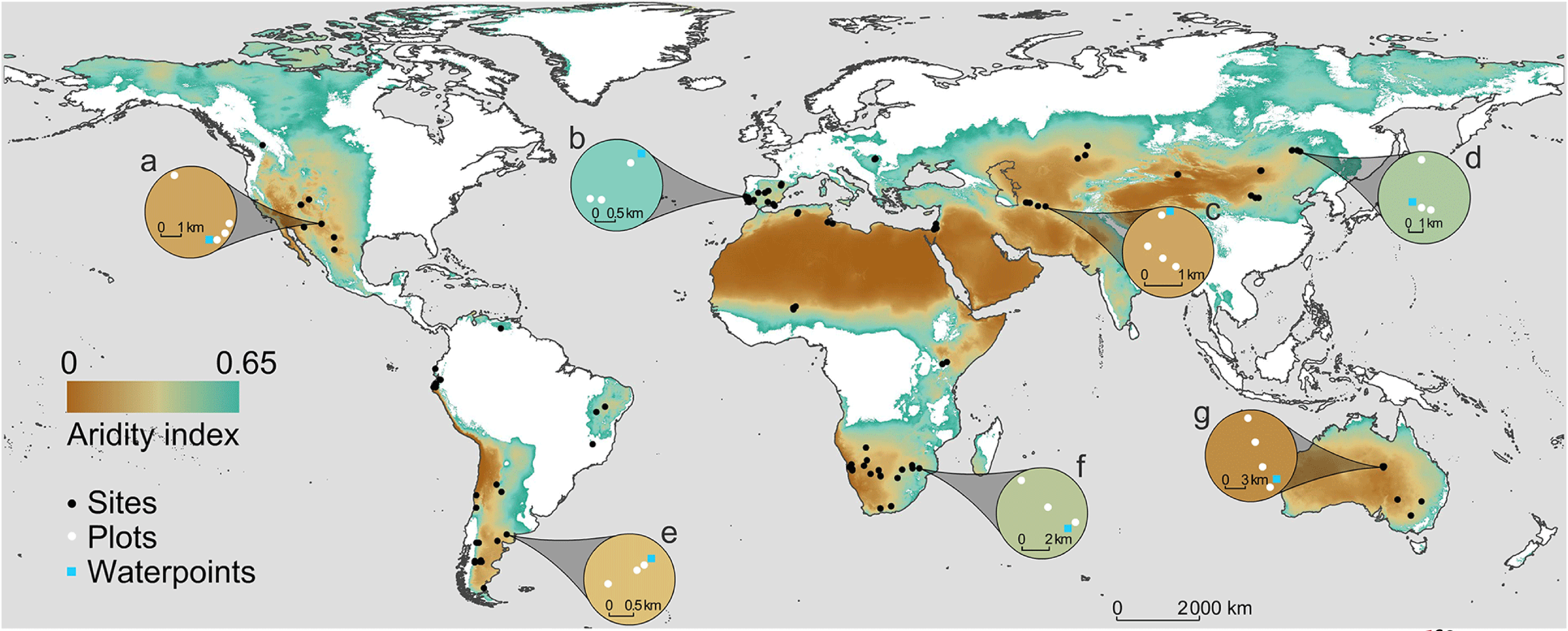



# Long story short…

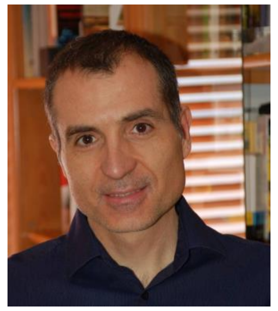
# B; the answer is B

And; what is it the role of grazing?

# The BIODESER project




biodesert



DRYLAND ECOLOGY AND GLOBAL CHANGE LAB

# Previously…

**nature**

**Explore content** ⌄ **About the journal** ⌄ **Publish with us** ⌄

nature > articles > article

Article | Published: 23 December 2015

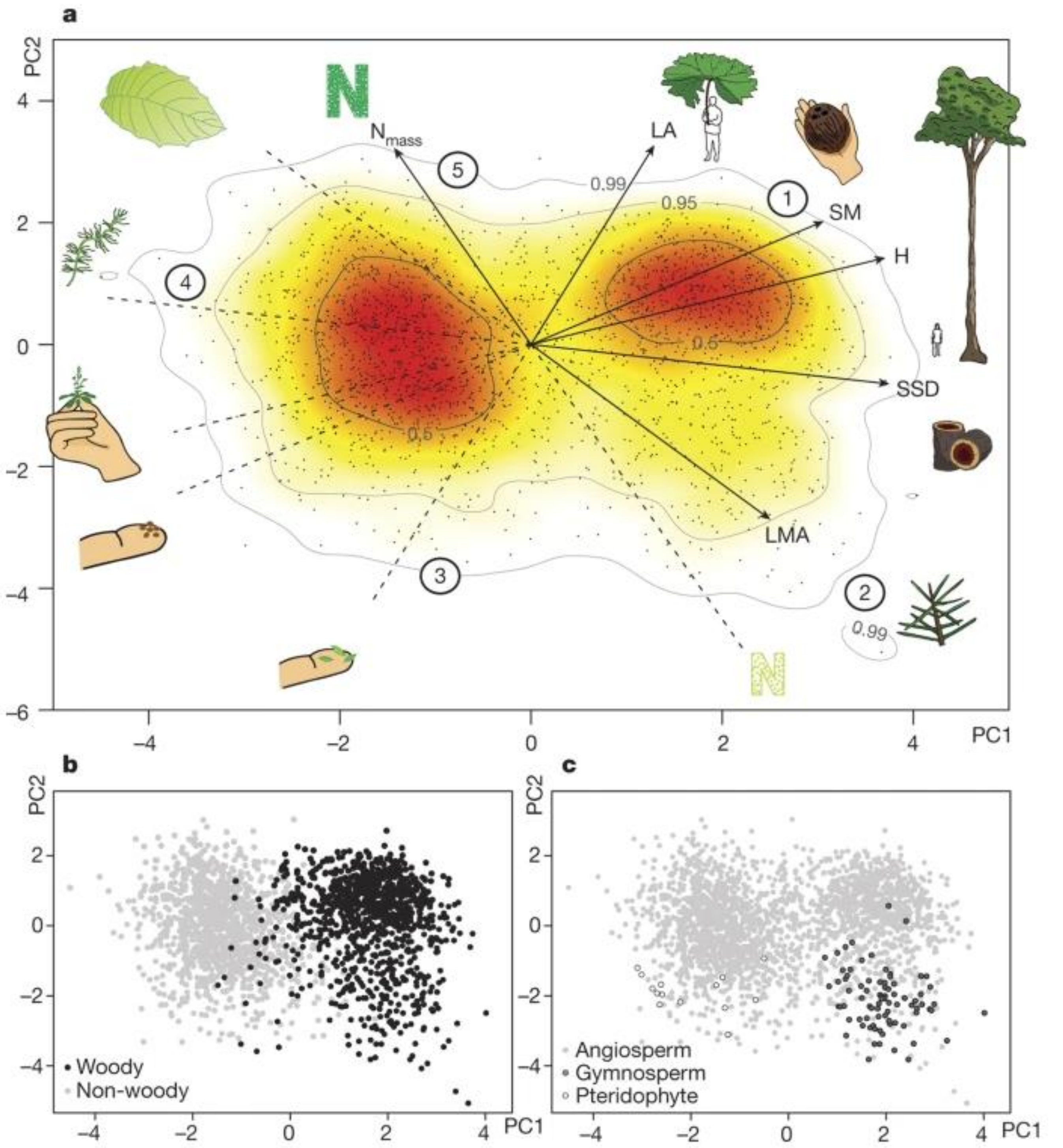
## The global spectrum of plant form and function

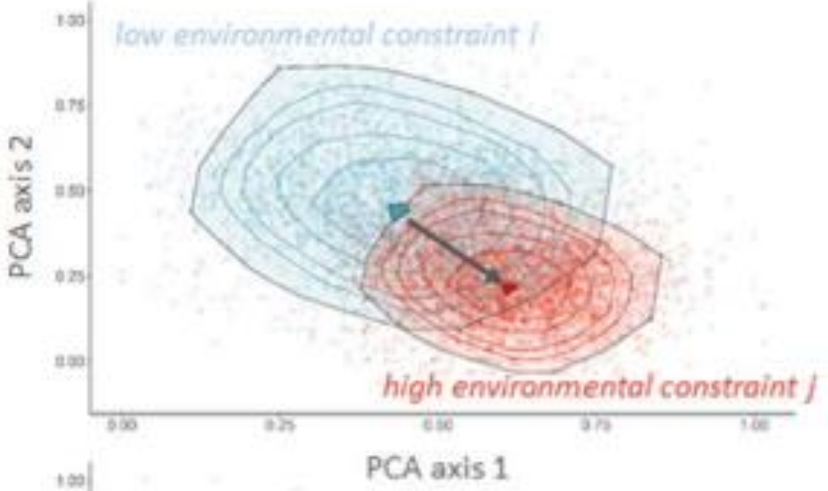
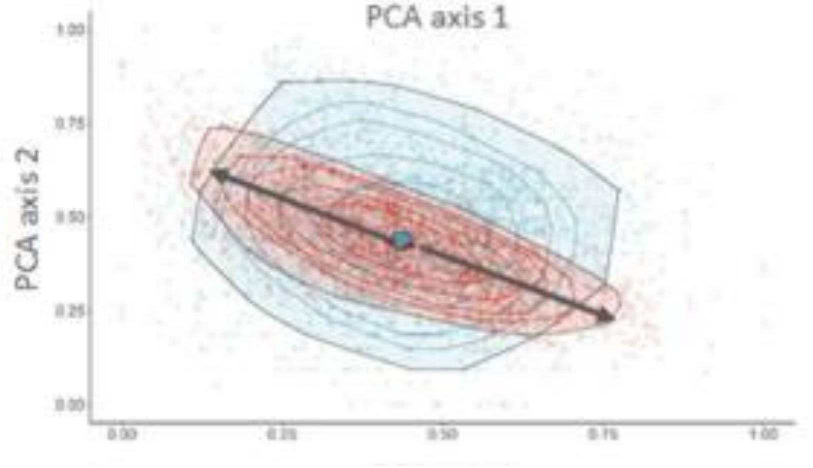
**Revisited**

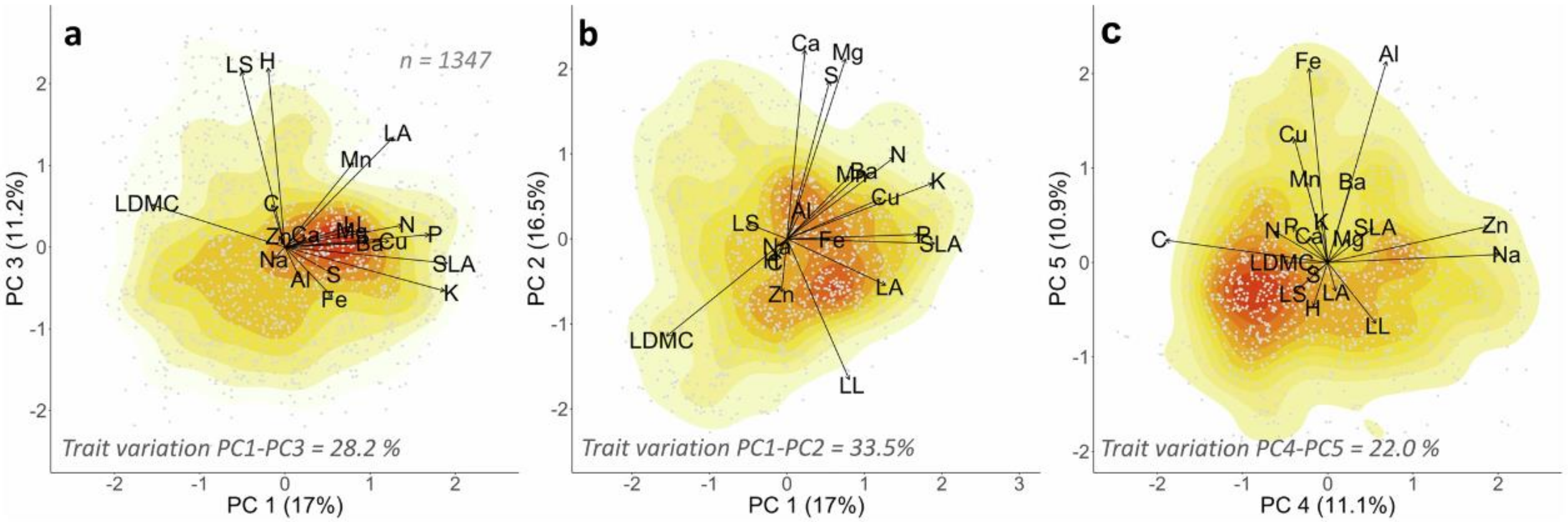
Sandra Díaz ✉, Jens Kattge, Johannes H. C. Cornelissen, Ian J. Wright, Sandra Lavorel, Stéphane Dray, Björn Reu, Michael Kleyer, Christian Wirth, I. Colin Prentice, Eric Garnier, Gerhard Bönisch, Mark Westoby, Hendrik Poorter, Peter B. Reich, Angela T. Moles, John Dickie, Andrew N. Gillison, Amy E. Zanne, Jérôme Chave, S. Joseph Wright, Serge N. Sheremet'ev, Hervé Jactel, Christopher Baraloto, … Lucas D. Gorné

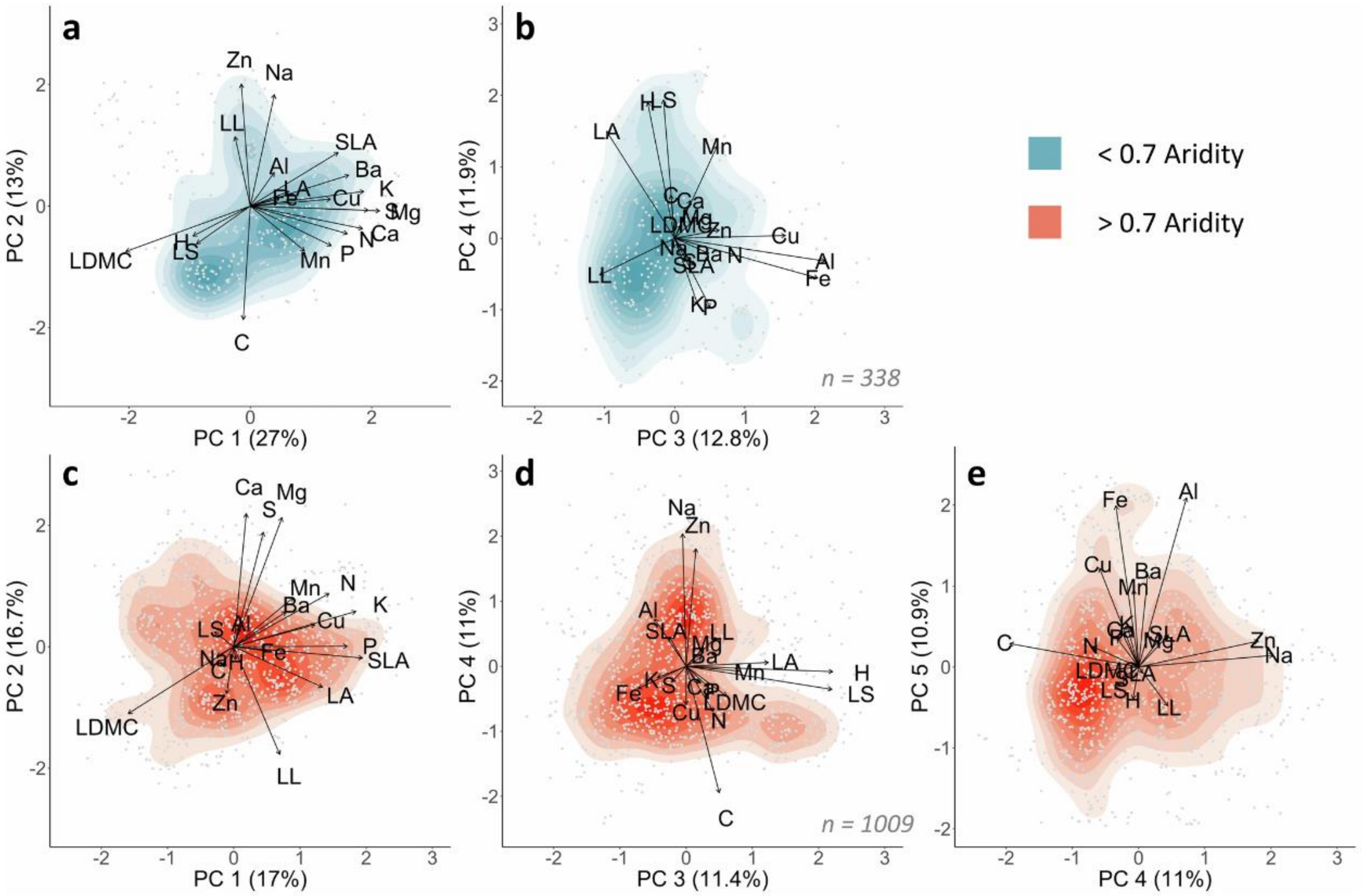
+ Show authors

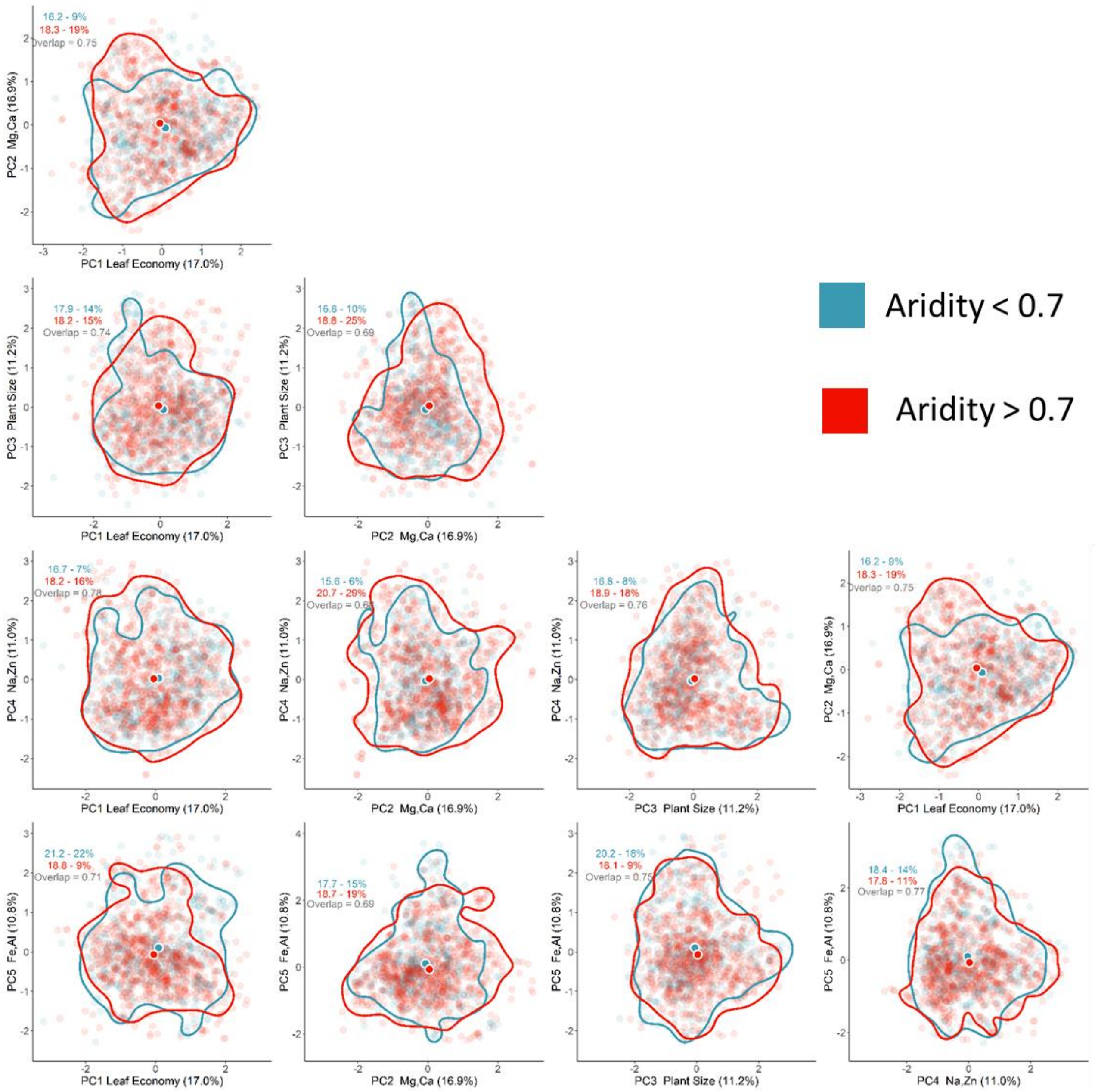
**Figure 2: The global spectrum of plant form and function.**



| Trait space | Observed pattern | Putative mechanisms |
| --- | --- | --- |
| | <u>Increasing environmental constraint</u>: | |
|  | a. Reduce the traits space and shift its location<br><br>Trait covariation i = Trait covariation j<br>Hypervolume i > Hypervolume j | Increasing environmental constraint filter out maladapted species and select species traits according to their match with the environment<br><br>e.g. Species tolerant to aridity or grazing |
|  | b. Reduce the traits space by increasing correlations among traits<br><br>Trait covariation i < Trait covariation j<br>Hypervolume i > Hypervolume j | Increasing environmental constraint act simultaneously on multiple traits and filter out specific trait combinations increasing trade-off among traits<br><br>e.g. Competitive vs. stress-tolerant species |


a
n = 1347
Trait variation PC1-PC3 = 28.2 %
PC 1 (17%)
PC 3 (11.2%)
b
Trait variation PC1-PC2 = 33.5%
PC 1 (17%)
PC 2 (16.5%)
c
Trait variation PC4-PC5 = 22.0 %
PC 4 (11.1%)
PC 5 (10.9%)


a
PC 1 (27%)
PC 2 (13%)
b
n = 338
PC 3 (12.8%)
PC 4 (11.9%)
< 0.7 Aridity
> 0.7 Aridity
c
PC 1 (17%)
PC 2 (16.7%)
d
n = 1009
PC 3 (11.4%)
PC 4 (11%)
e
PC 4 (11%)
PC 5 (10.9%)


Aridity < 0.7
Aridity > 0.7

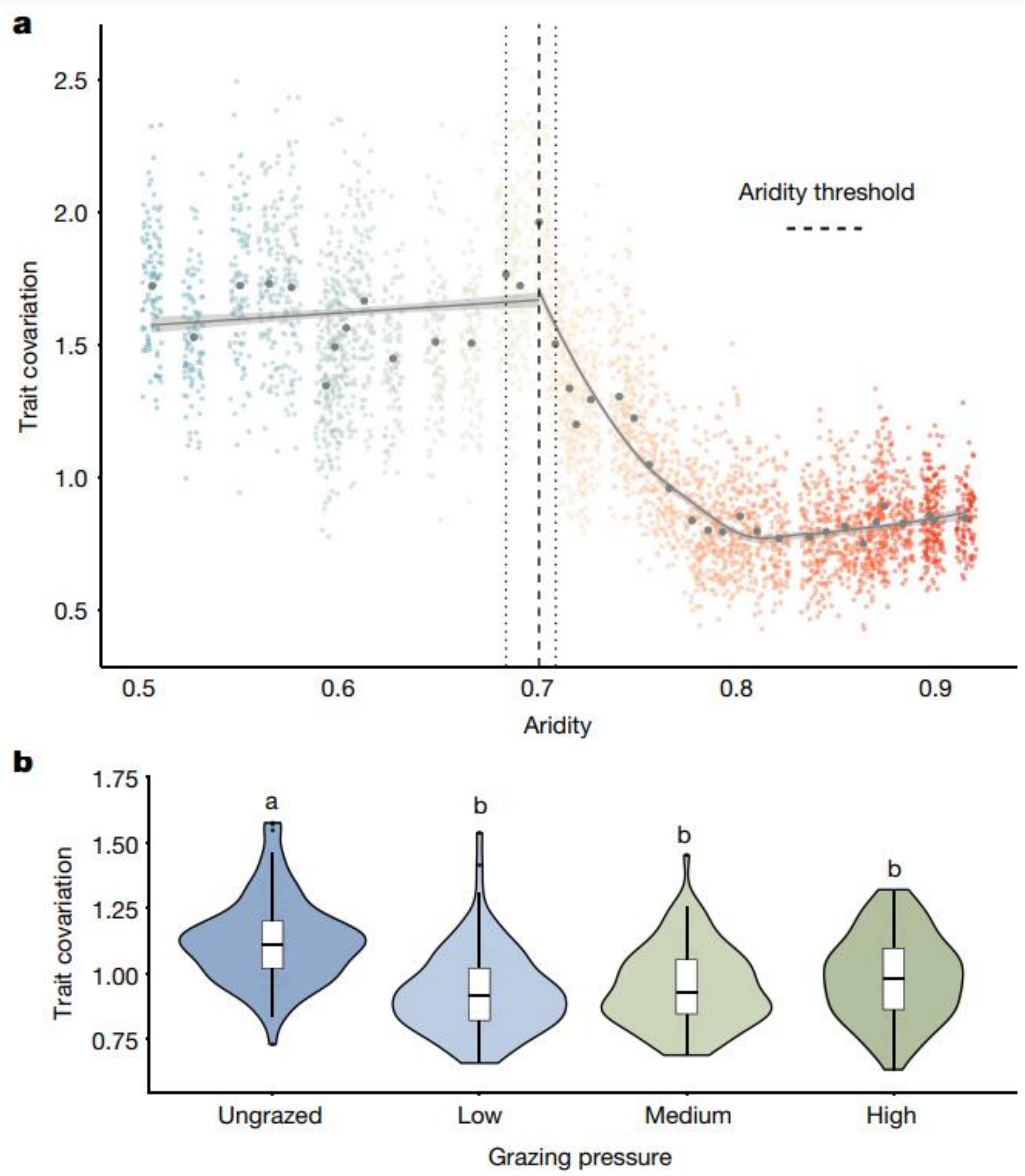
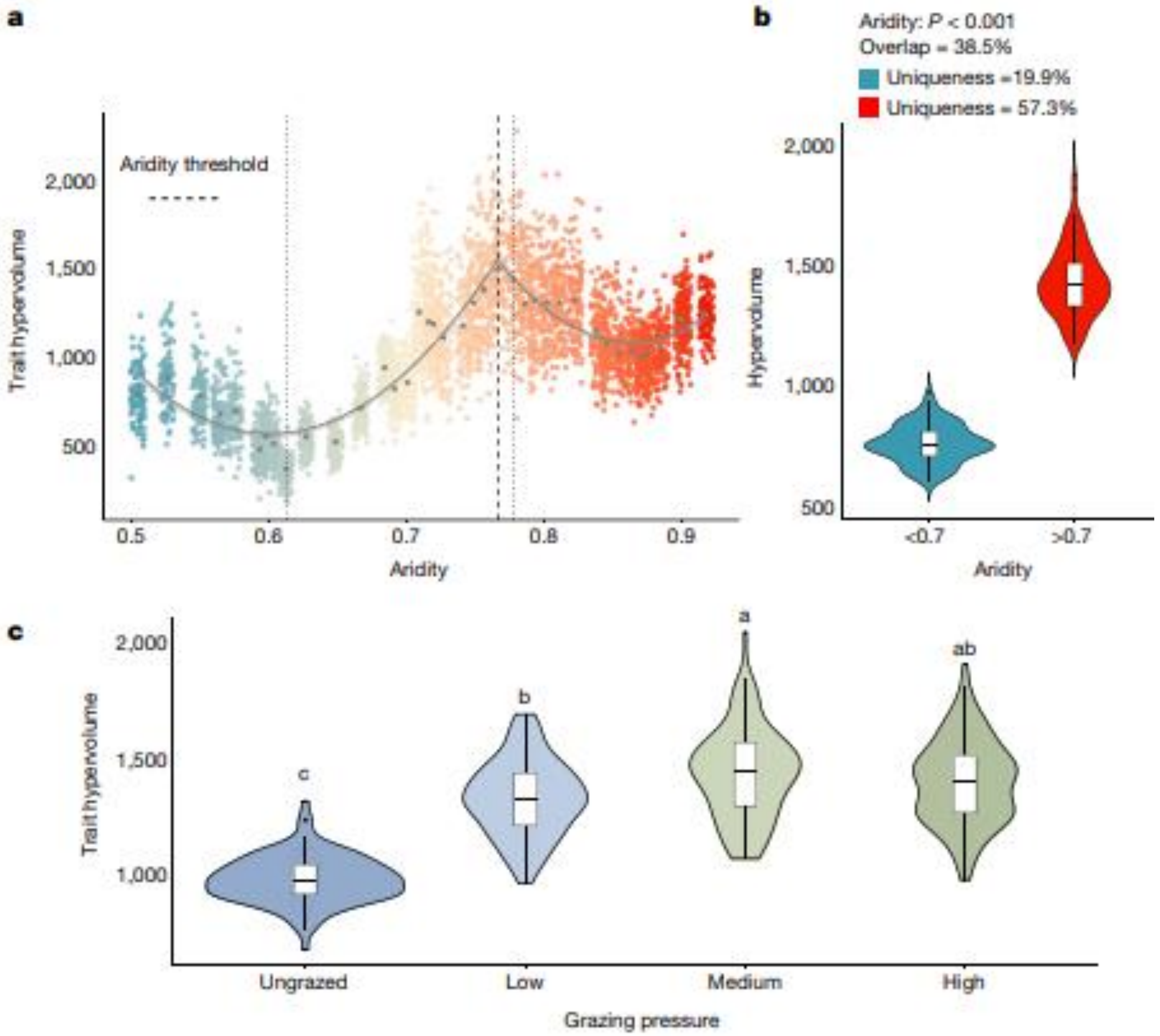
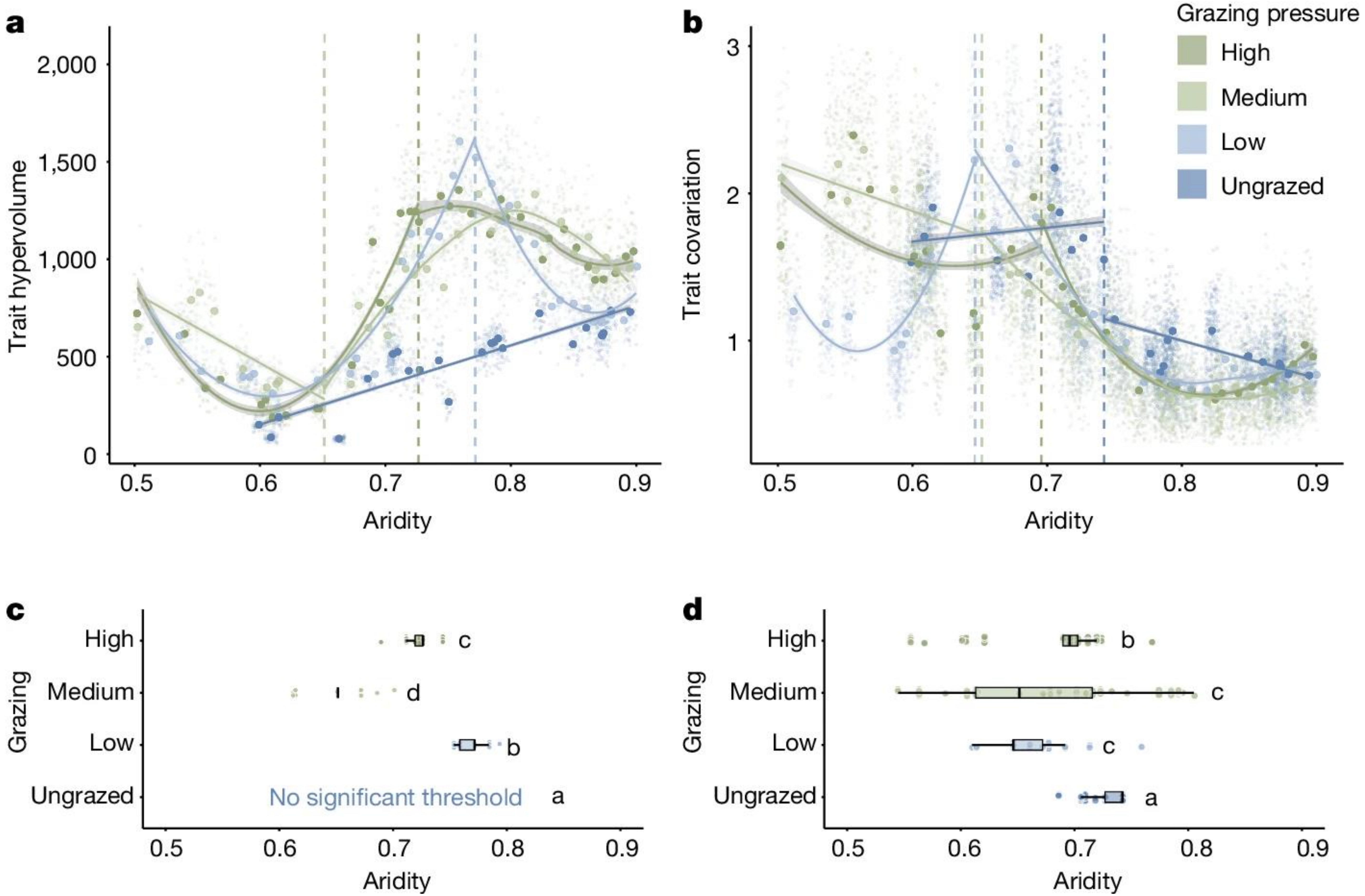



**Fig. 3 | Abrupt changes in trait covariations after crossing the aridity threshold. a**, Strength of trait covariations measured using a phenotypic

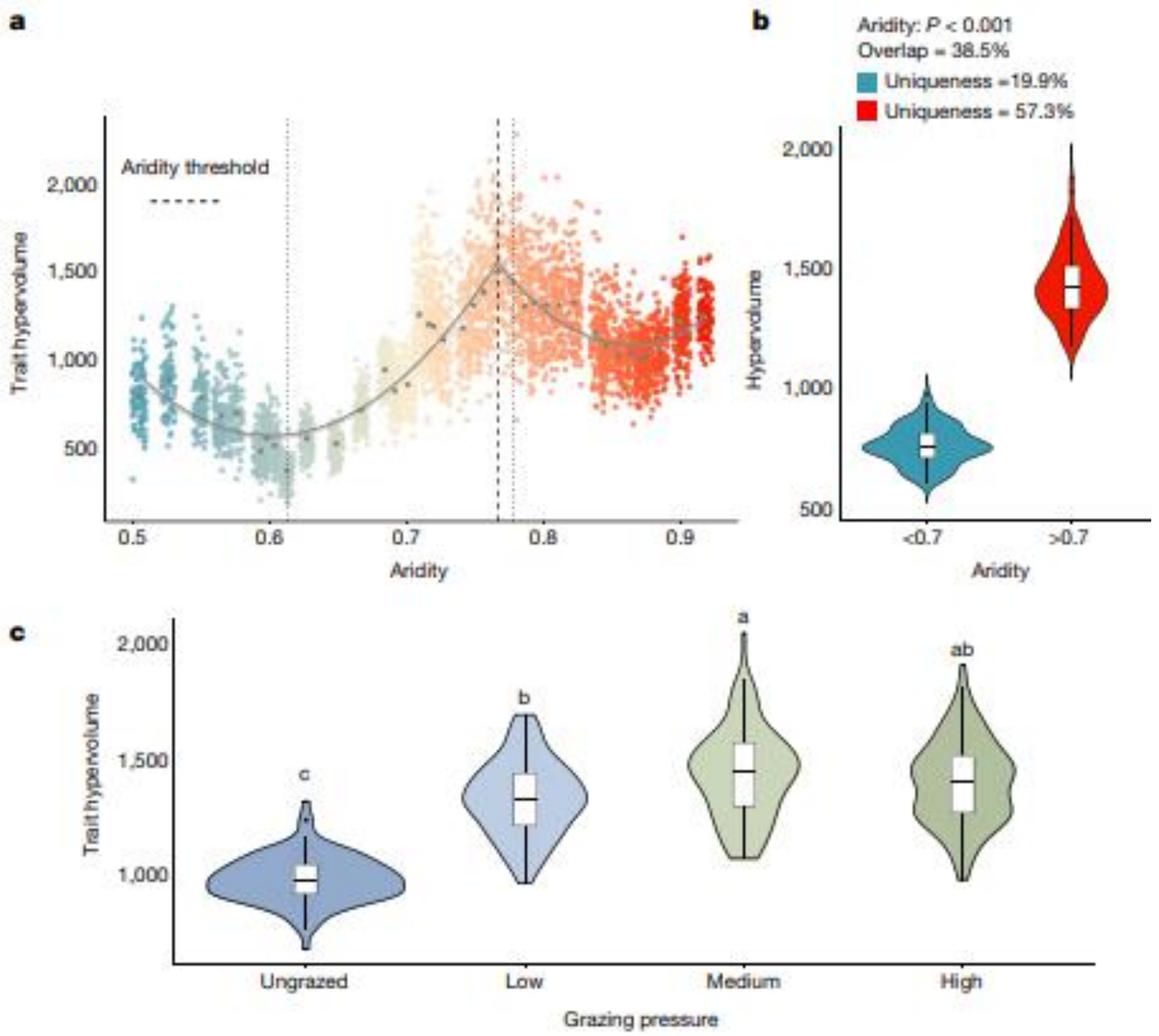



a
Trait hypervolume
2,000
1,500
1,000
500
0
0.5
0.6
0.7
0.8
0.9
Aridity
b
Trait covariation
3
2
1
Grazing pressure
High
Medium
Low
Ungrazed
c
Grazing
High
Medium
Low
Ungrazed
c
d
b
No significant threshold
a
d
b
c
c
a

**Article**

# Unforeseen plant phenotypic diversity in a dry and grazed world

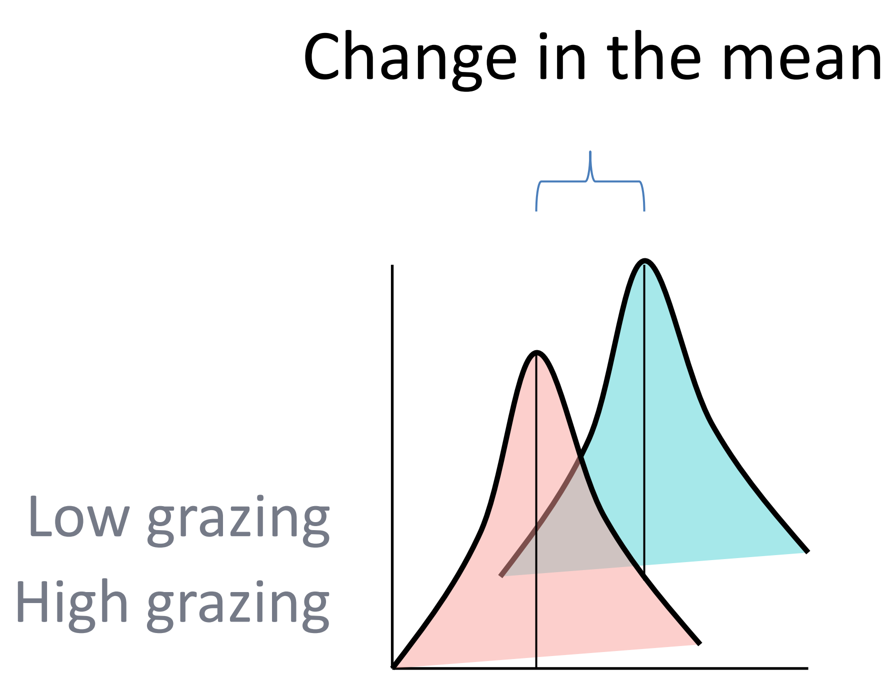
Created by Gan Khoon Lay from the Noun Project



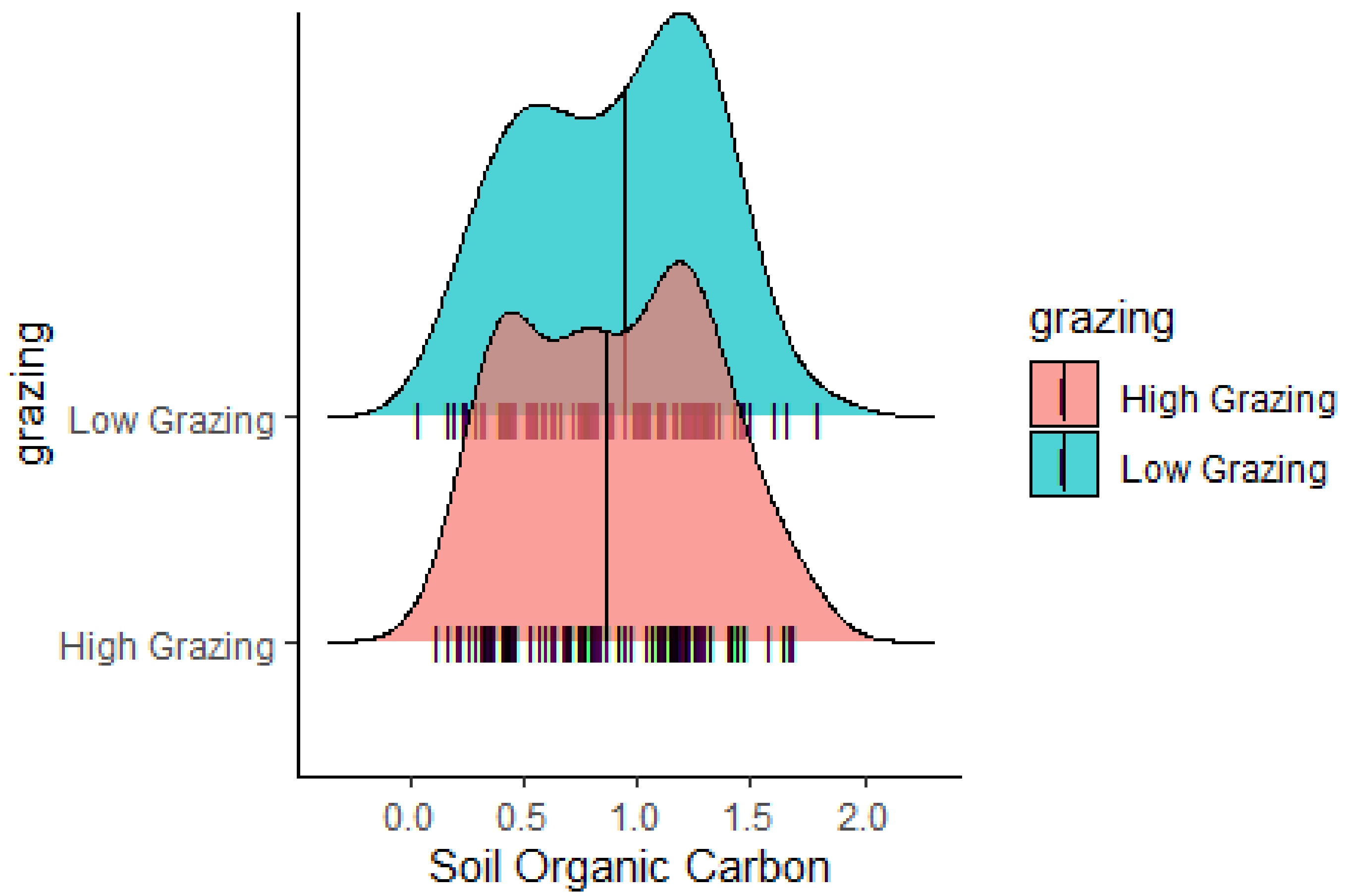


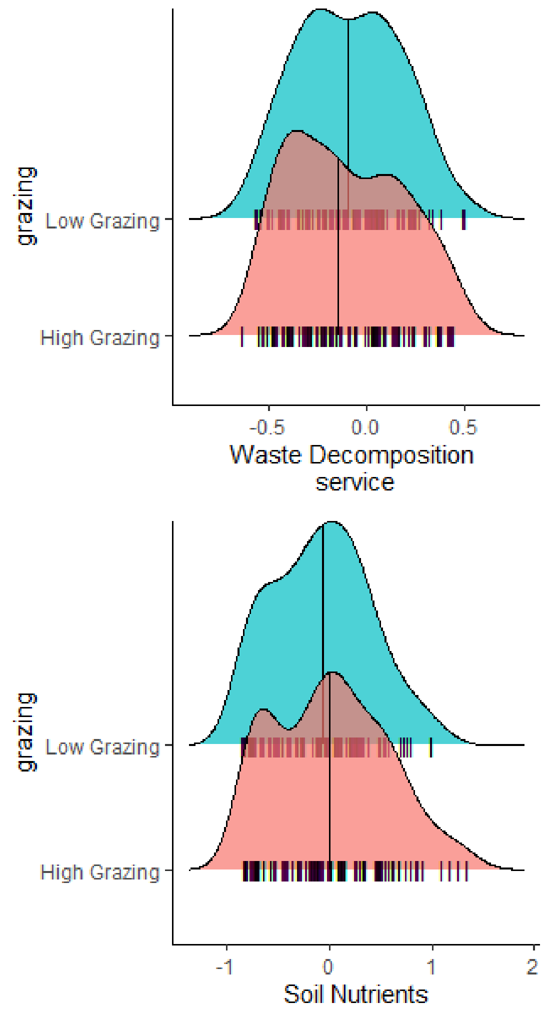
Aridity thresholds separate plant communities which morphological diversity is completely different or appear to be driven by different mechanisms

## Change expected if grazing exerts lineal effect

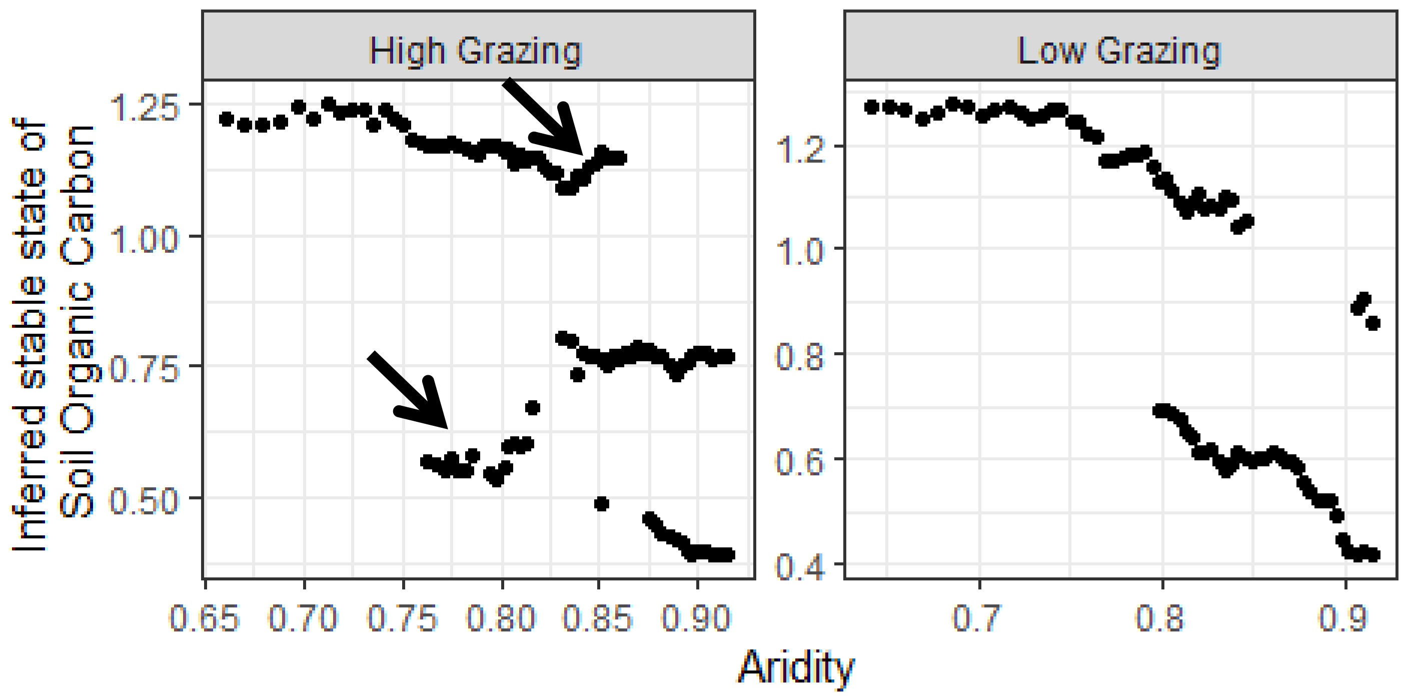


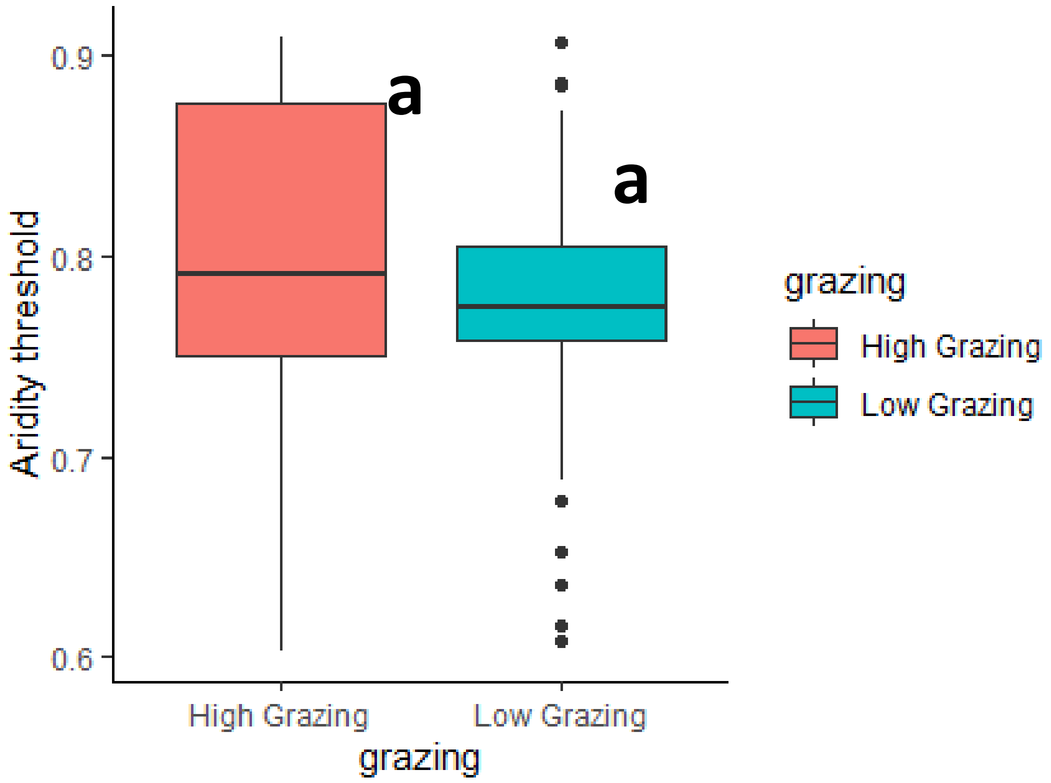

## Changes found



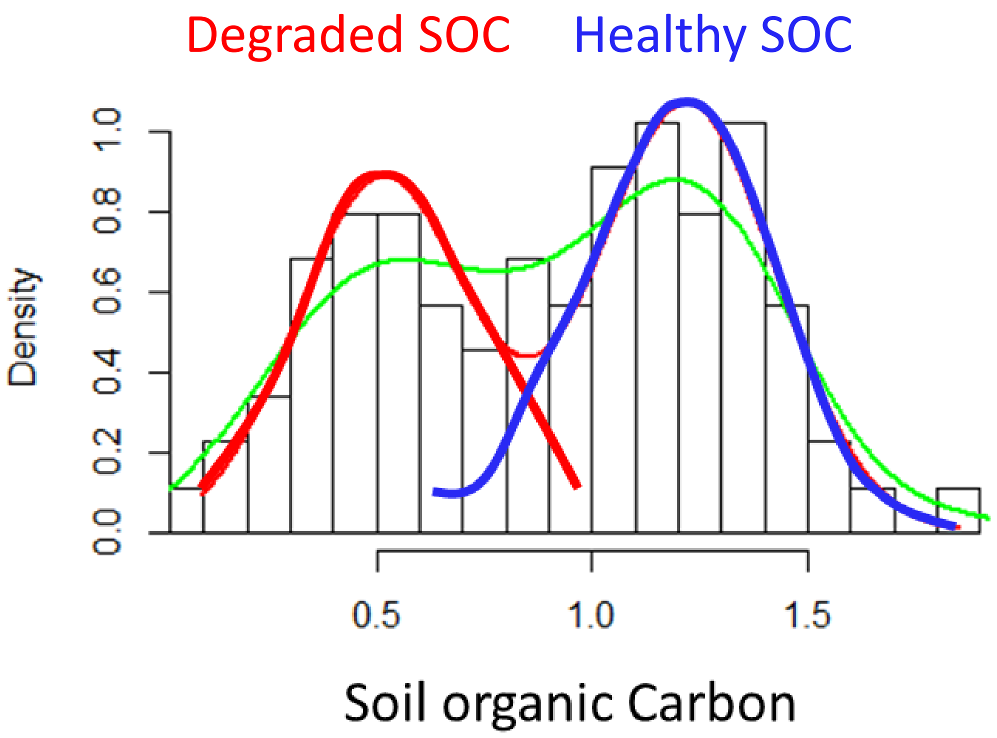



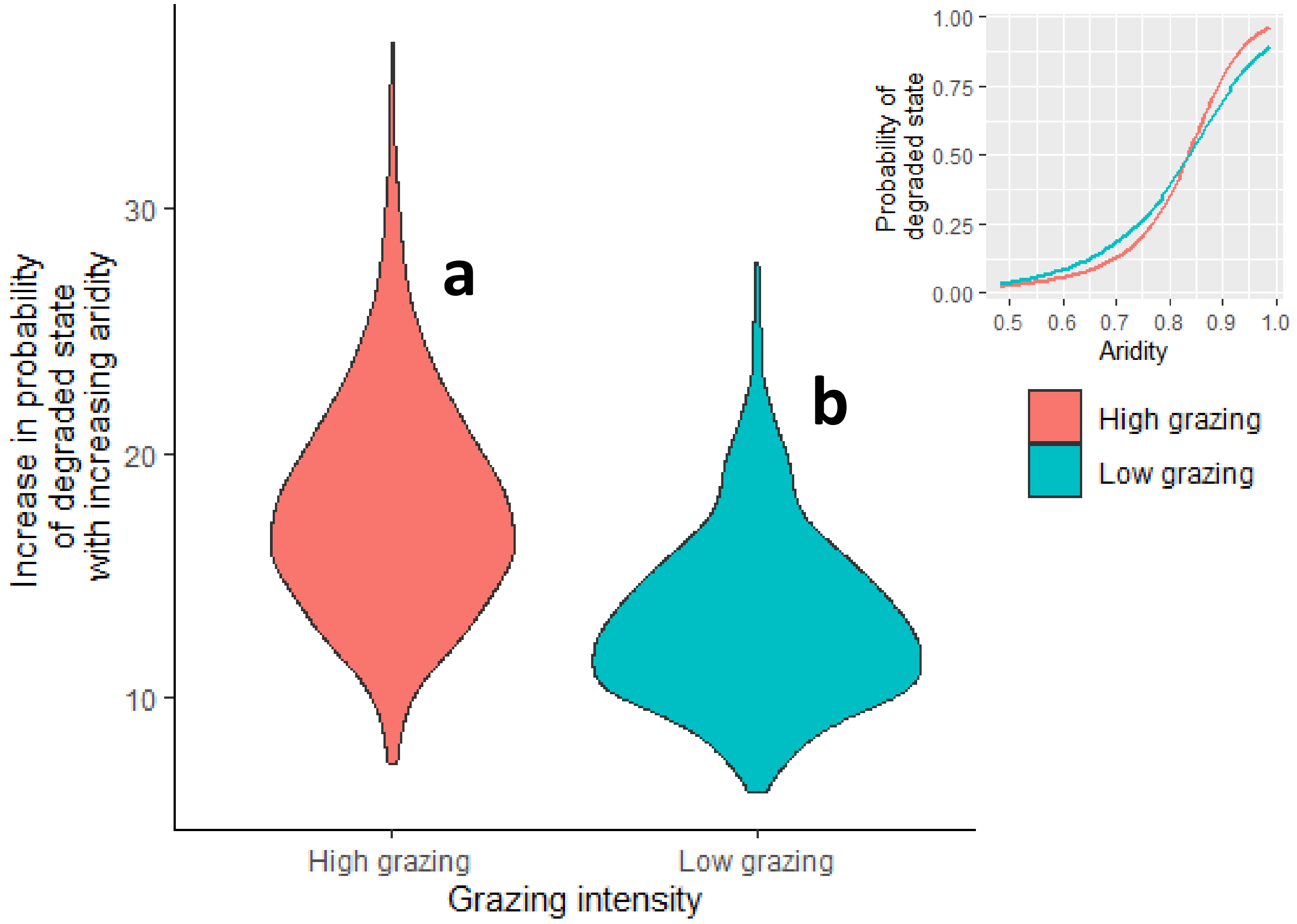

Grazing do not modified the mean value of ecosystem services, but it modifies importantly the distribution of their values, exacerbating bimodality and suggesting for stronger presence of stable states



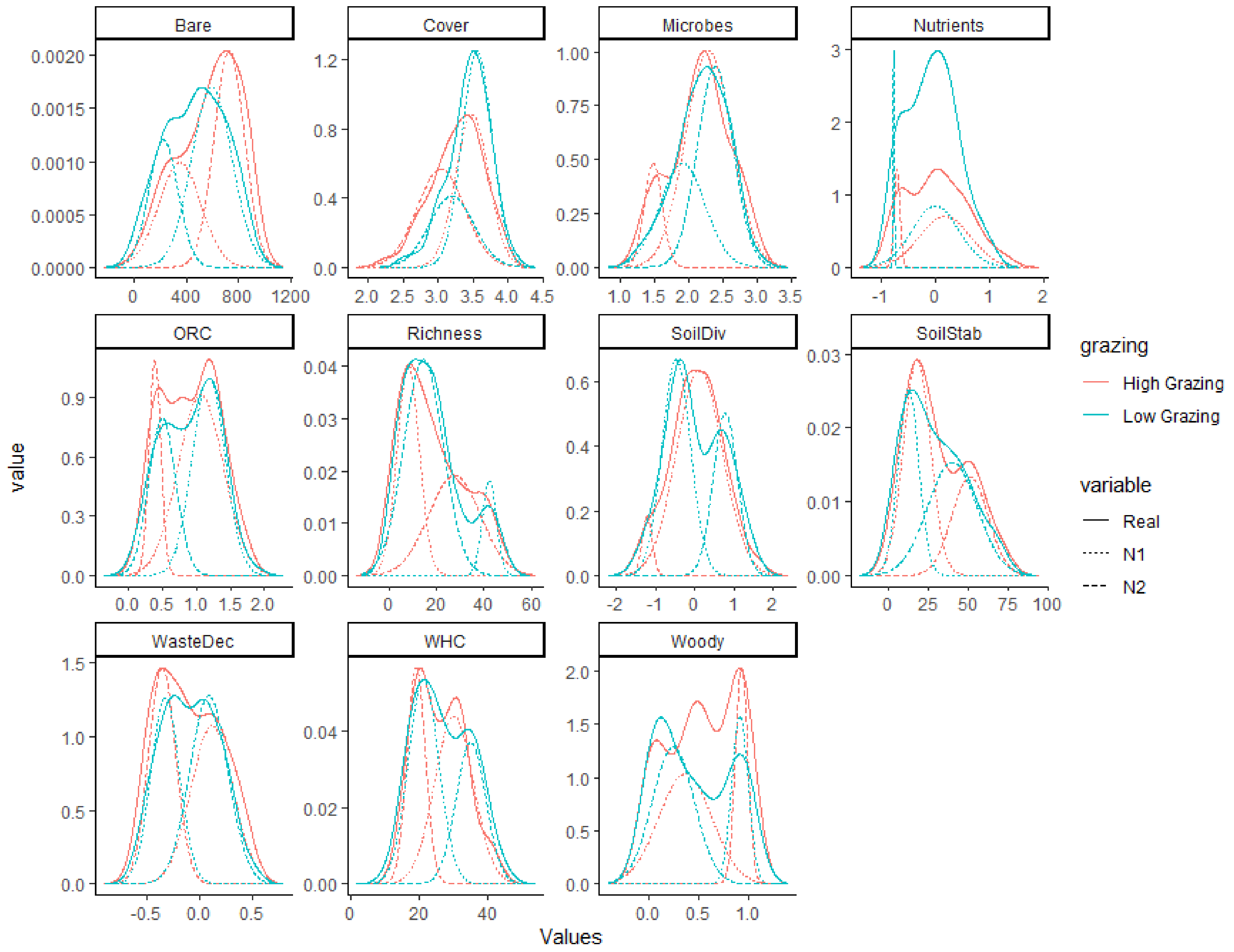




Those stable states configure through aridity gradients with slight modifications in high vs low grazing sites.
Values of aridity thresholds, however are not significantly modified*

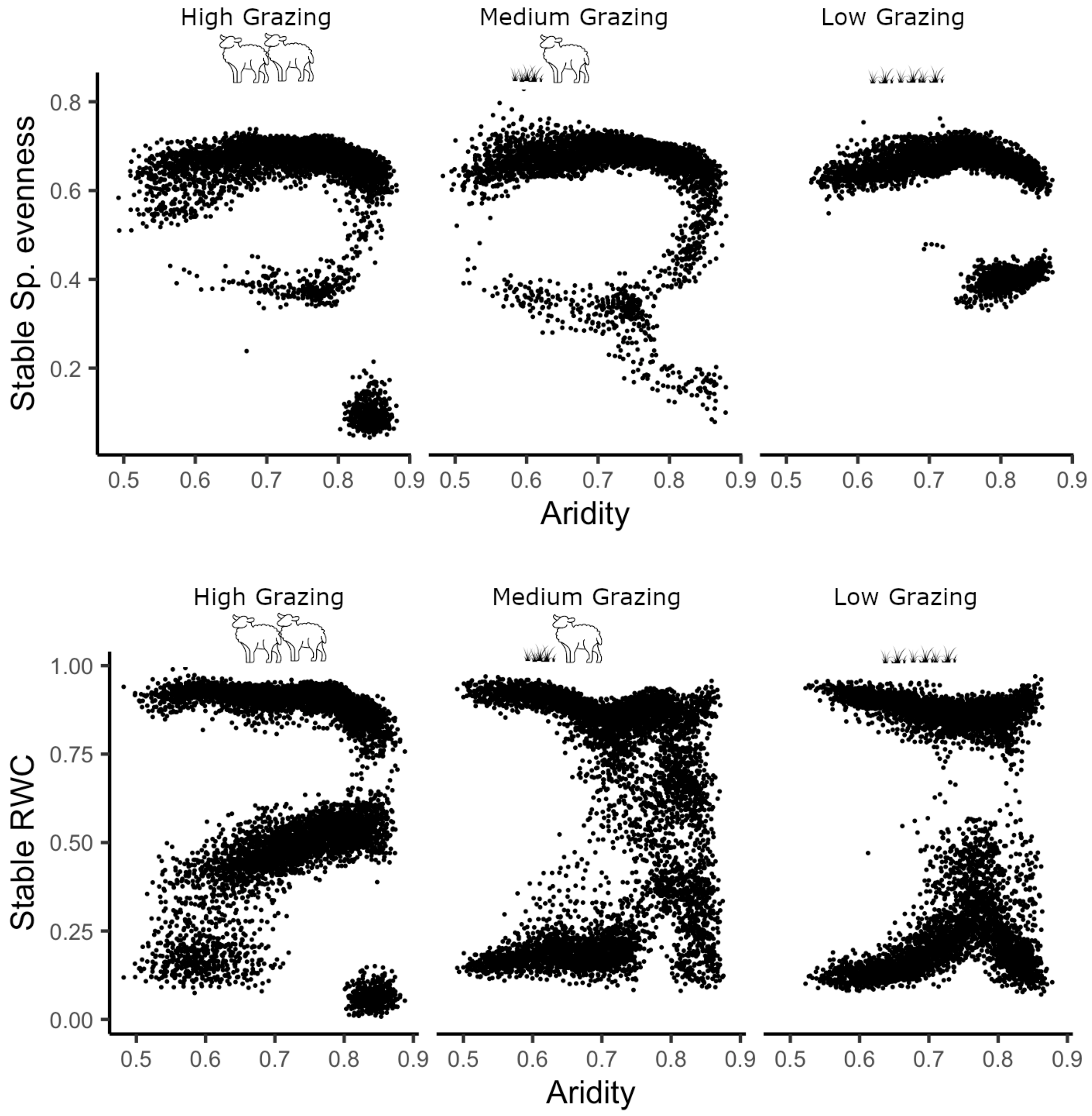



Instead what we observe is that, is the change from a healthy to a degraded state of SOC along aridity gradients are significantly more steep in high grazing places than in low grazing ones.

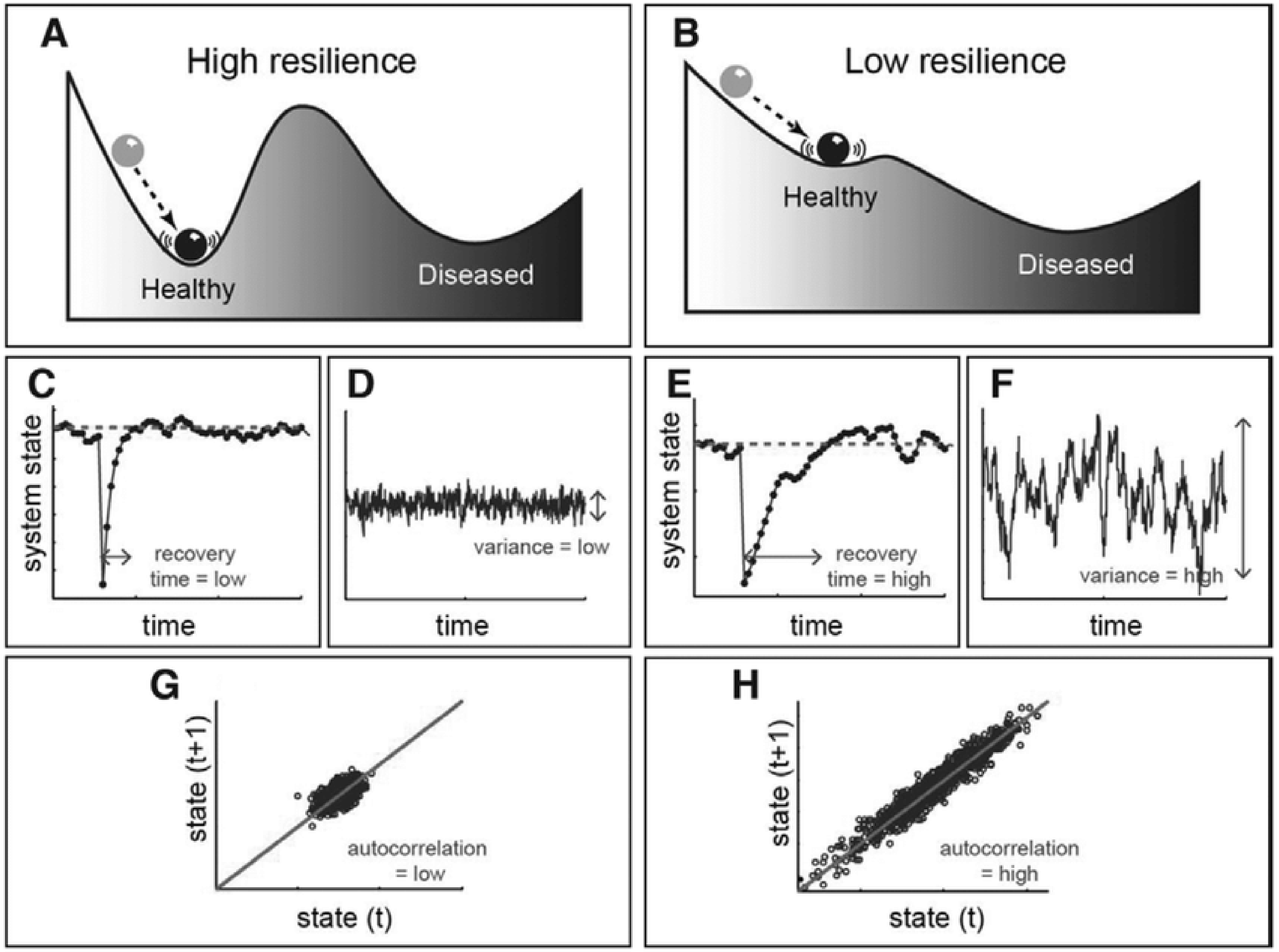


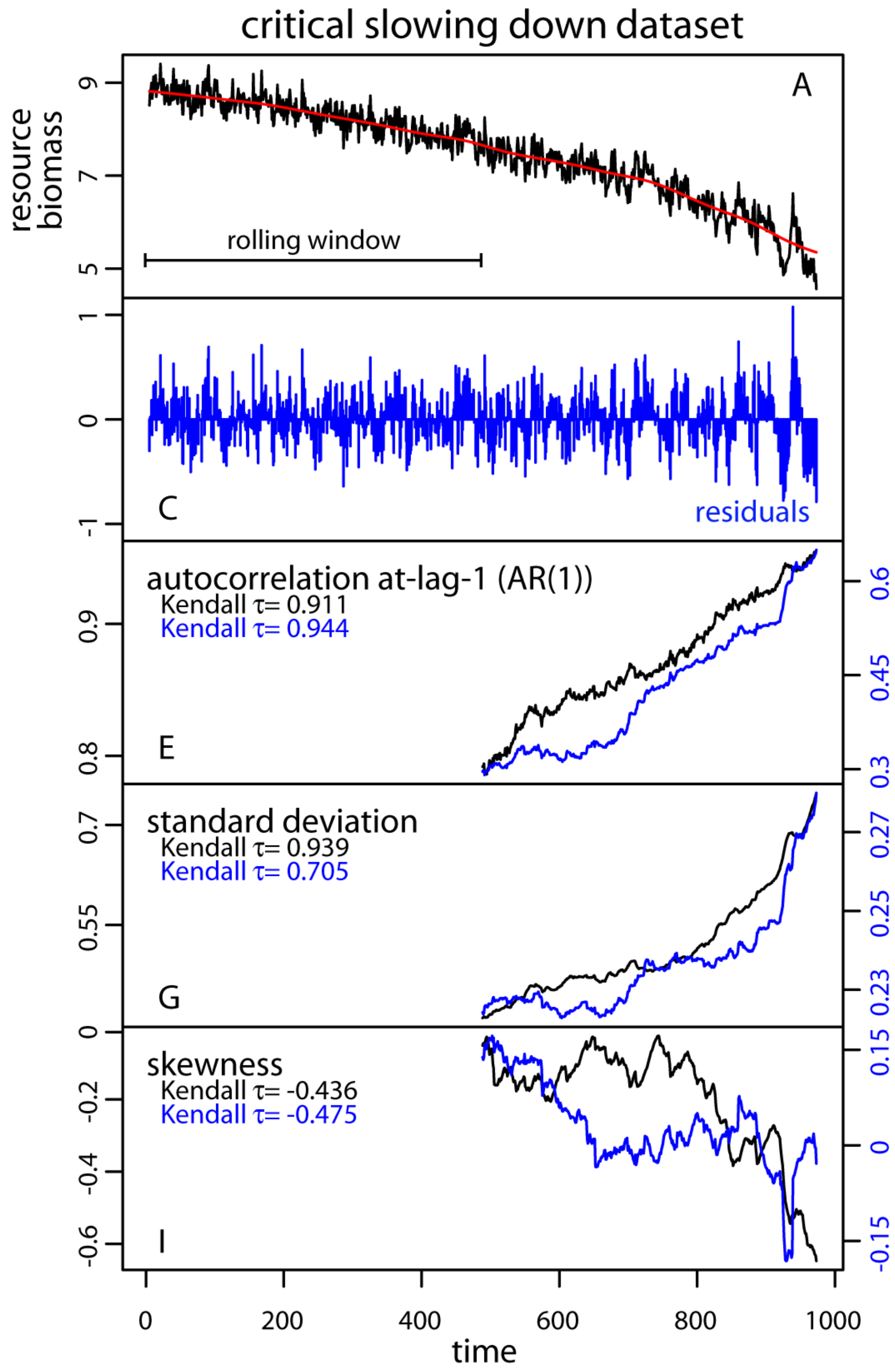
Bare
Cover
Microbes
Nutrients
ORC
Richness
SoilDiv
SoilStab
WasteDec
WHC
Woody
value
Values
grazing
High Grazing
Low Grazing
variable
Real
N1
N2




So; if you put grazing into the equation the threshold is still there. Maybe more abrupt

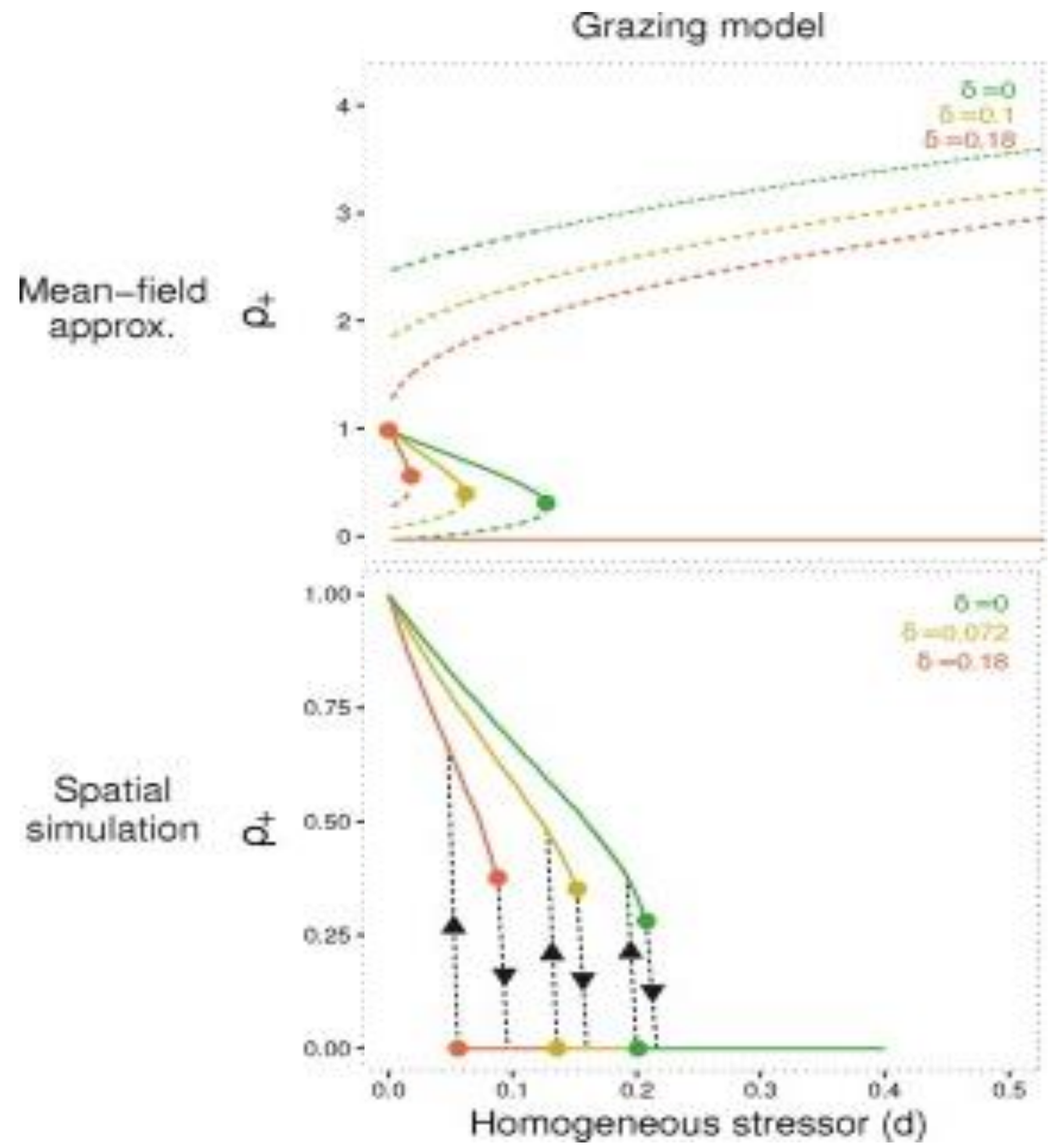
# Early warning signals

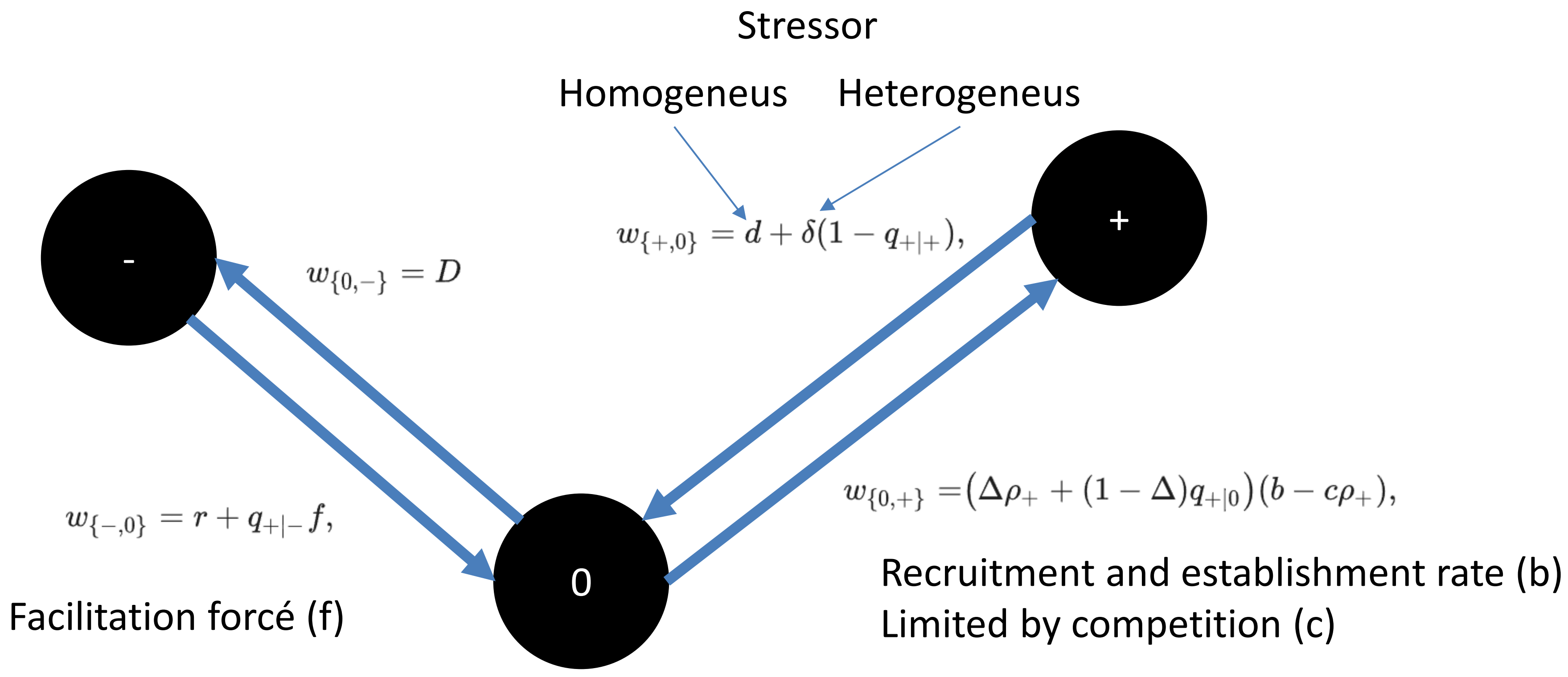


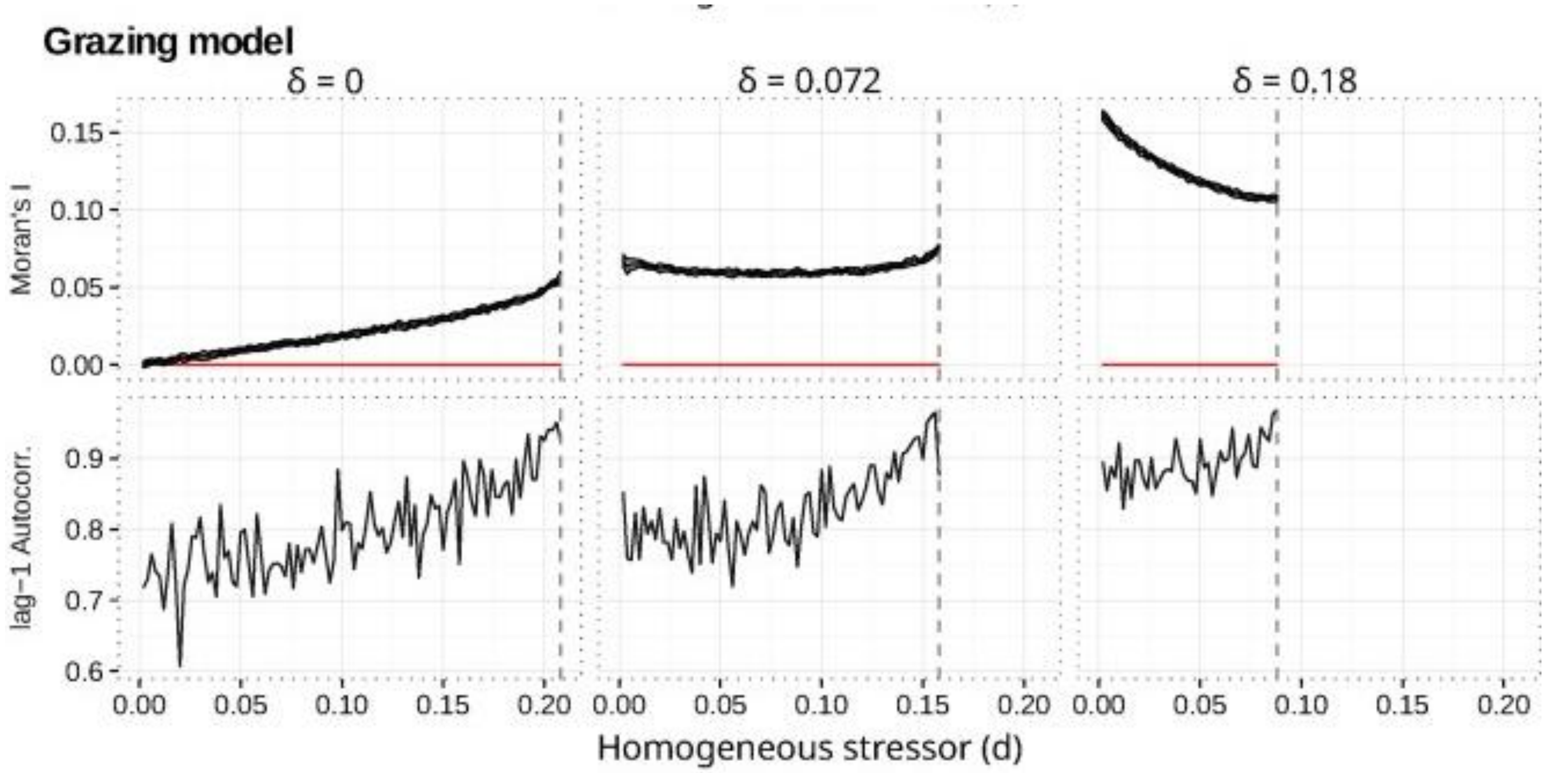




Dakos et al., 2012 PlosONE

# Grazing may mask EWS performance



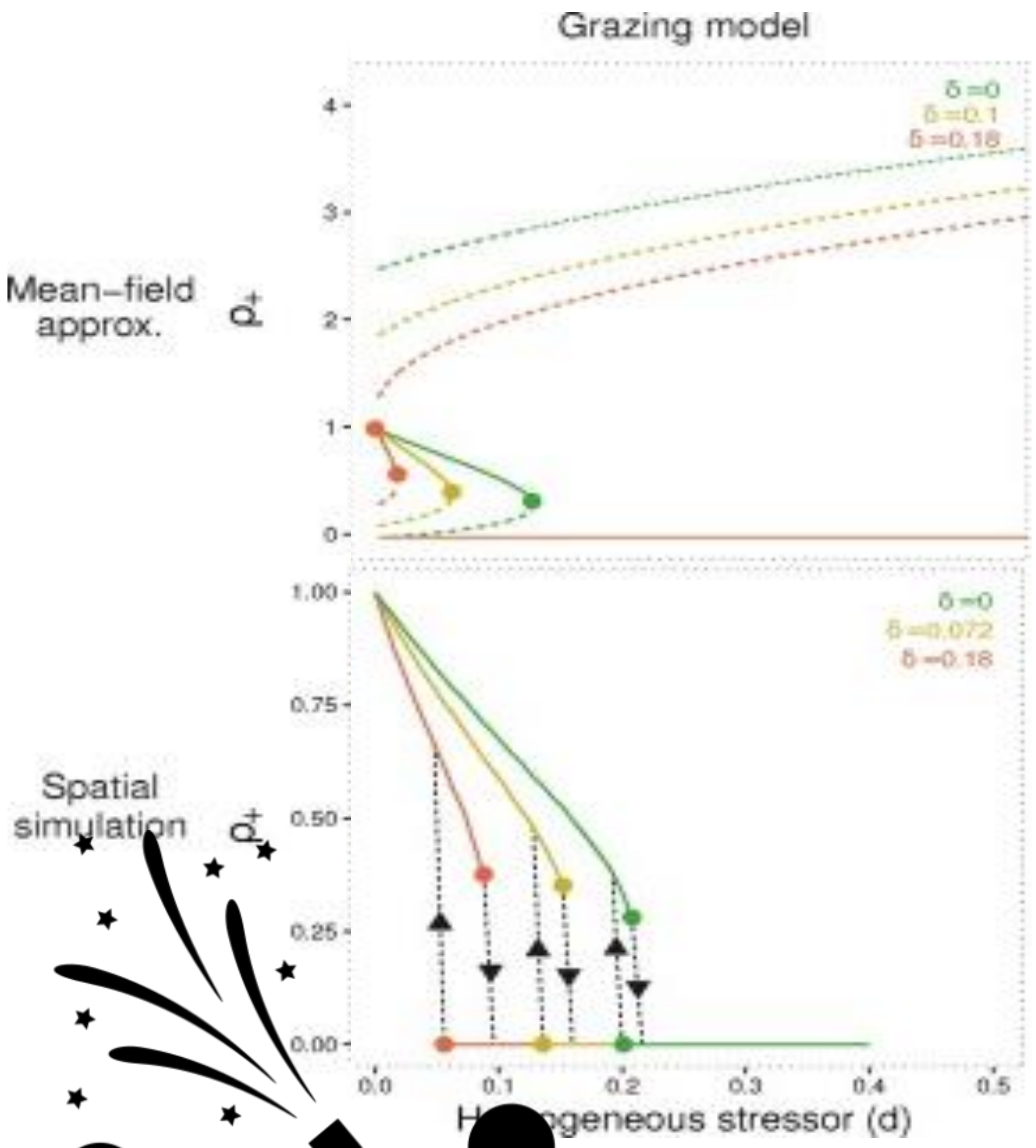



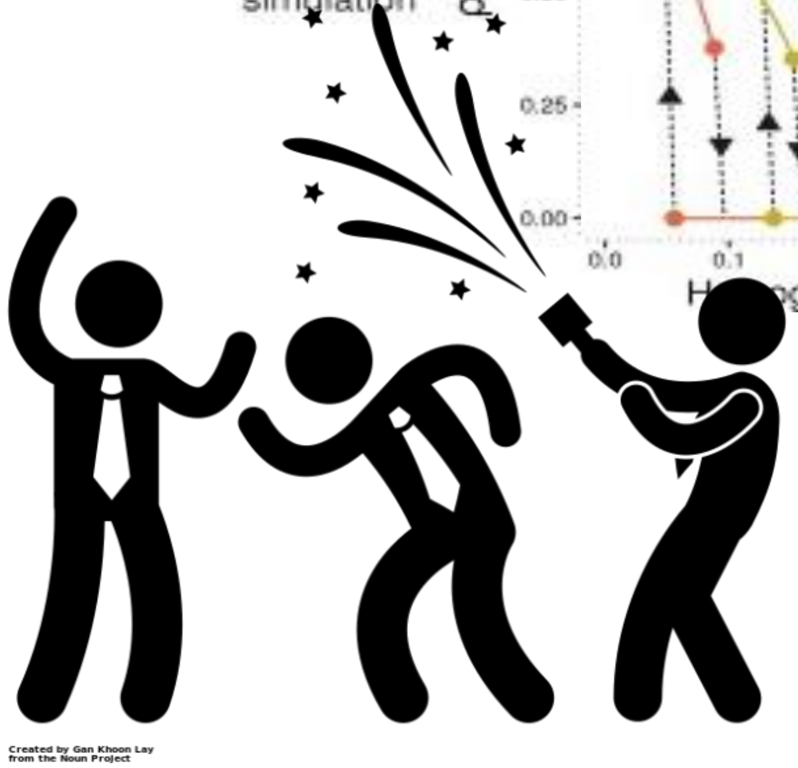
Ecological Indicators
Volume 94, Part 1, November 2018, Pages 520-533

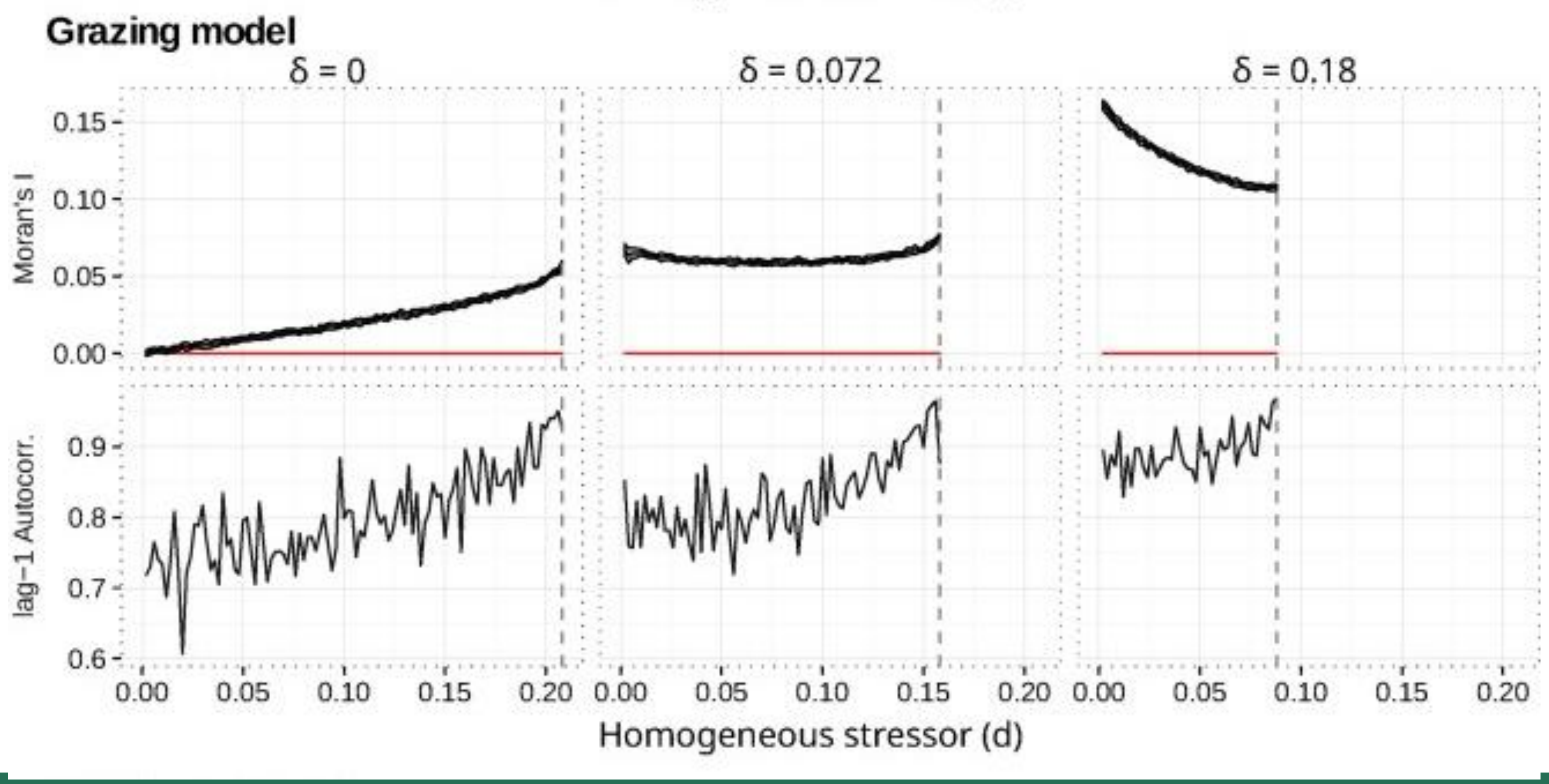
Original Article

# Spatially heterogeneous stressors can alter the performance of indicators of regime shifts

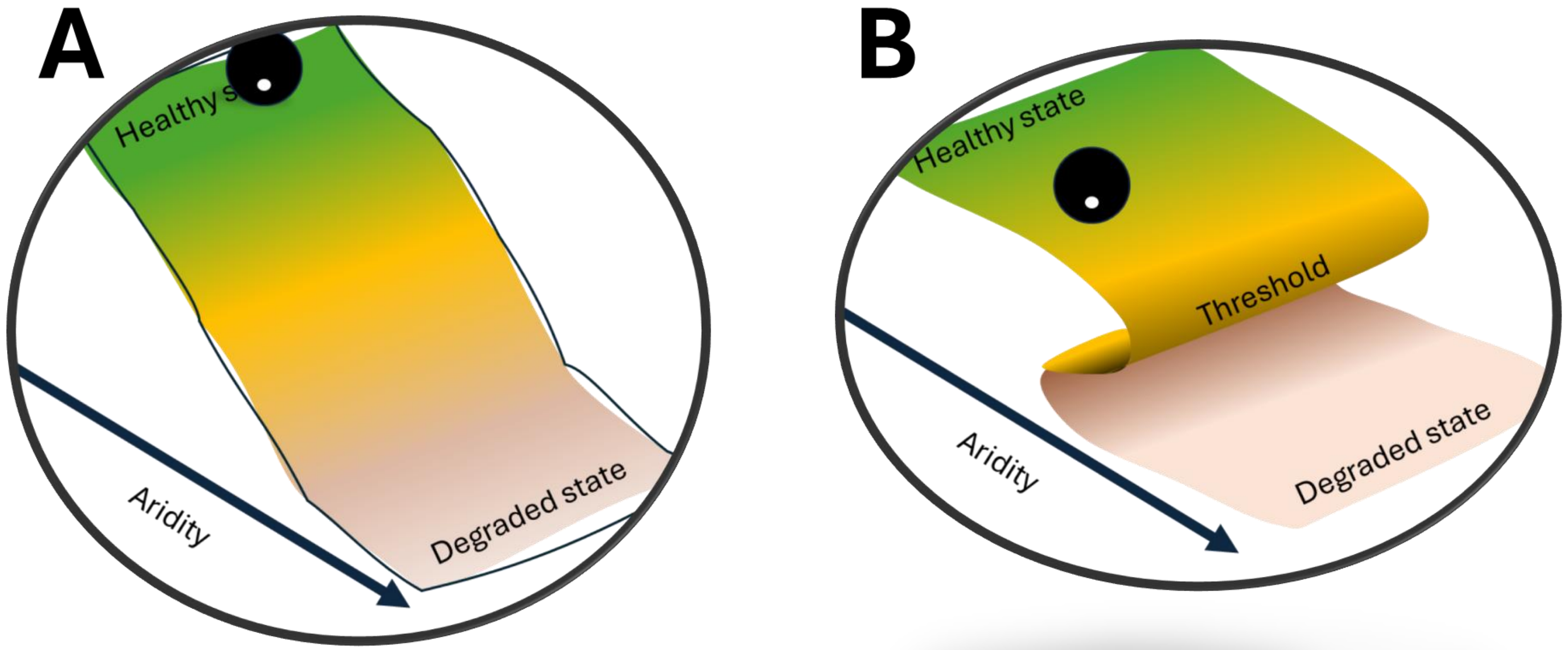
Alexandre Génin [a 1], Sabiha Majumder [b 1], Sumithra Sankaran [c 1], Florian D. Schneider [a d], Alain Danet [a], Miguel Berdugo [e], Vishwesha Guttal [c], Sonia Kéfi [a]



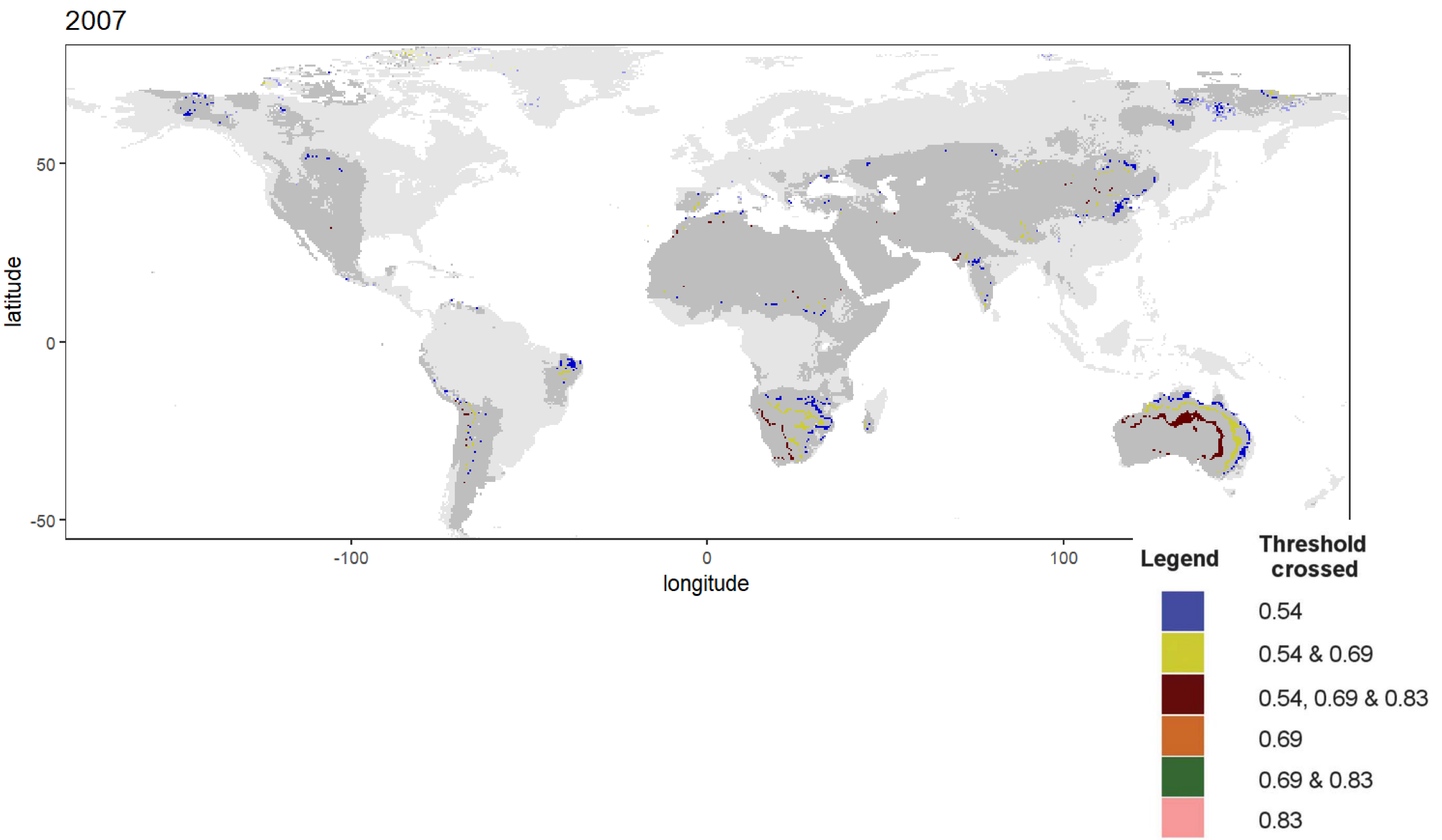



## How are drylands?




I got it,
the answer is
B

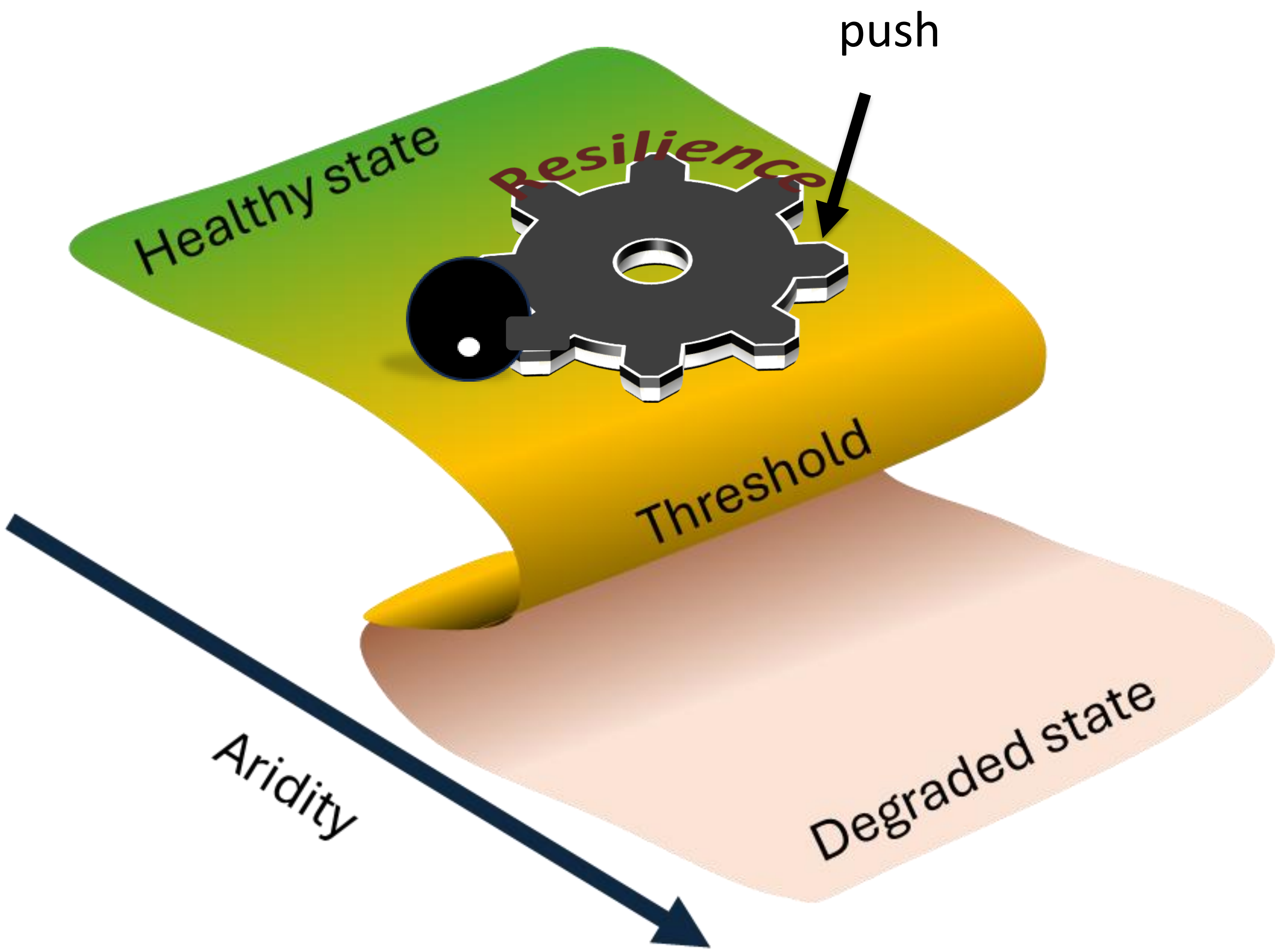
# So… what know?


2007
latitude
50
0
-50
-100
0
100
longitude
Legend
Threshold crossed
0.54
0.54 & 0.69
0.54, 0.69 & 0.83
0.69
0.69 & 0.83
0.83

# How to save a threshold

Gaining a comprehensive understanding of **resilience** around aridity thresholds is the key to design global strategies to confront hypothetical upcoming abrupt changes triggered by climate change-driven aridification

**INtegrating Ecosystem Resilience around Thresholds In Aridity: unveiling nature-based mechanisms to endure abrupt desertification**

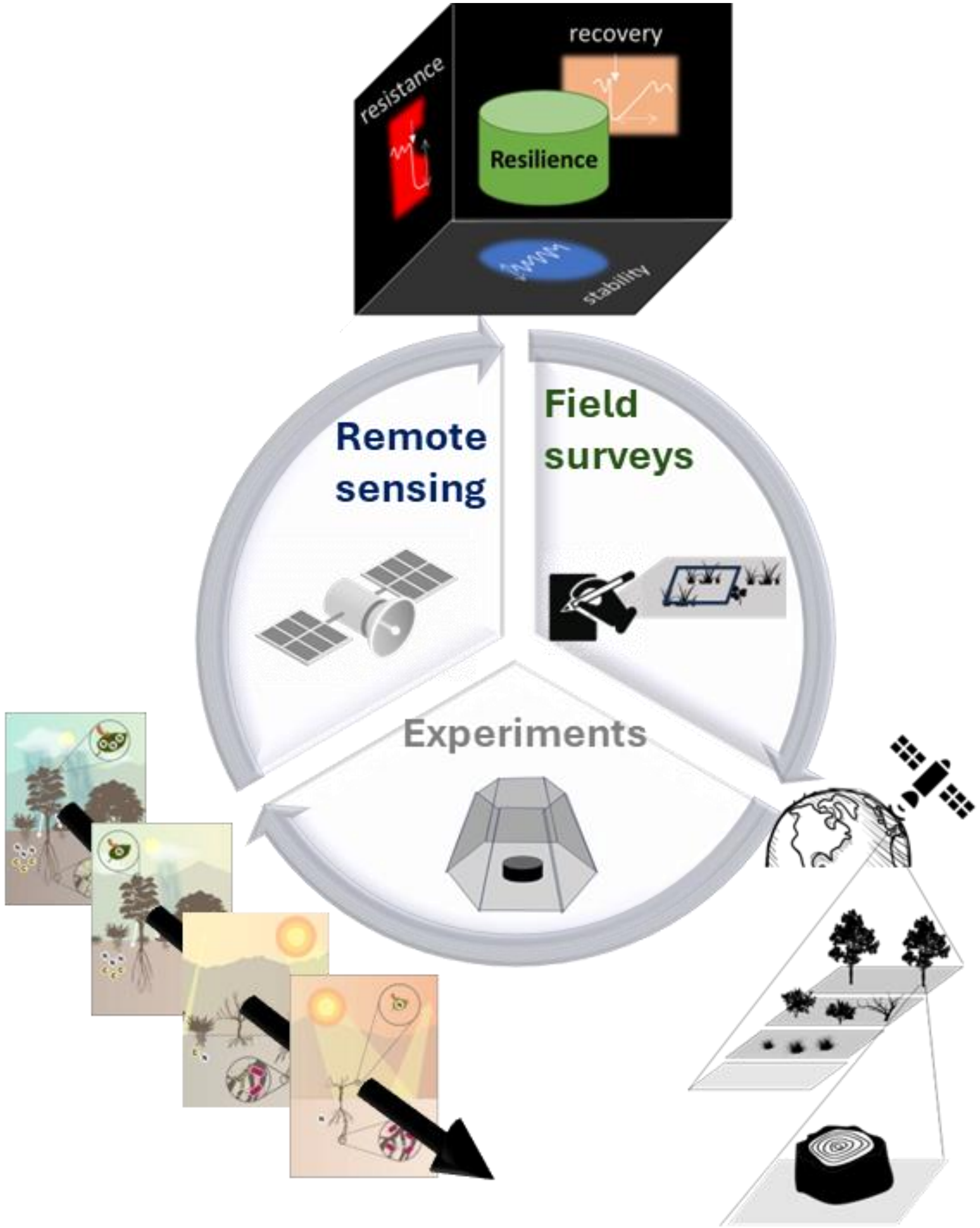


INERTIA

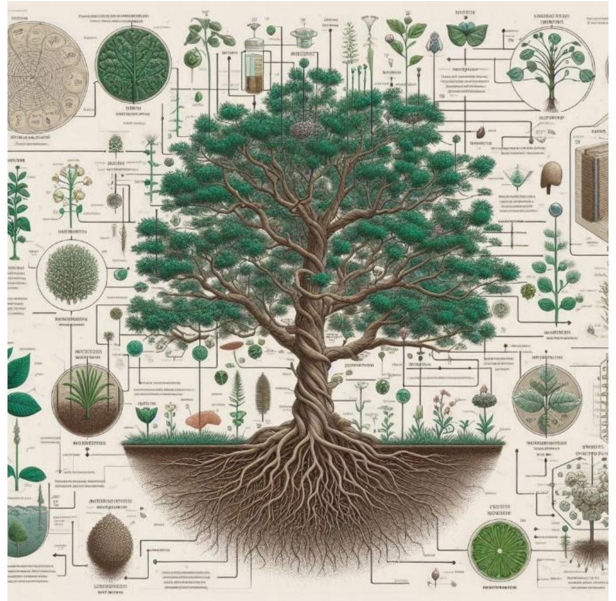
TIPS$^2$

erc European Research Council
Established by the European Commission

GOBIERNO
DE ESPAÑA



resistance
recovery
Resilience
stability
Remote sensing
Field surveys
Experiments



**Ecosystem level (~$10^3$ m)**

*Climate and climate legacy*
*Ecosystem (vegetation) type*
*Landscape Connectivity*
*Topography*
*Soil type*

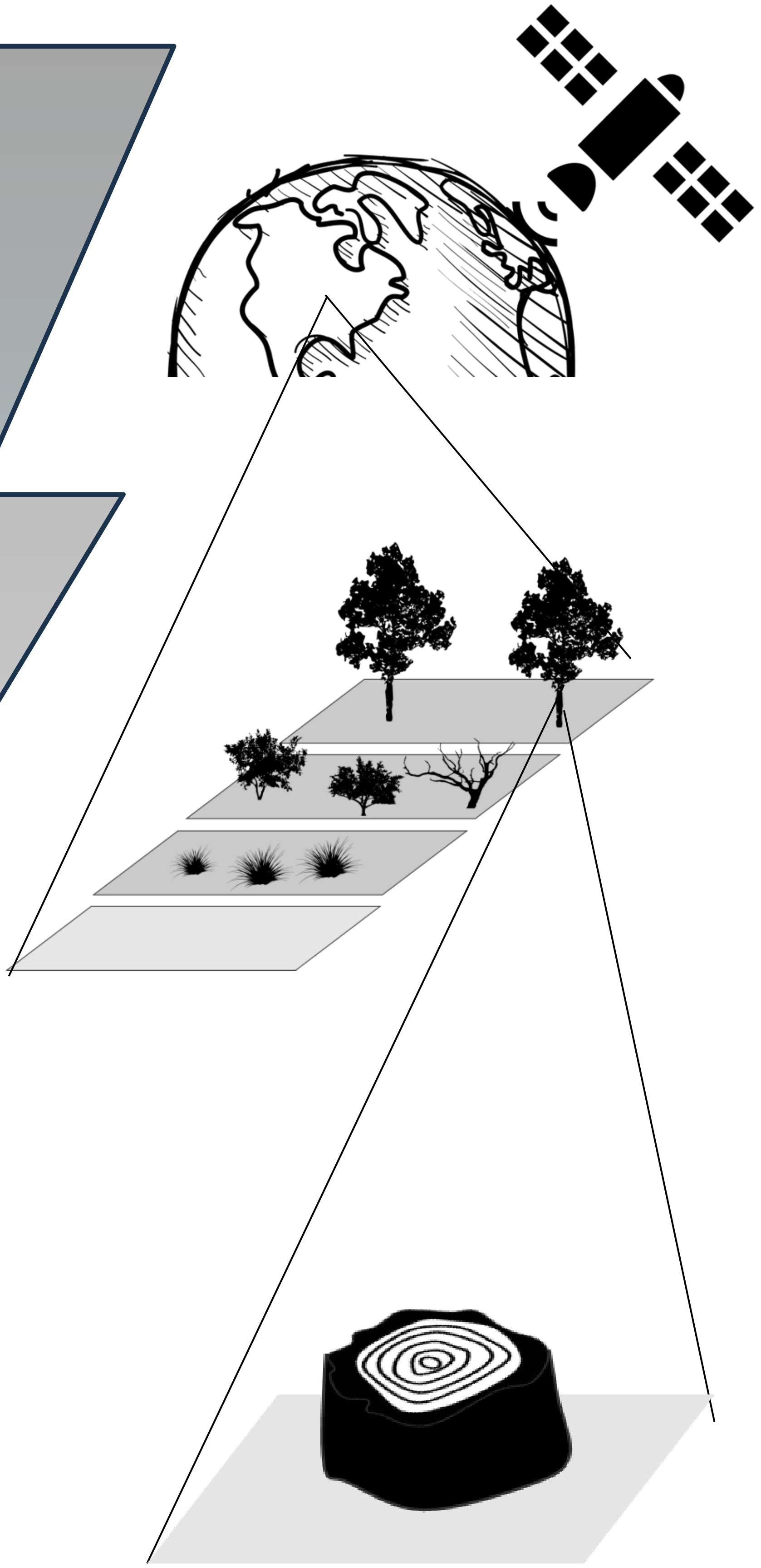
**Community level (~10 m)**

*Plant & soil community assemblage,*
*Biodiversity,*
*Soil nutrient cycling*
*Soil fertility*

**Individual level (~1 m)**

*Species adaptation*
*Local adaptation*
*acclimation*

RESILIENCE

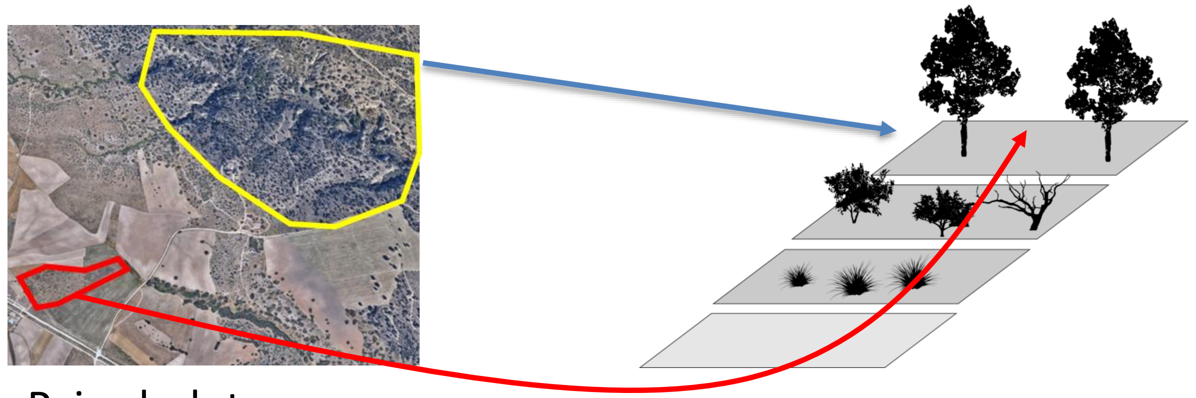


*Assessing the effects of aridity thresholds in the integration of resilience facets and metrics*

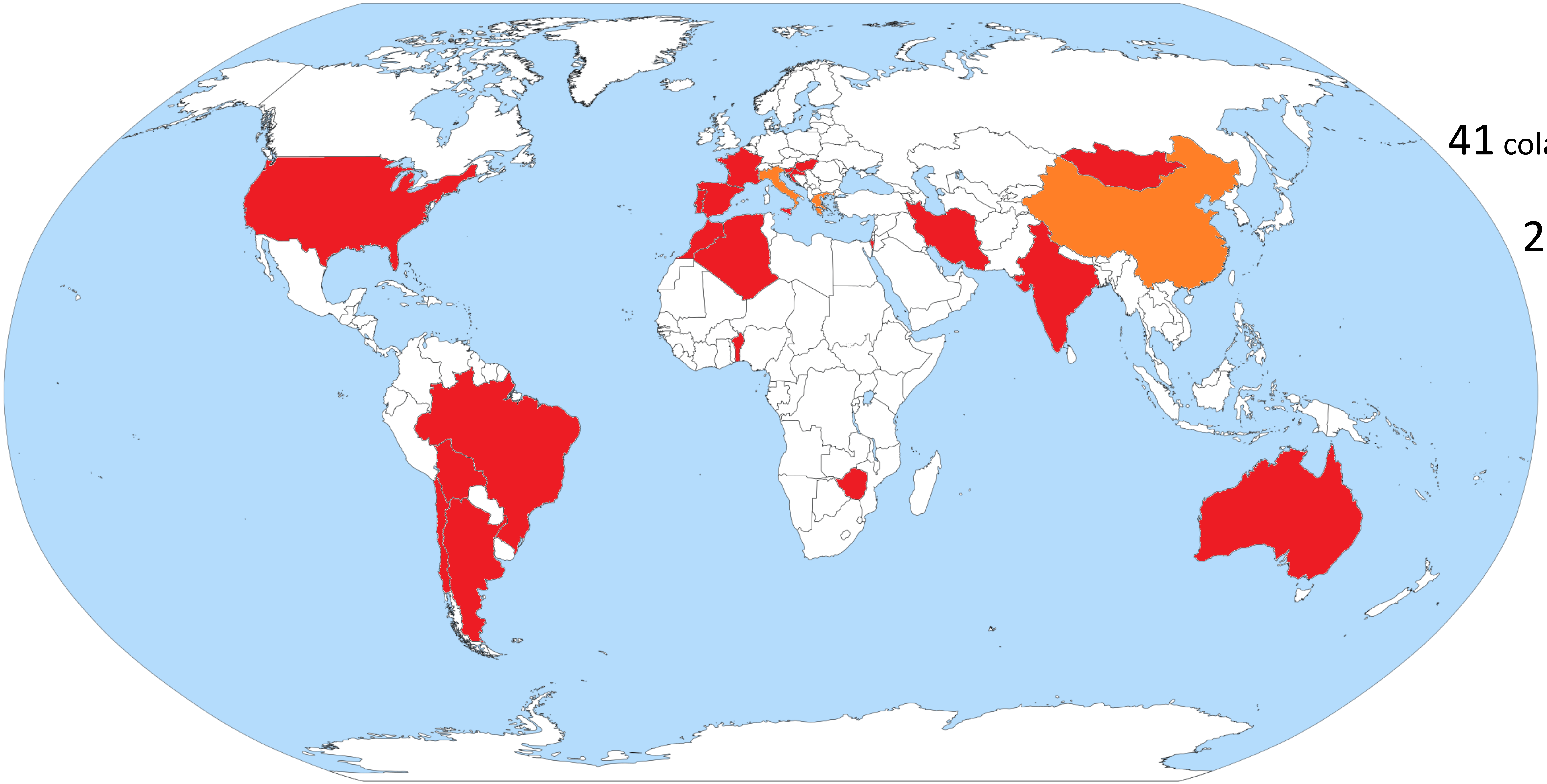
*Assess globally and in situ the simultaneous recovery of multiple functional and structural ecosystem attributes after land abandonment*

*Assessing the effects of aridity thresholds in the success of global restoration activities*

*Restoring aridity threshold transgression with biocrusts*



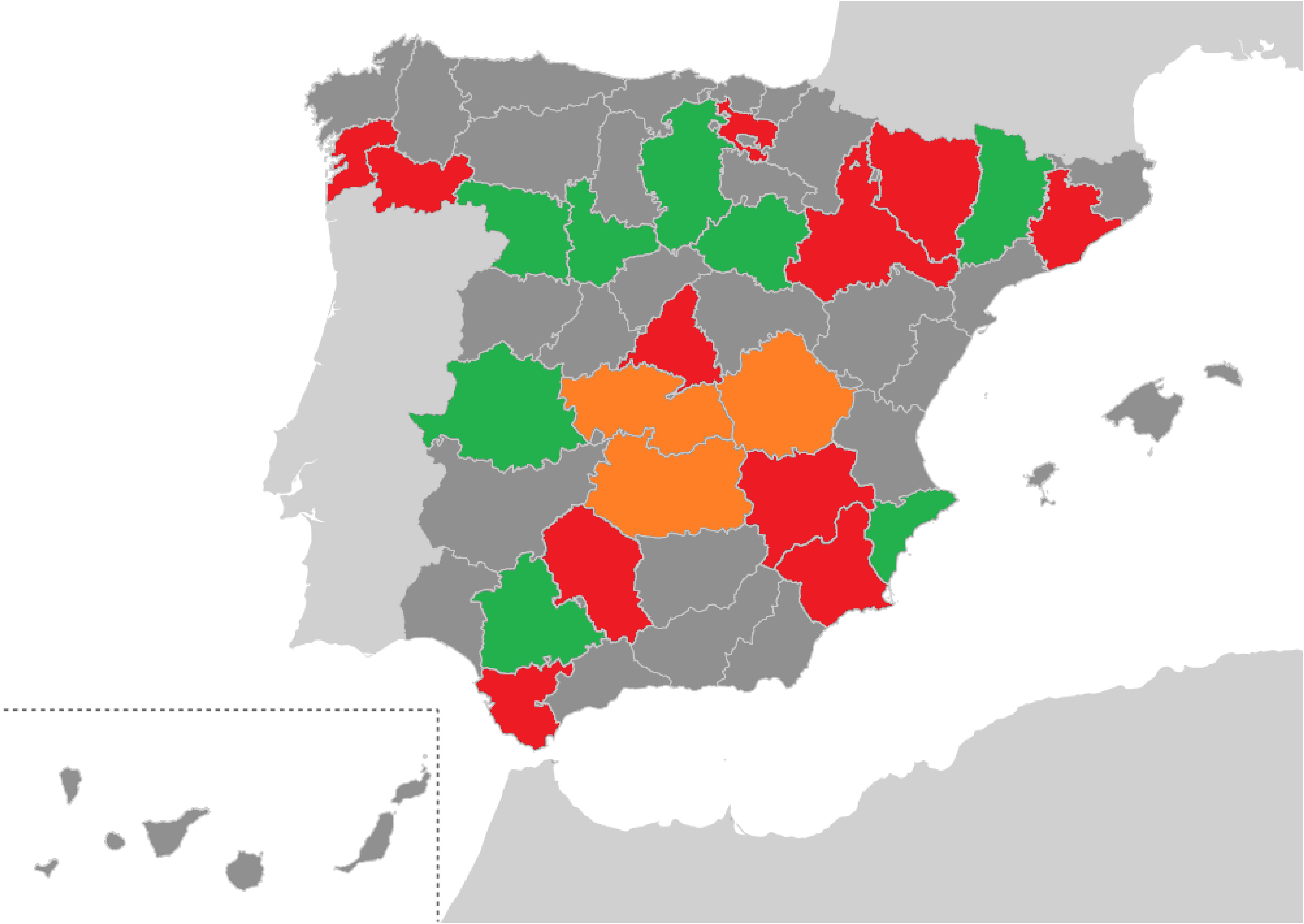
Paired-plot
Disturbance level



41 colaborators

22 countries

120 sites




ALTERNATIVE STATES RESILIENCE LAB
WE NEED YOU

# OBRIGADO (A)

Nome: Miguel Berdugo

Email: miberdug@ucm.es

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Commission . Neither the European Union nor the European Commission can be held responsible for them.