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Climate Change Effects on Biodiversity in Europe

Carl Beierkuhnlein

Universität Bayreuth, Germany
Universidad de Granada, Spain

LifeWatch
ERIC

BEeS
2026

The LifeWatch ERIC Biodiversity
& Ecosystem eScience Conference
PLOVDIV, BULGARIA 7-10 JULY 2026

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Biodiversity and ecosystem responses to climate change

Carl Beierkuhnlein

Universität Bayreuth, Germany
Universidad de Granada, Spain

LifeWatch
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The LifeWatch ERIC Biodiversity
& Ecosystem eScience Conference
PLOVDIV, BULGARIA 7-10 JULY 2026

Overview

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Scales and Processes

Linking Data and Methods

Geodiversity and the Earth Critical Zone

Data and Methods

- Case Study: Nature Conservation / Protected Areas
- Case Study: Land Use / Grasslands
- Case Study: Human Health / Vector-Borne Diseases

Uncertainty

Conclusions



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Scales and Processes

Scales

"The problem of pattern and scale is the central problem in ecology, unifying population biology and ecosystems science, and marrying basic and applied ecology. …

Furthermore, there is **no single natural scale** at which ecological phenomena should be studied; systems generally show **characteristic variability on a range of spatial, temporal, and organizational scales**."

Simon A. Levin

Margalef Prize in Ecology and Environmental Sciences
ESA Eminent Ecologist Award

Scales and Processes

Climate change and **biodiversity loss** are environmental challenges **on a global and continental scale**.

These **long-term** and **large-scale** processes are beyond the perception of our regular daily life.

How do **local processes** contribute, adapt, mitigate ?

How do **global changes** affect local ecosystems ?

Which **aspects of climate** change are relevant ?

Which **facets of biodiversity** loss are relevant ?

How do these changes **interact** ?

Climate Change

Climatic changes include **decadal trends** and **short-term events**,

both in **temperature** and in **precipitation**.

Biota and ecosystems are challenged by emerging unexperienced **climatic extremes**.

Biodiversity Loss

Biodiversity loss includes changes in **species richness** and in **species assemblages**.

Taxonomic depauperation (loss of **alpha diversity**) and homogenization (loss of **beta diversity**) can reduce **ecosystem stability and resilience**.

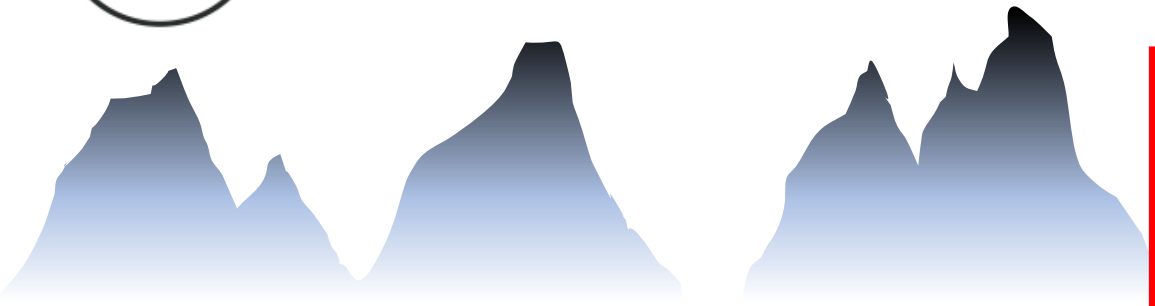
Consequences

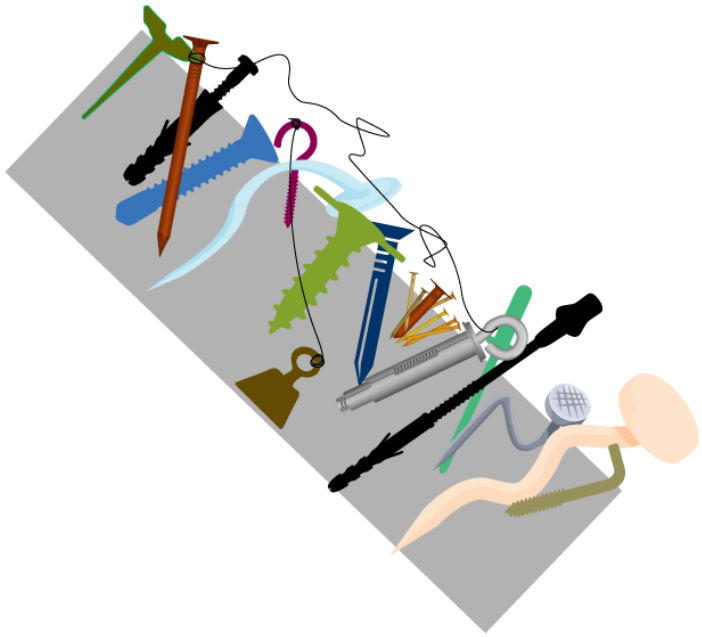
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Important ecosystem services and nature's contributions to people are at risk, with negative consequences for economy, human health and societal stability.

Consequences

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Slope stability is maintained by functional diversity in mountaints

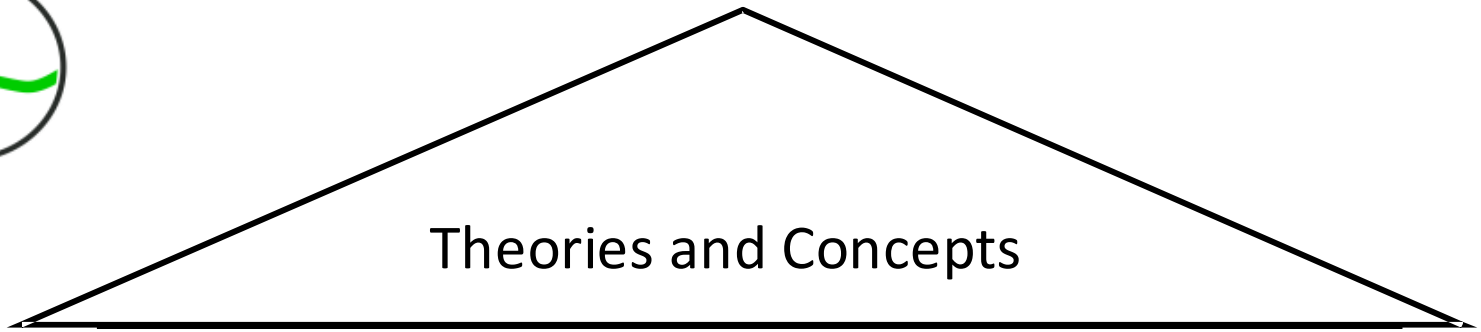
Diverse communities support much better the stability of soils and avoid erosion and land slides due to diverse rooting systems.



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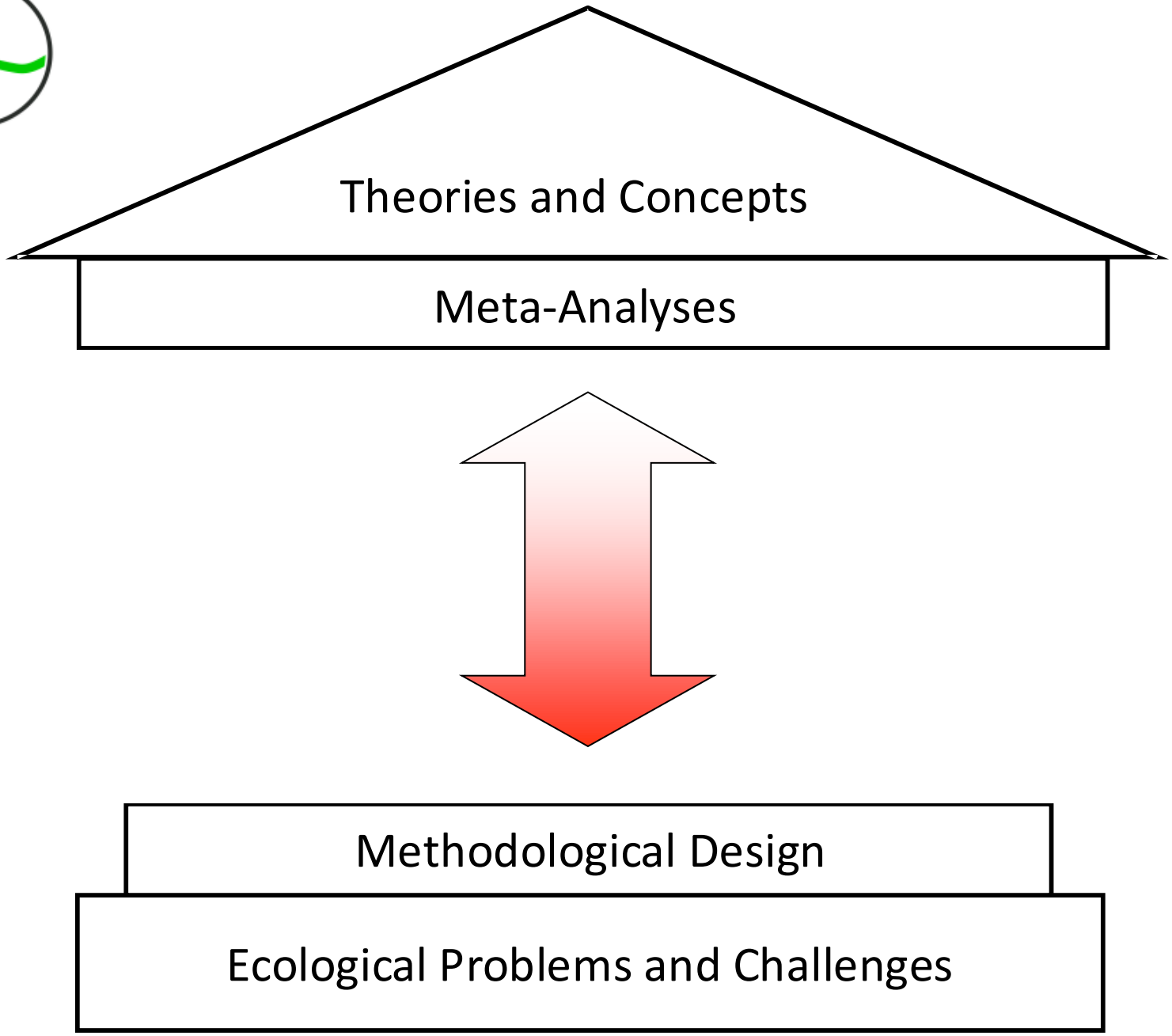


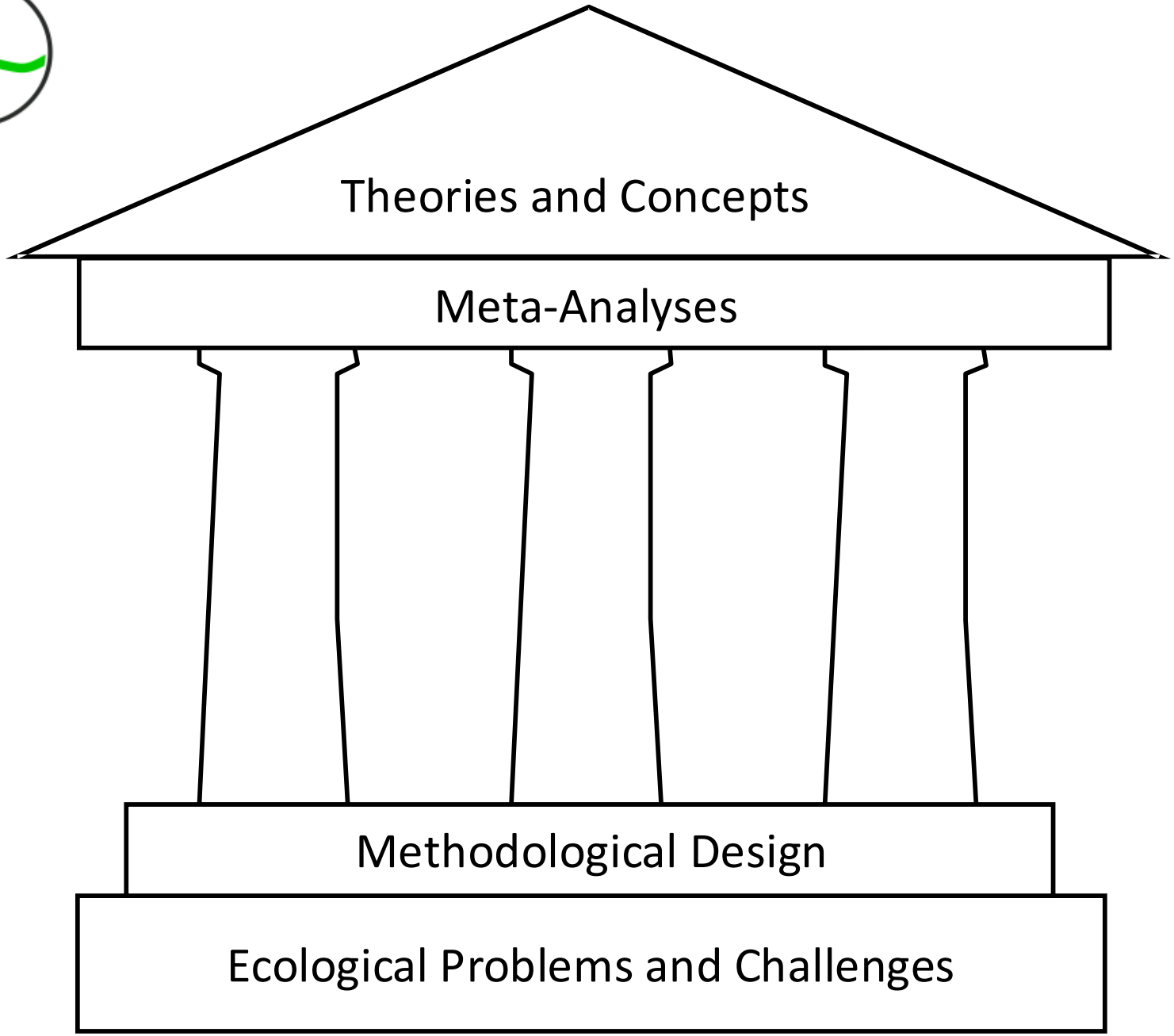
Linking Data and Methods

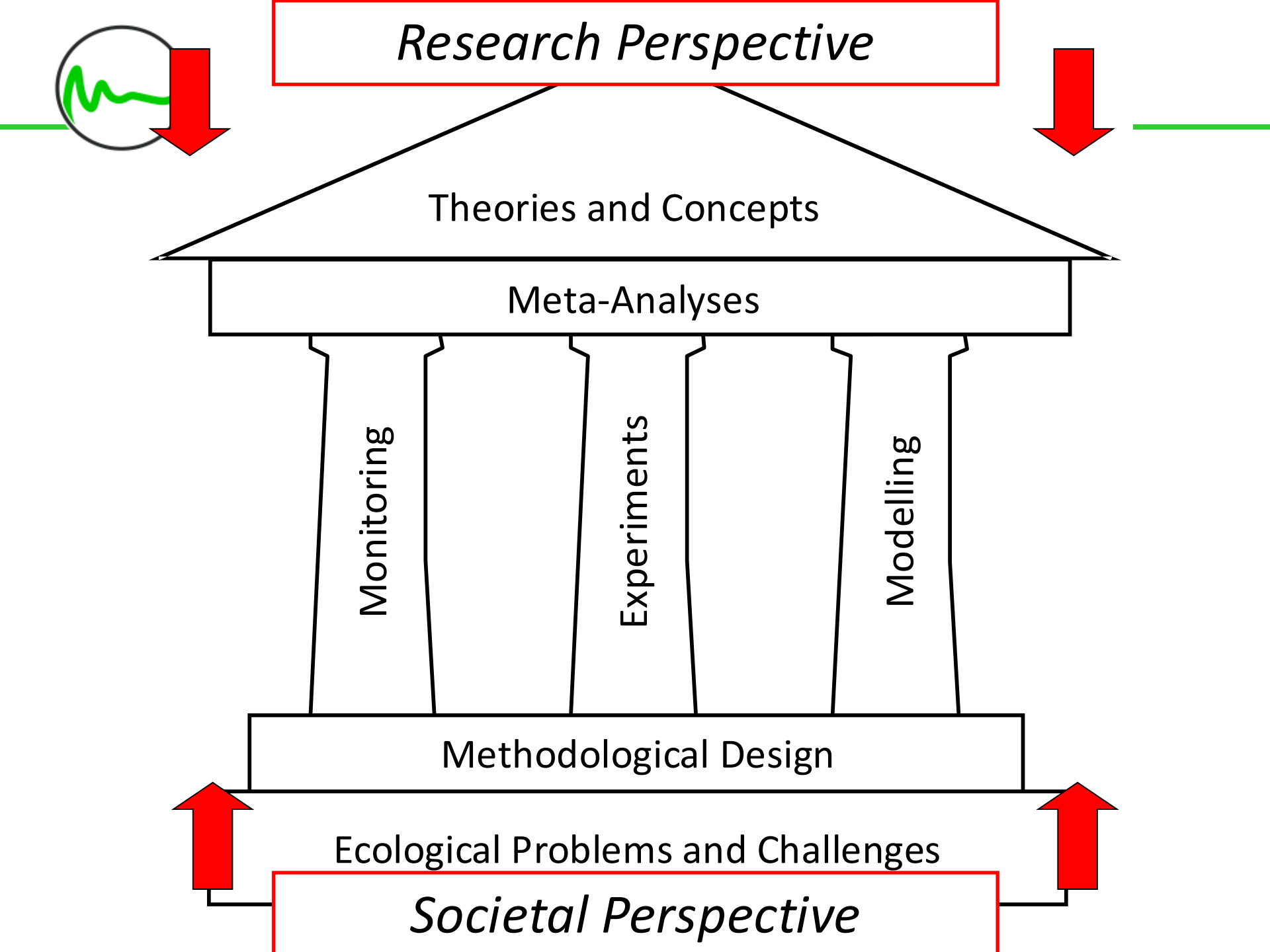


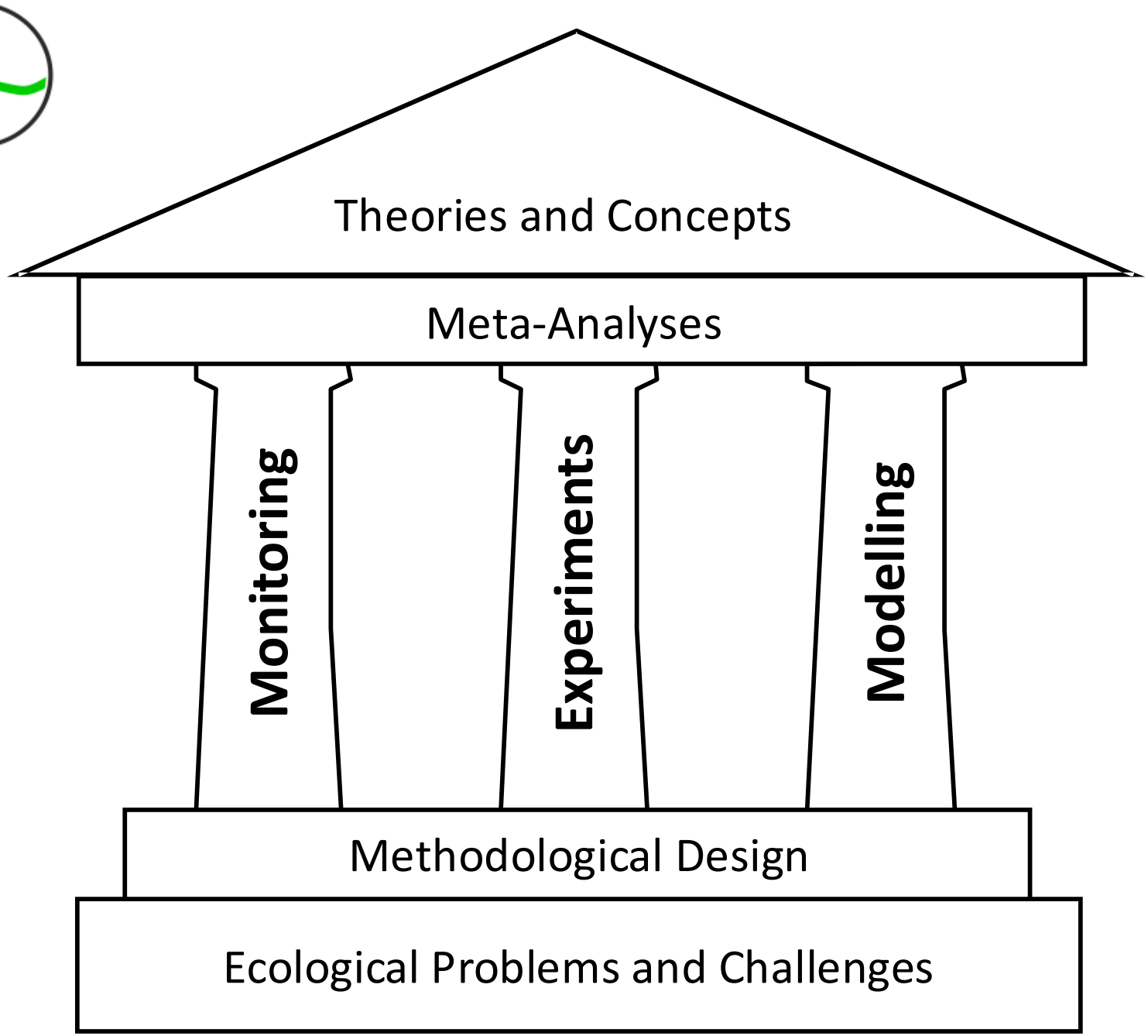
No real life problem can be solved
without theoretical background

Ecological Problems and Challenges


Theories and Concepts
Meta-Analyses
Methodological Design
Ecological Problems and Challenges

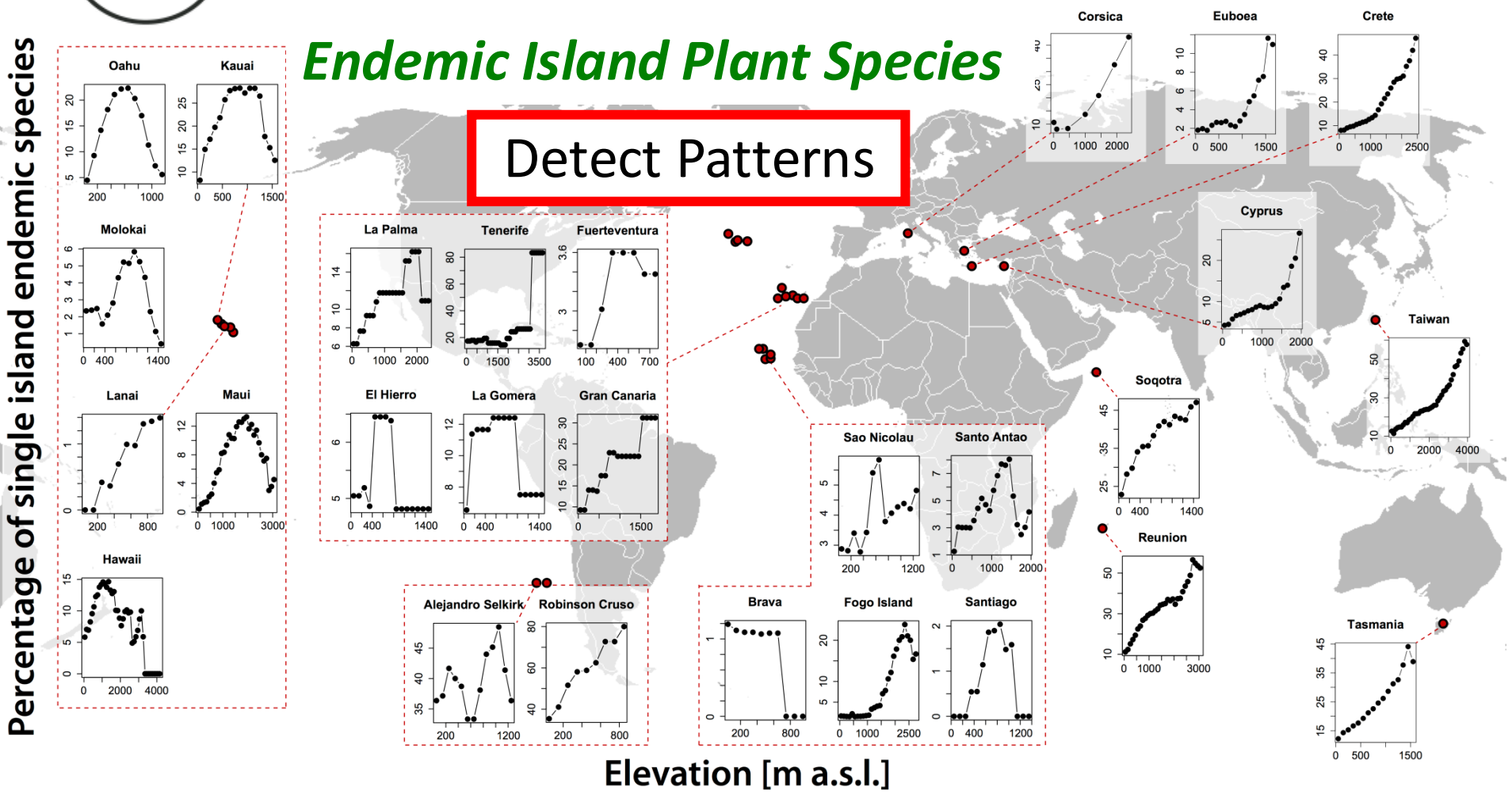

Theories and Concepts
Meta-Analyses
Methodological Design
Ecological Problems and Challenges


Research Perspective
Theories and Concepts
Meta-Analyses
Monitoring
Experiments
Modelling
Methodological Design
Ecological Problems and Challenges
Societal Perspective


Theories and Concepts
Meta-Analyses
Monitoring
Experiments
Modelling
Methodological Design
Ecological Problems and Challenges

Monitoring and Big Data

Endemic Island Plant Species



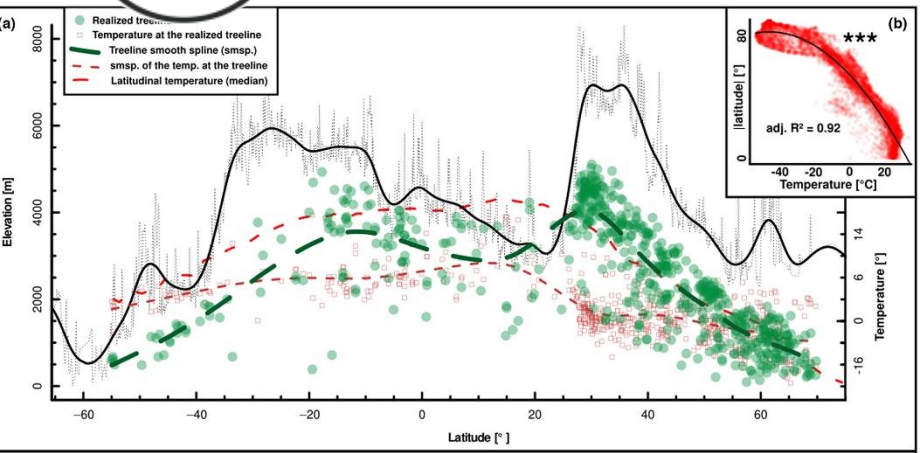
Increasing percentage of single-island endemic plant species with elevation.

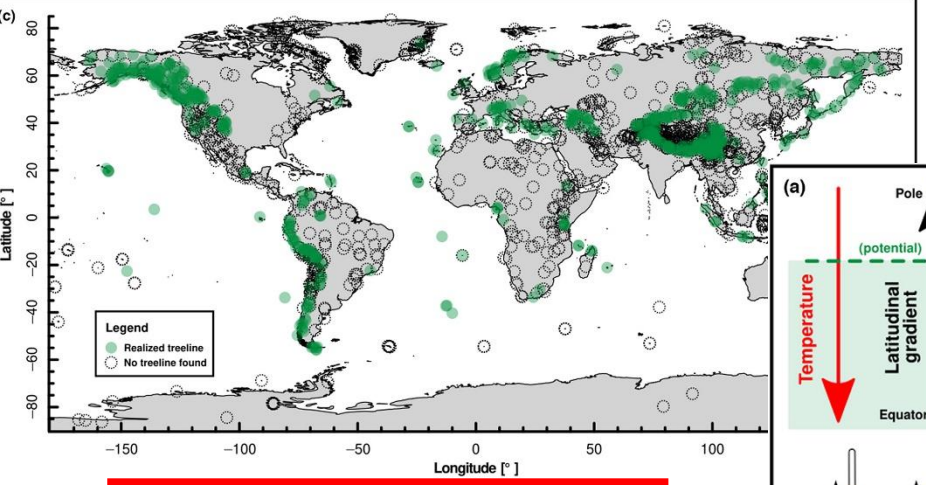
Steinbauer M … Beierkuhnlein C 2016. Topography-driven isolation, speciation and a global increase of endemism with elevation, Global Ecology and Biogeography, 25(9), 1097–1107

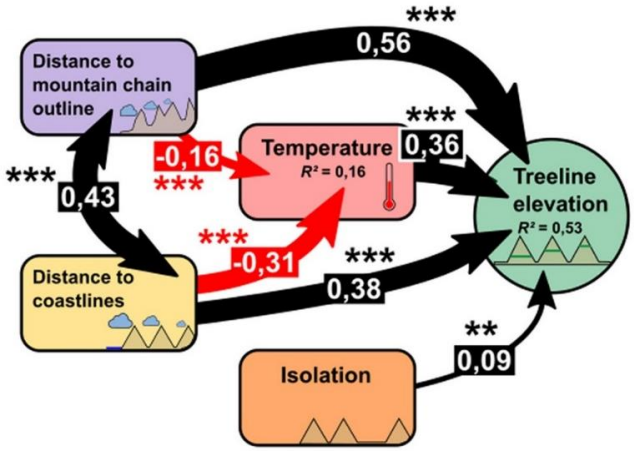
Monitoring and Big Data

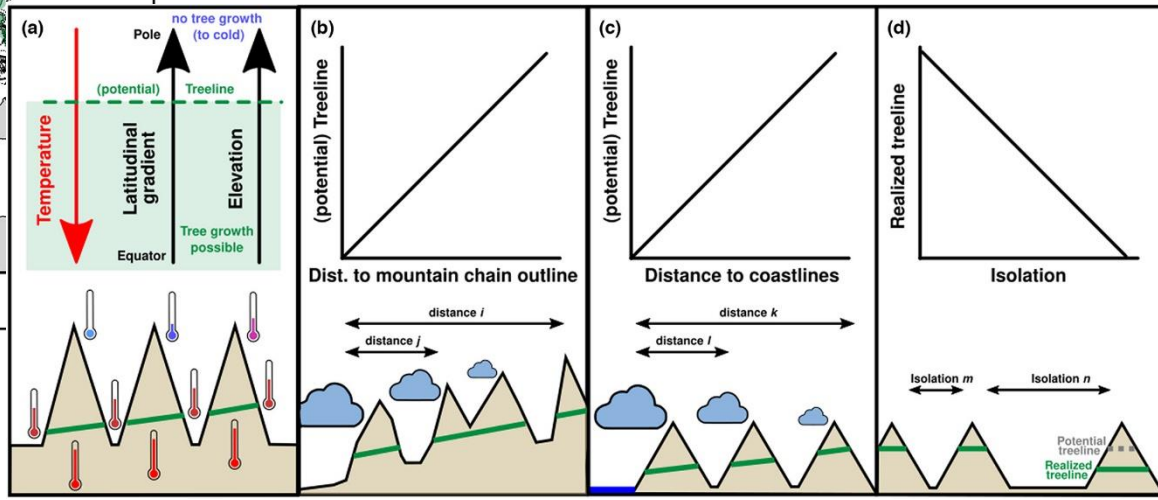
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Mass Elevation Effect









Detect Patterns

Kienle D, Irl S, Beierkuhnlein C 2023. Mass elevation effect and continentality have a stronger impact on global treelines than spatial isolation. Global Ecology and Biogeography 32, 1087-1097.

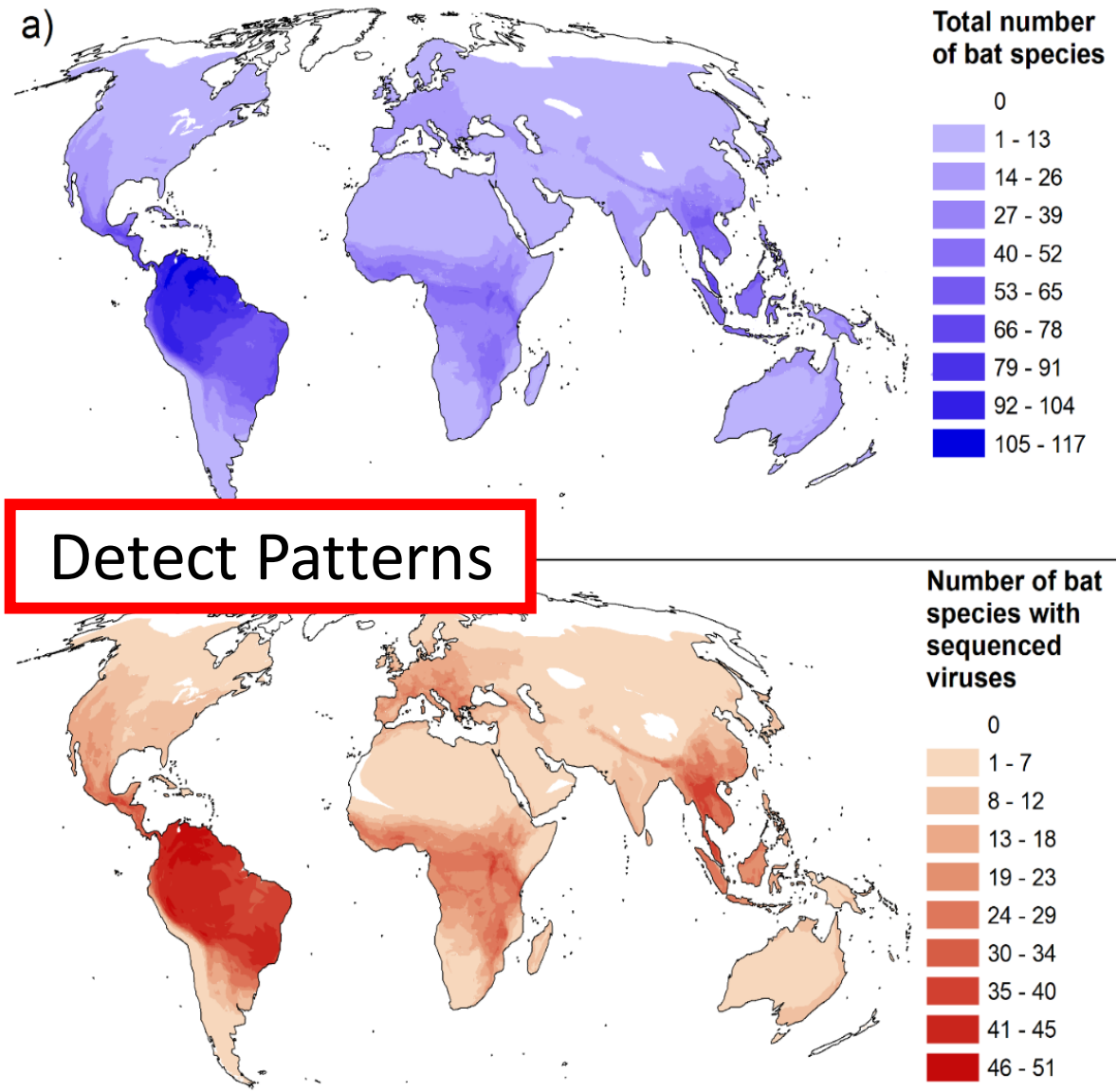
Monitoring and Big Data

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Bat-borne Viruses

Bats are mammals that host a high diversity of viruses that could potentially spill-over to humans.

We analyse global patterns of bats and bat-borne viruses to identify those areas with alert for possible risks to human health.



Biedermann … Beierkuhnlein In review.

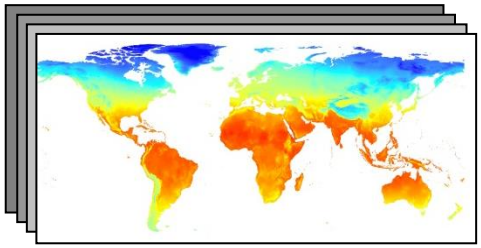
Linking Big Data with Models

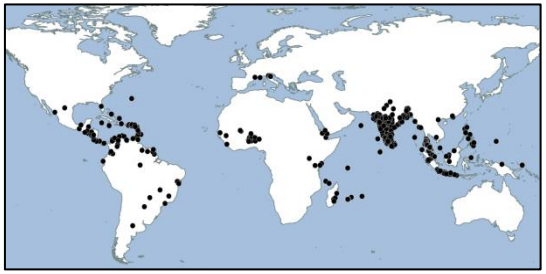
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Correlative Models

1. Existing Data

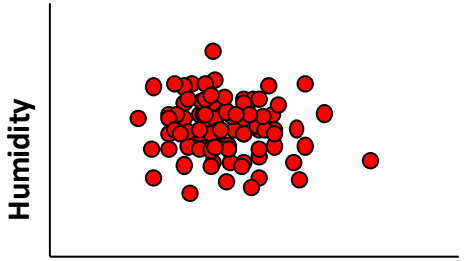
Link current climate data and species occurences

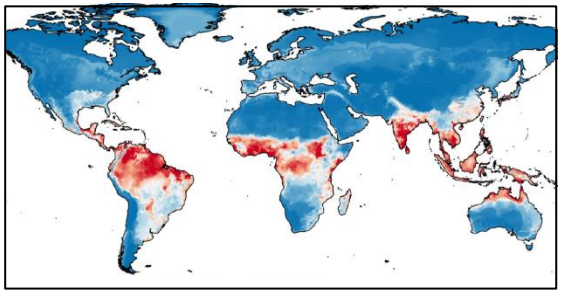




2. Climate Niche

Identify current climatic conditions for a species

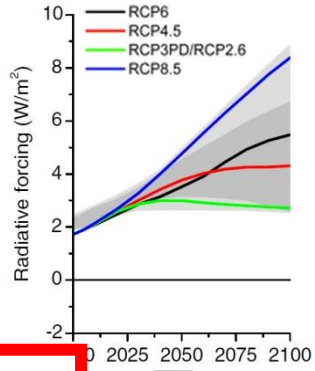




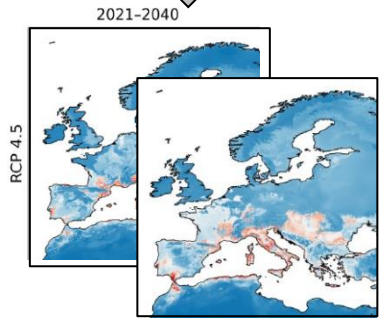
Current possible range

3. Future Projection

Climate change scenarios and models



Predict Trends



Future possible range

Linking Big Data with Models

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2021-2040 | 2041-2060 | 2061-2080

RCP 4.5

RCP 8.5

GCM: MPI-ESM-LR;

SDM Ensemble: GLM, GBM, RF and MAXENT

Invasive Disease Vectors

Predict Trends

Climatic suitability

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

no data

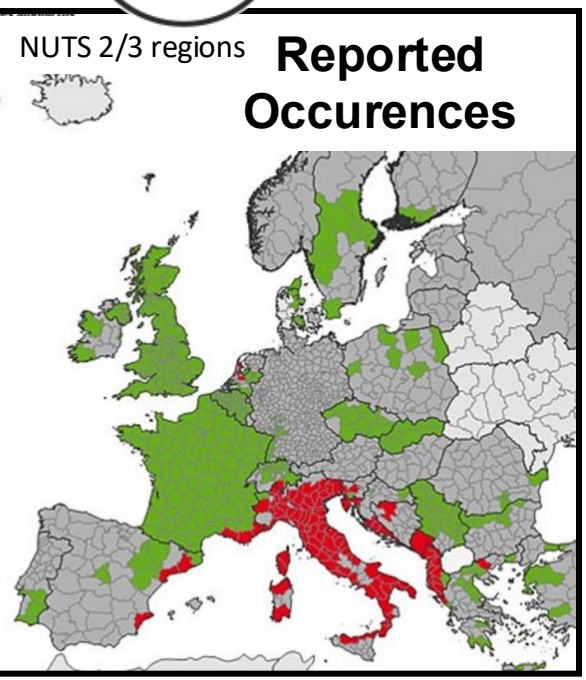


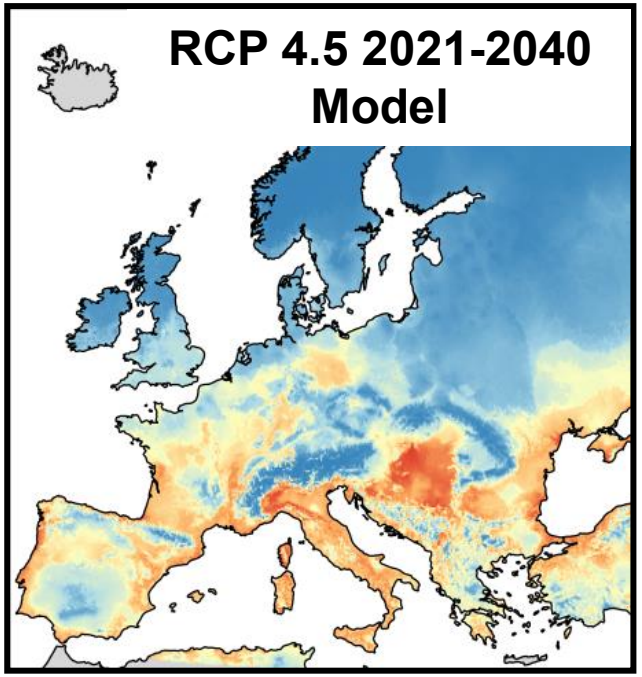
Aedes albopictus

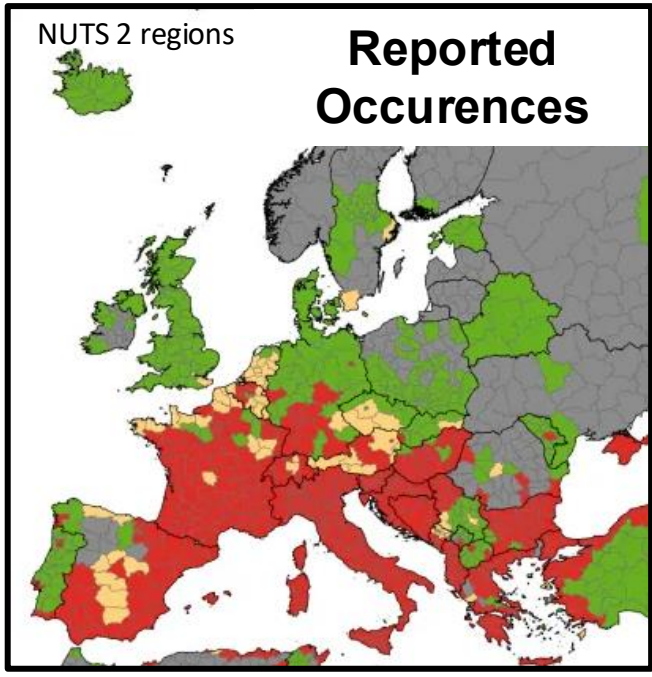
Fischer... Beierkuhnlein **2014.** Climatic suitability of Aedes albopictus in Europe referring to climate change projections: Comparison of mechanistic and correlative niche modelling approaches. Eurosurveillance 19, 20696.

Linking Big Data with Models

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June 2010 | **Model 2014** | **June 2025**

- Established
- Introduced
- Absent
- No Data
- Unknown

Predict Trends

High predictive power !



Aedes albopictus

Fischer... Beierkuhnlein **2014.** Climatic suitability of Aedes albopictus in Europe referring to climate change projections: Comparison of mechanistic and correlative niche modelling approaches. Eurosurveillance 19, 20696.

Experiments

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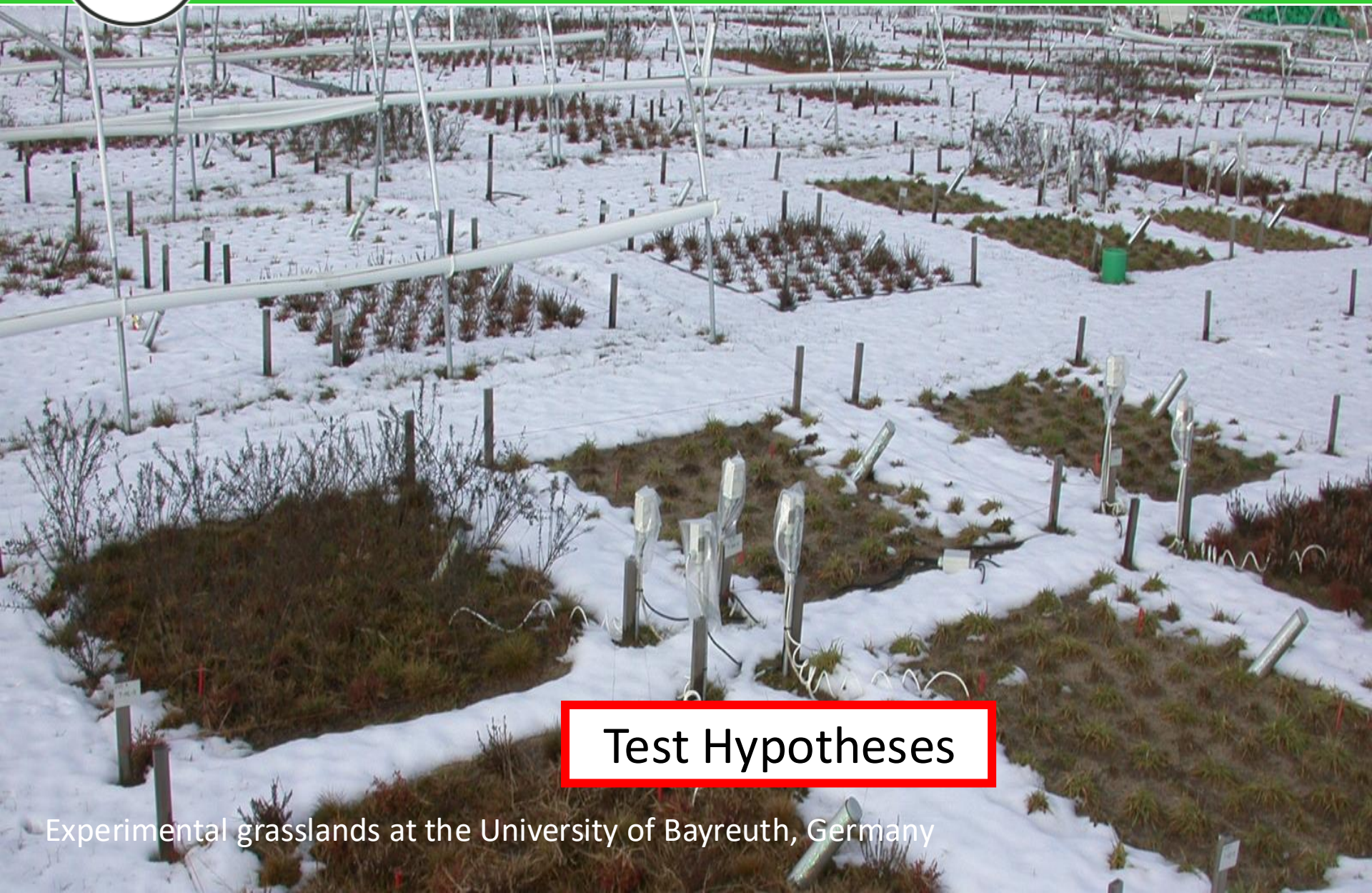
Experimental grasslands at the University of Bayreuth, Germany

Experiments



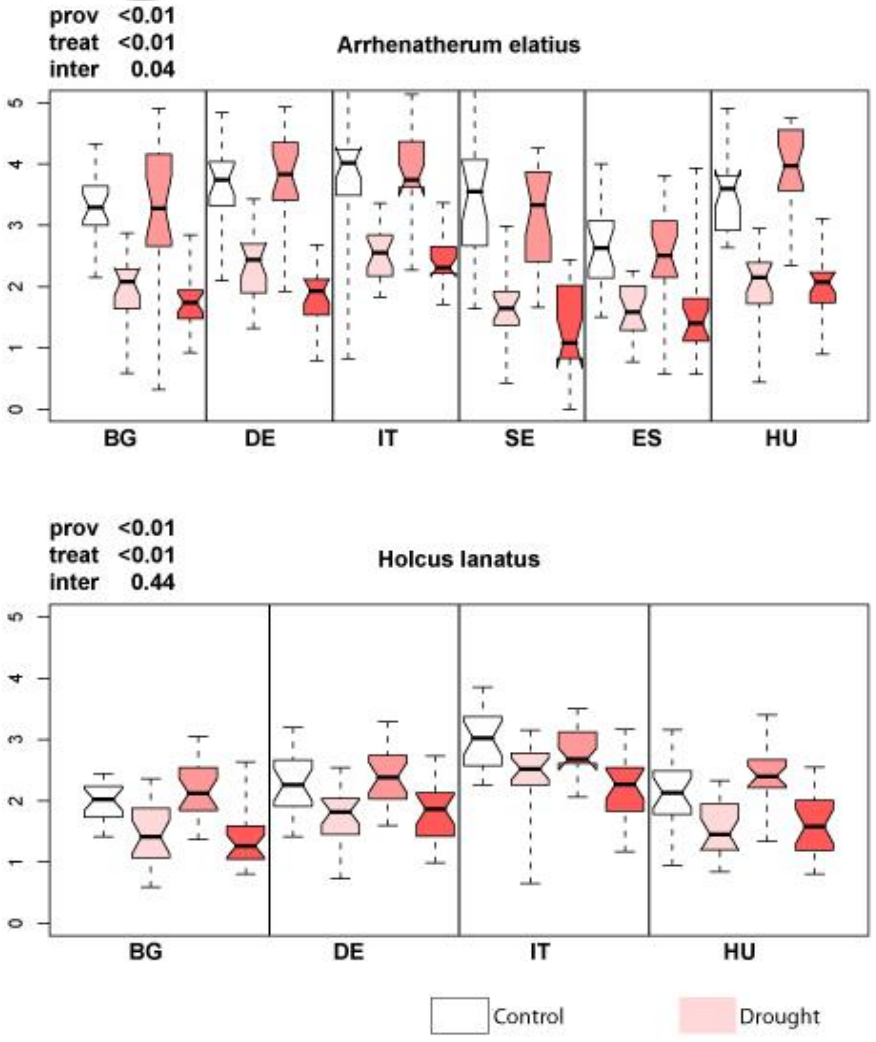
Experimental grasslands at the University of Bayreuth, Germany

Experiments

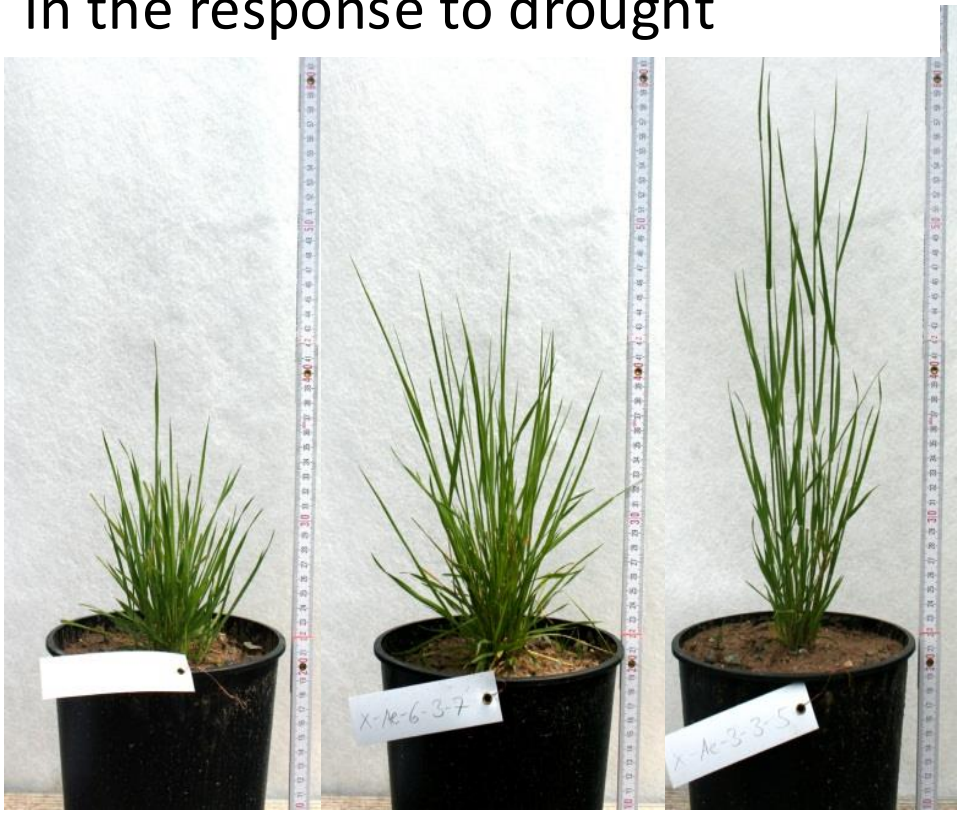


Experimental grasslands at the University of Bayreuth, Germany

Experiments



Variability within the same species in the response to drought

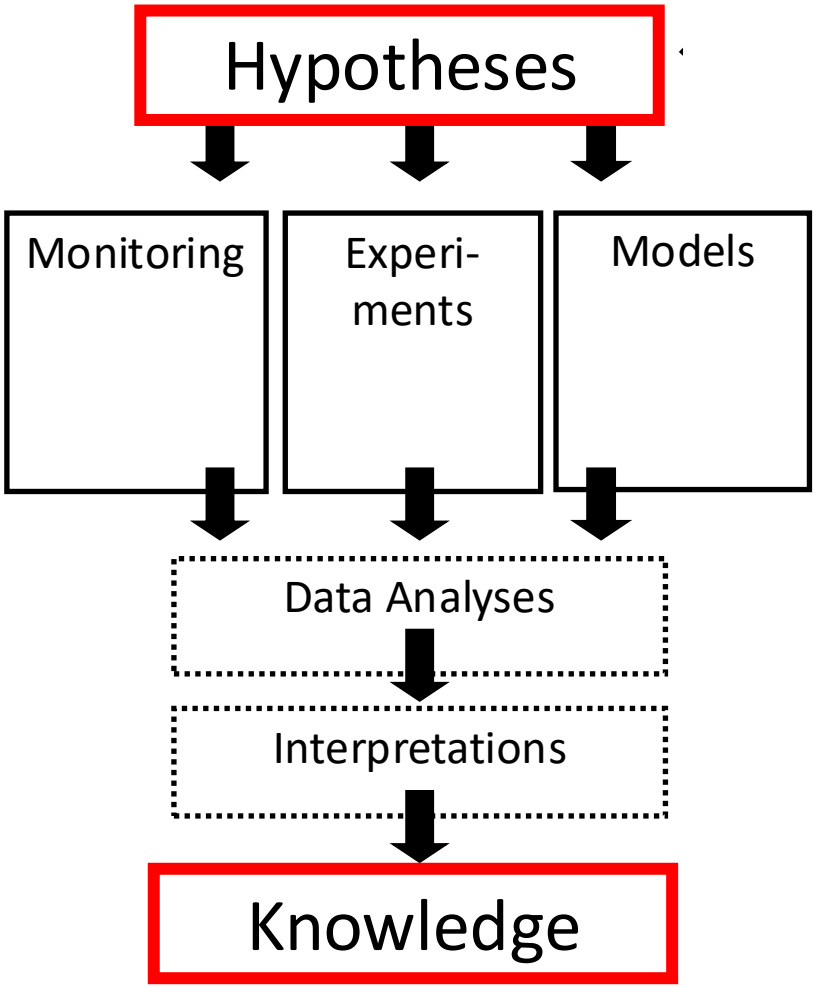


Germany Hungary Italy

Beierkuhnlein, C., Kreyling, J., Thiel, D., Jentsch, A. (2010) Species-specific and provenance-specific responses of key grass species to extreme climatic events. Journal of Ecology 99, 703-713.

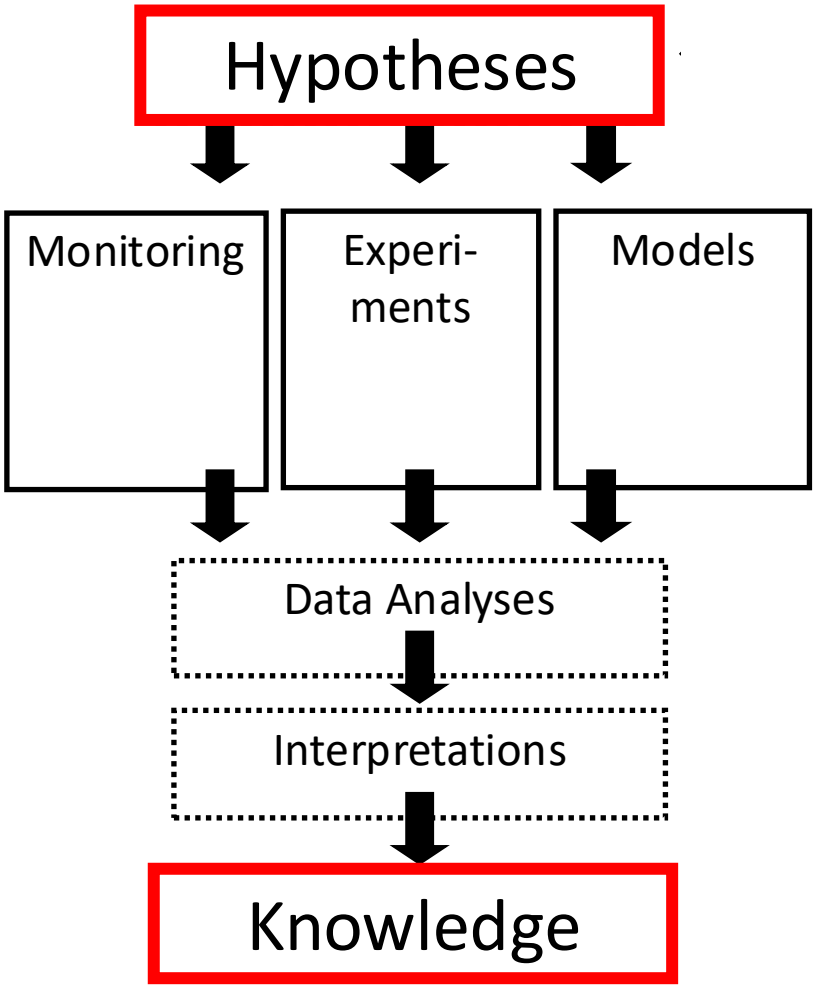
Science and Society

Heuristic-Scientific Domain

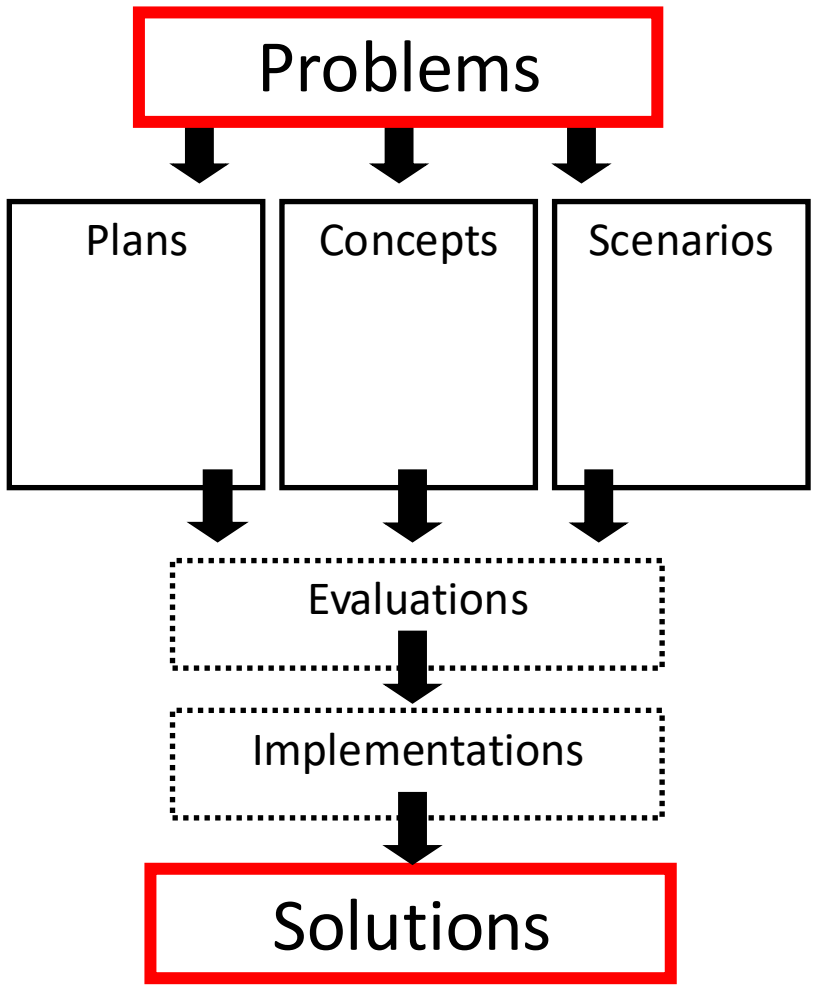


Science and Society

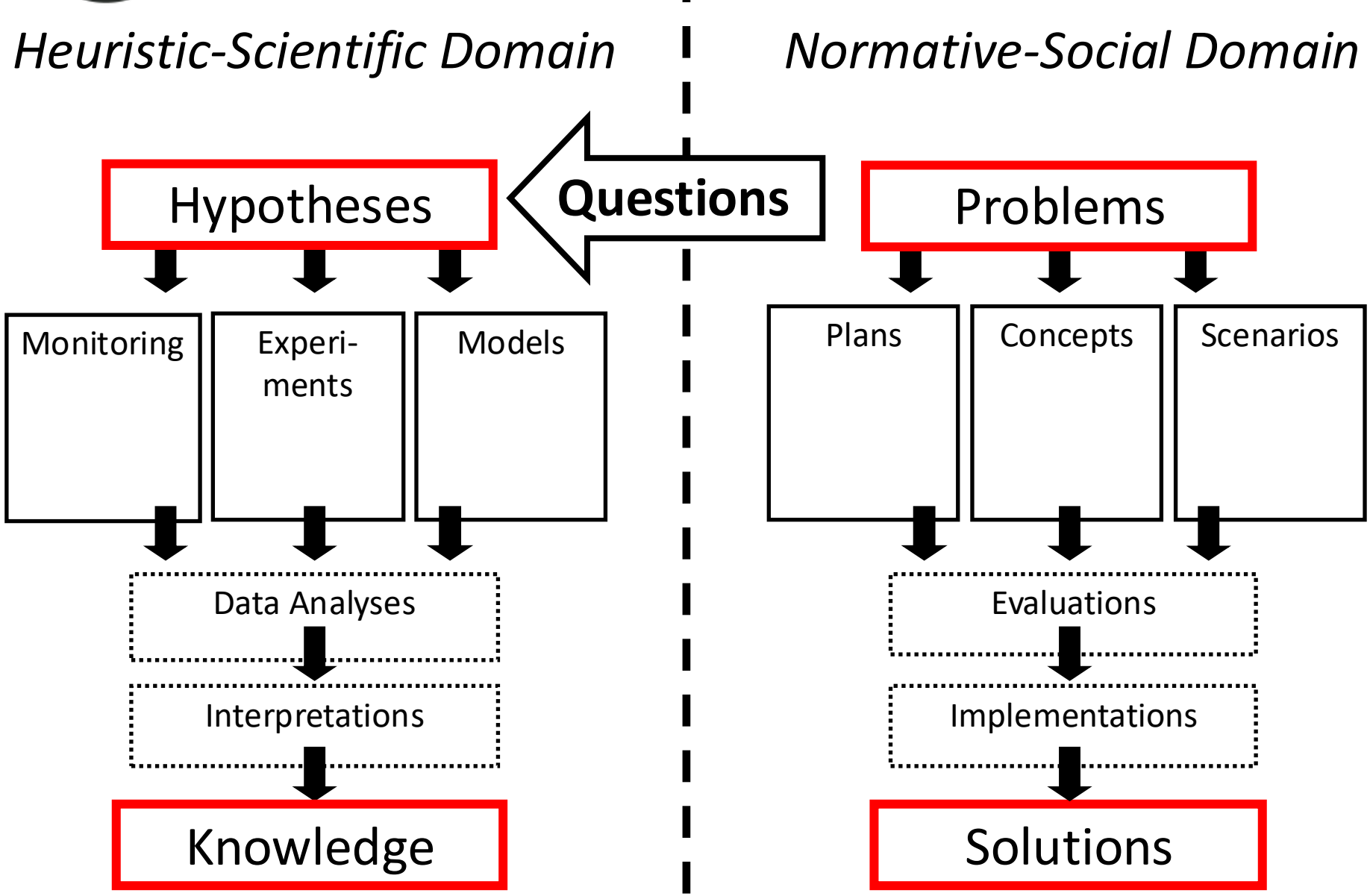
Heuristic-Scientific Domain



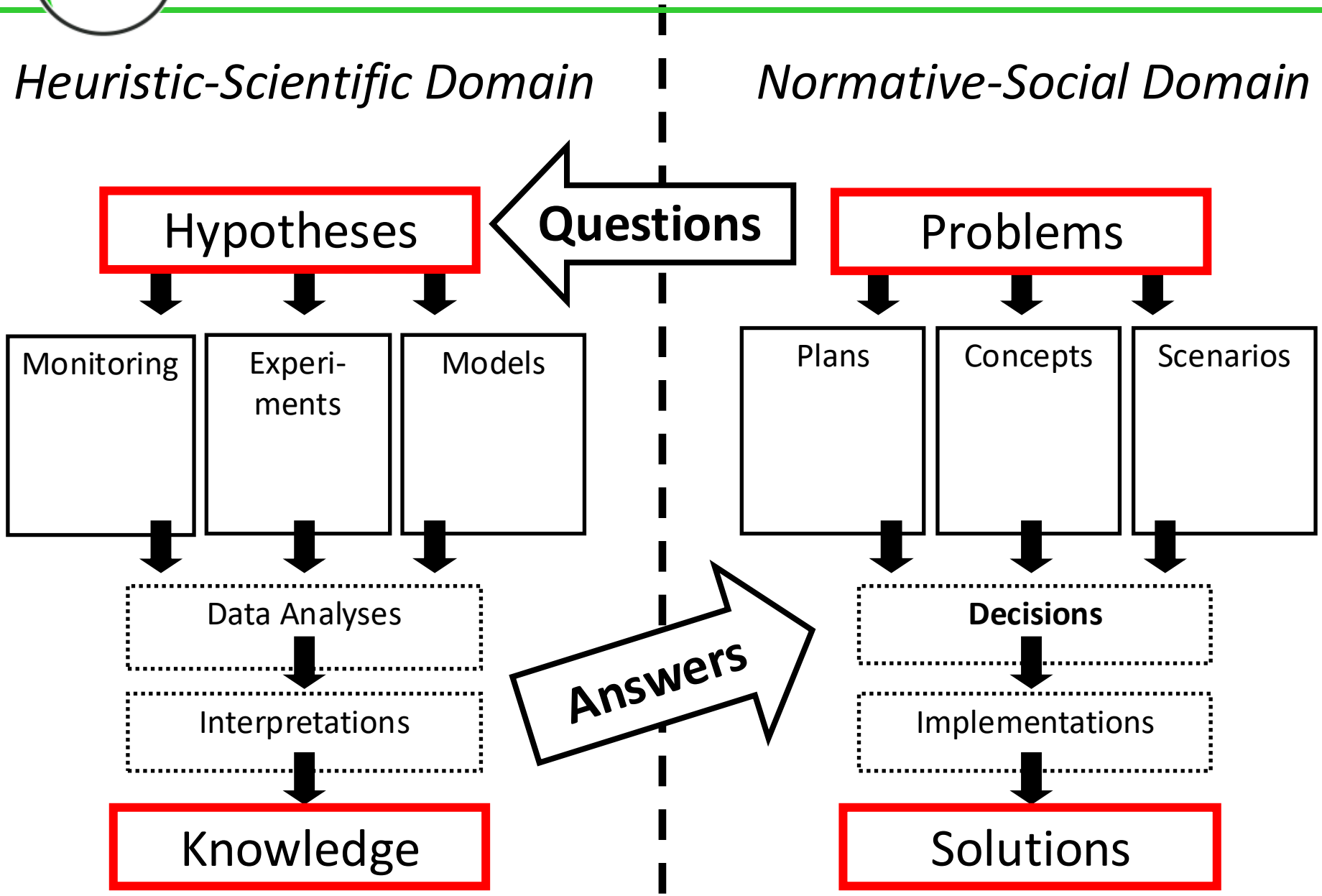
Normative-Social Domain



Science and Society



Science and Society



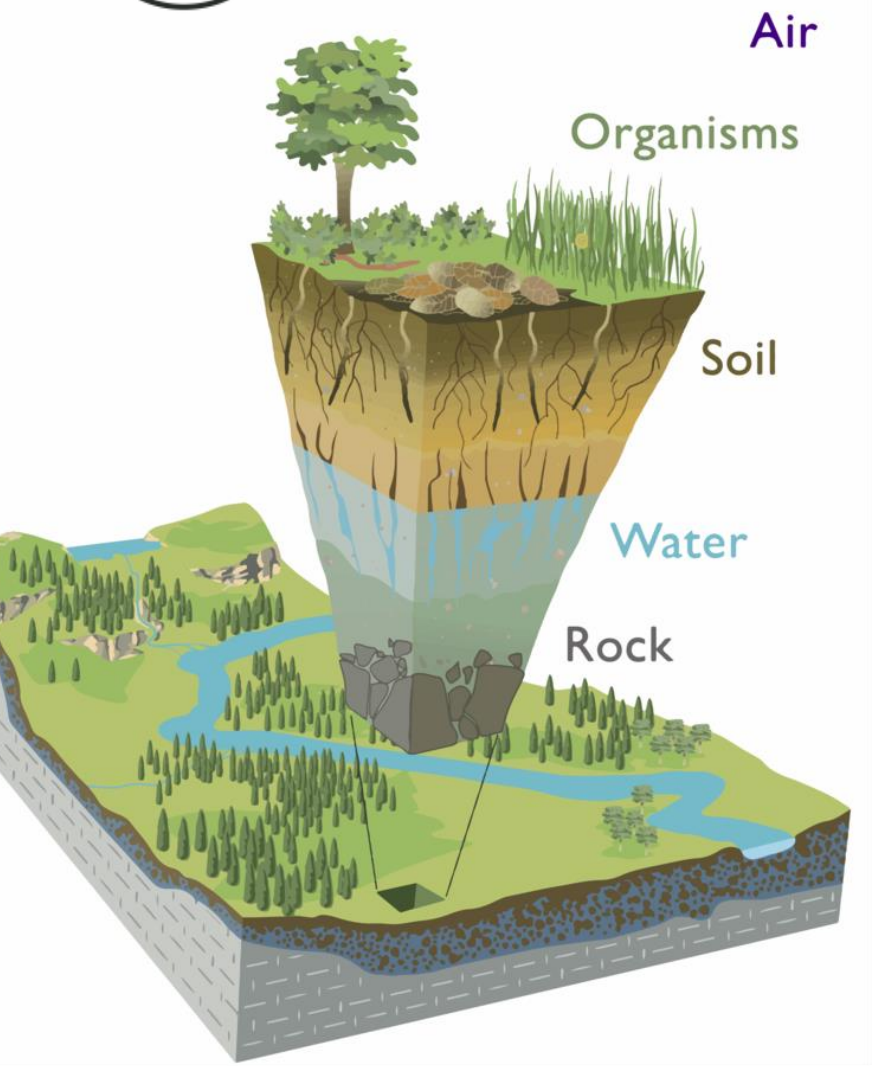


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Geodiversity and Earth Critical Zone

Earth Critical Zone



The Earth Critical Zone refers to the thin skin of ecological processes at the Earth surface.

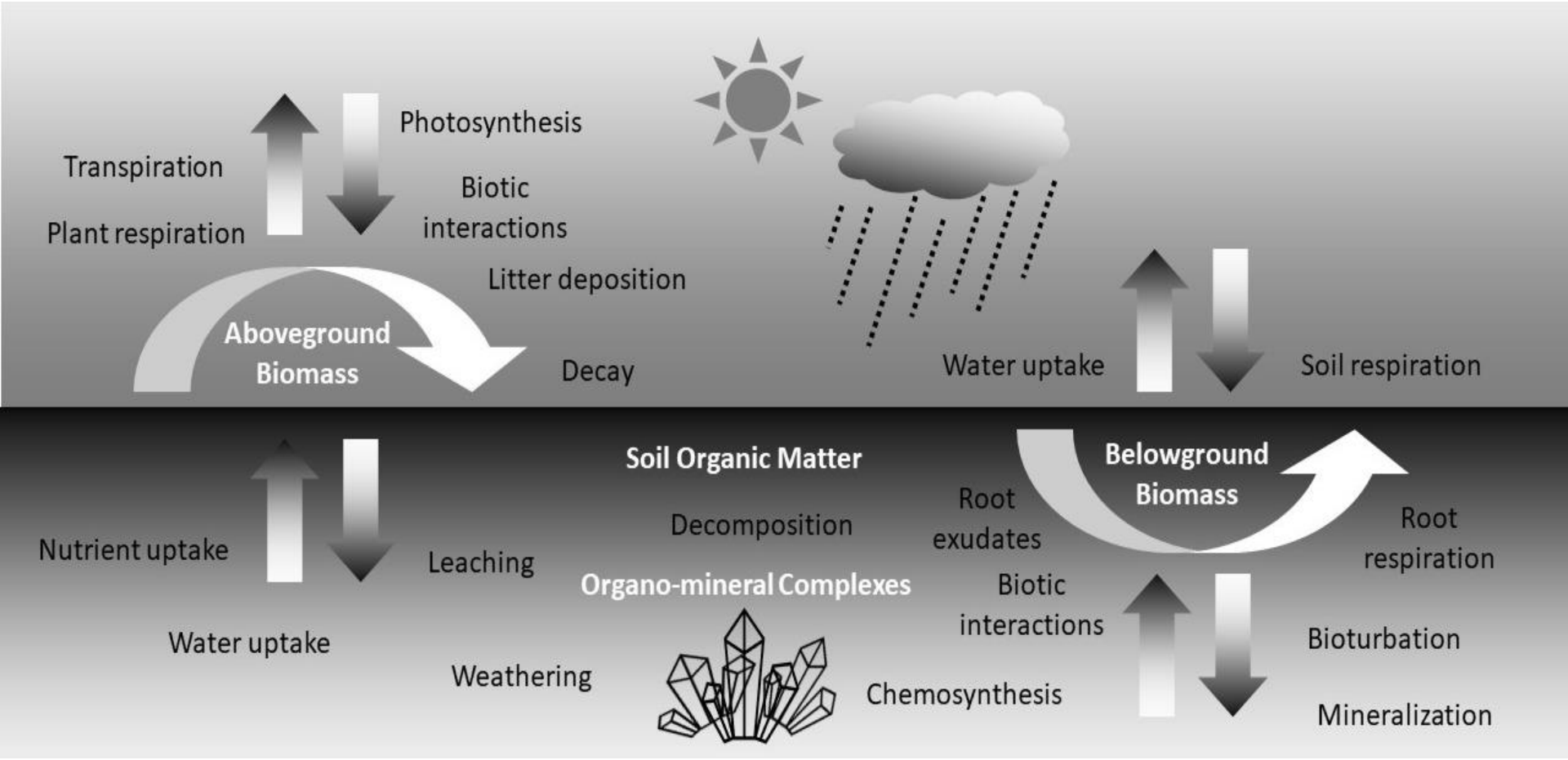
It is linking the biosphere, the pedosphere, the lithosphere, the hydrosphere, and the atmosphere.

Chorover, J., R. Kretzschmar, F. Garcia-Pichel, and D. L. Sparks. 2007. Soil biogeochemical processes in the critical zone. Elements 3, 321-326.

Earth Critical Zone

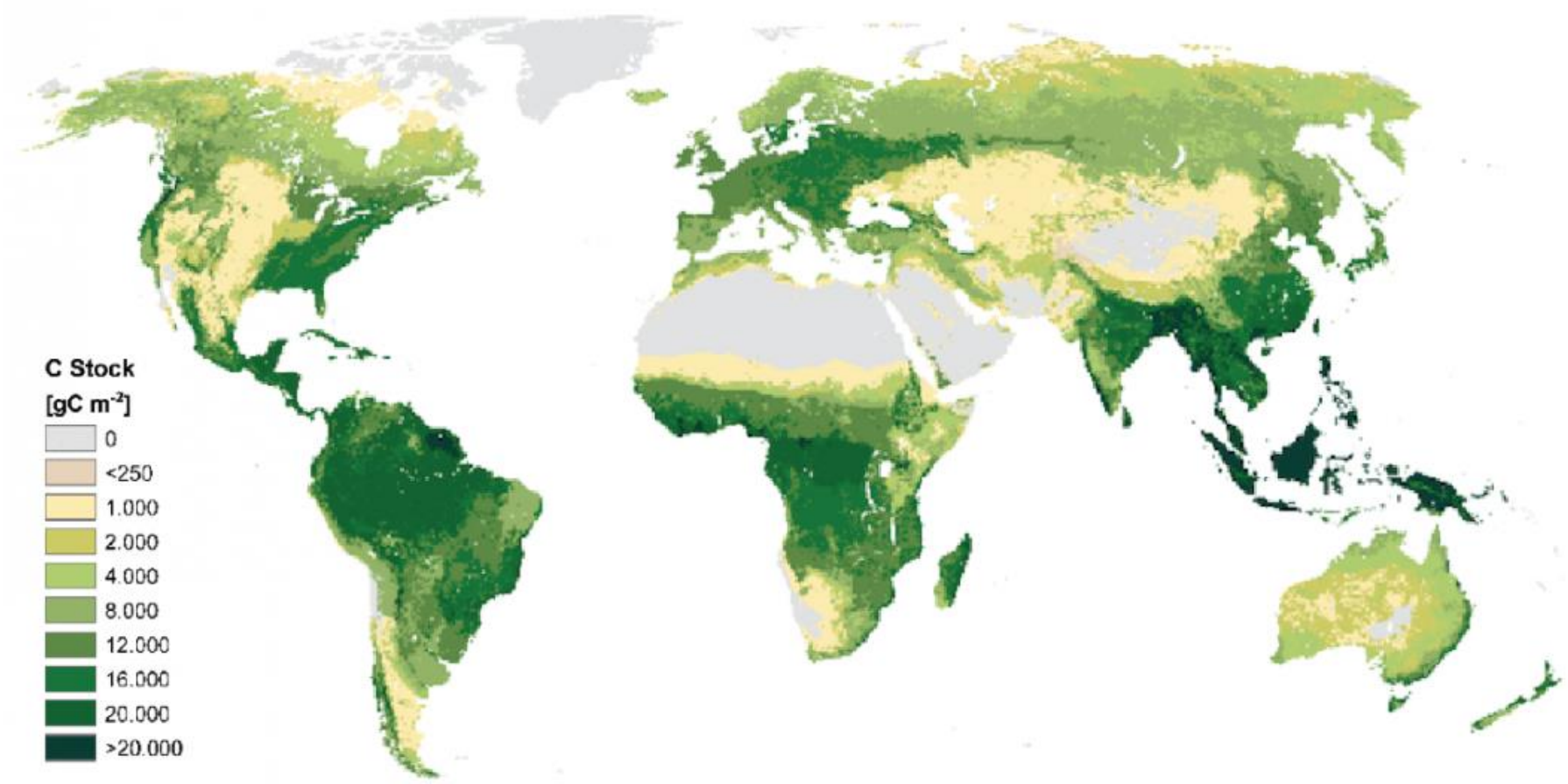
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Biodiversity is regulating major ecosystem functions.



Beierkuhnlein & Shrestha 2024: The Biogeography of the Earth Critical Zone.
In: White & Provenzale (eds) Critical Zone and Ecosystem Dynamics, Springer Nature, 51-77.

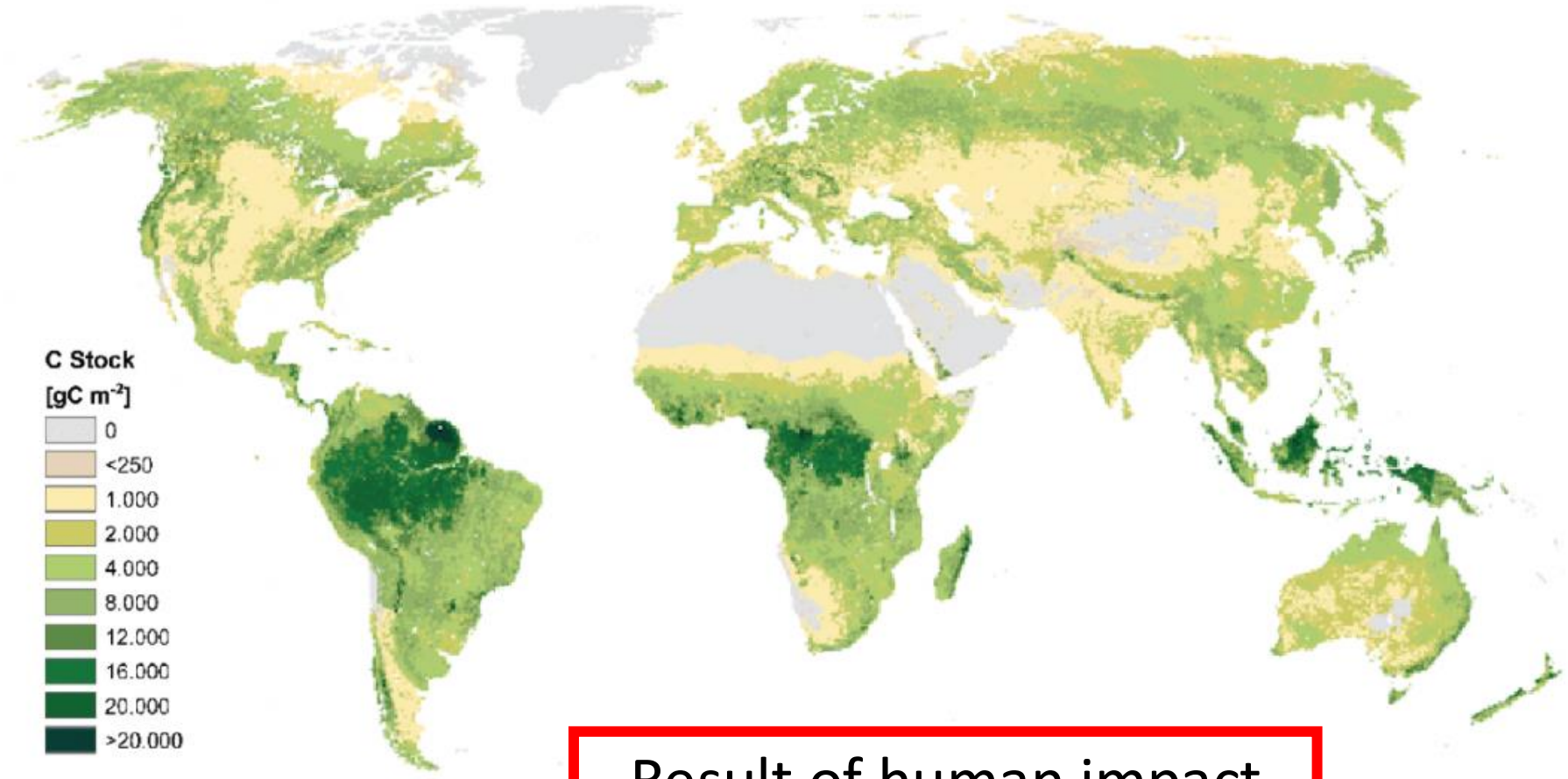
Potential biomass stocks



Earth Critical Zone

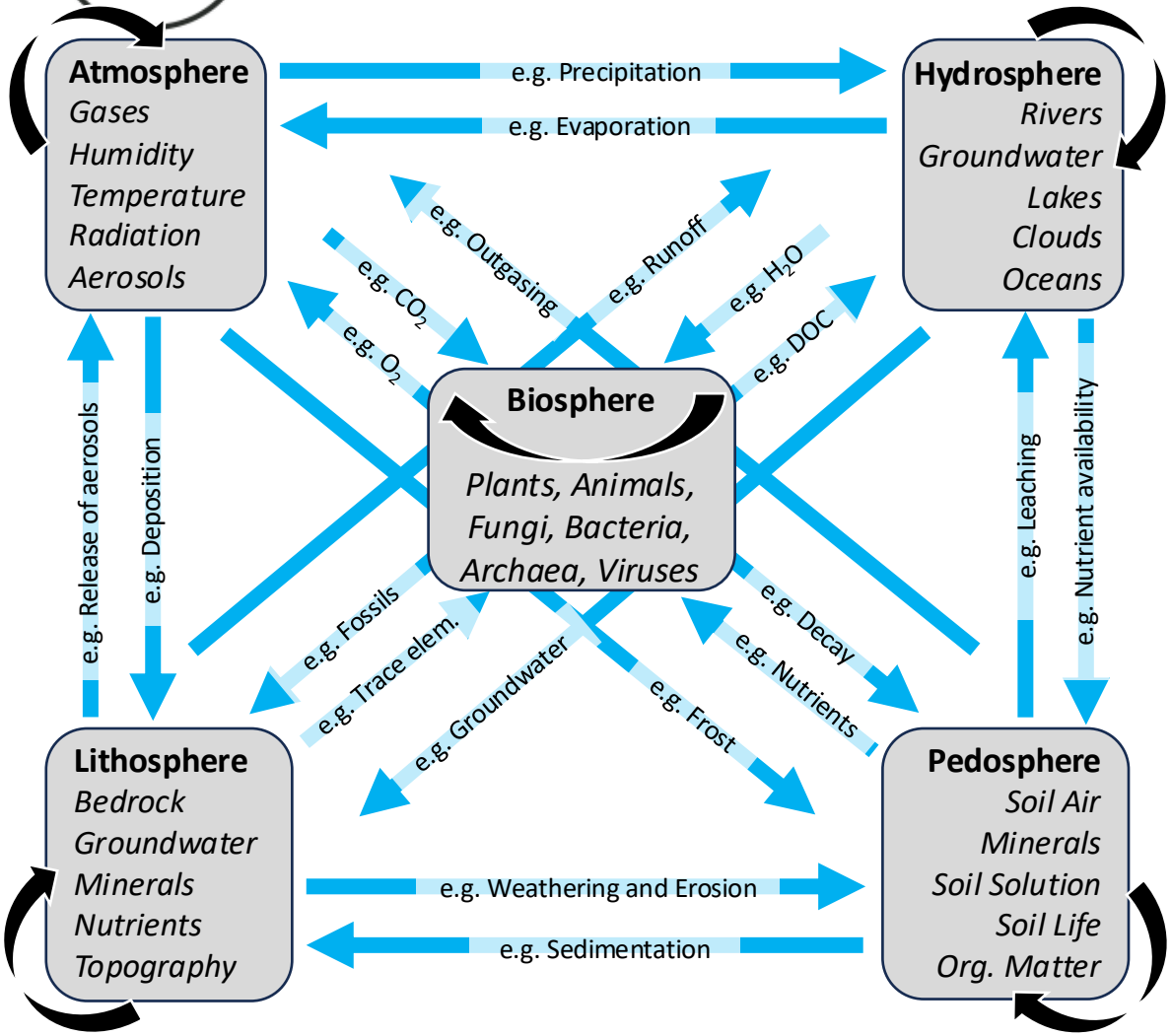
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Real biomass stocks



Result of human impact

Earth Critical Zone



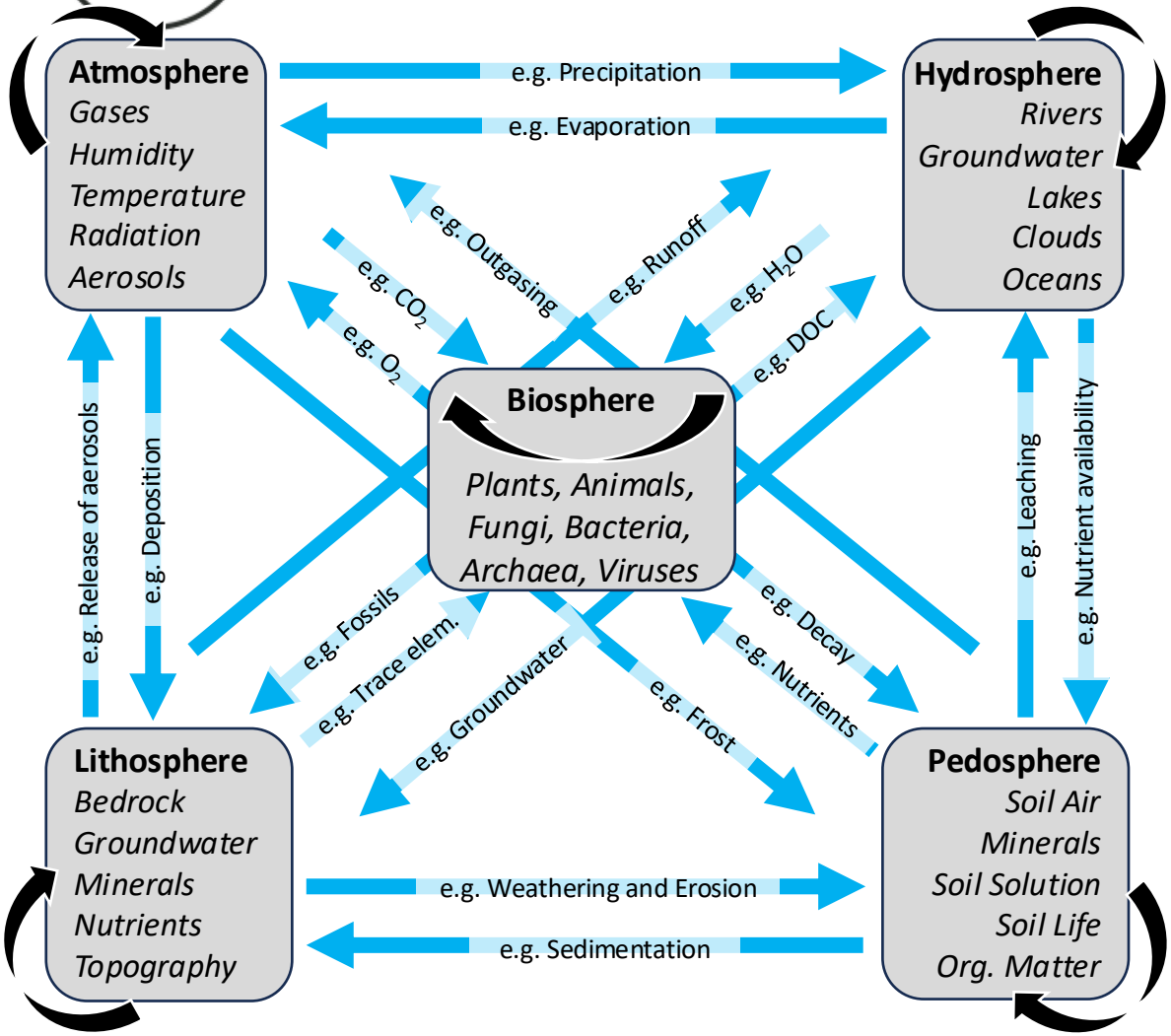
Conditions, traits, objects, compartments, attributed to spheres

Processes and functions linking compartments and spheres

Internal processes and fluxes within spheres

Beierkuhnlein, C., Pugh, B., Justice, S., Schrodt, F., El Serafy, G., Jenerowicz-Sanikowska, M., Karnieli, A., Lillebø, A., Mallast, U., Manakos, I., Mirtl, M., Nietsch, L., Peñas de Giles, J., Peterek, A., Poursanidis, D., Wozniak, E., Field, R., Provenzale, A. (2025) Towards a Comprehensive Geodiversity - Biodiversity Nexus. Earth Science Reviews 264, 105075.

Earth Critical Zone



Prozesses !

Matter

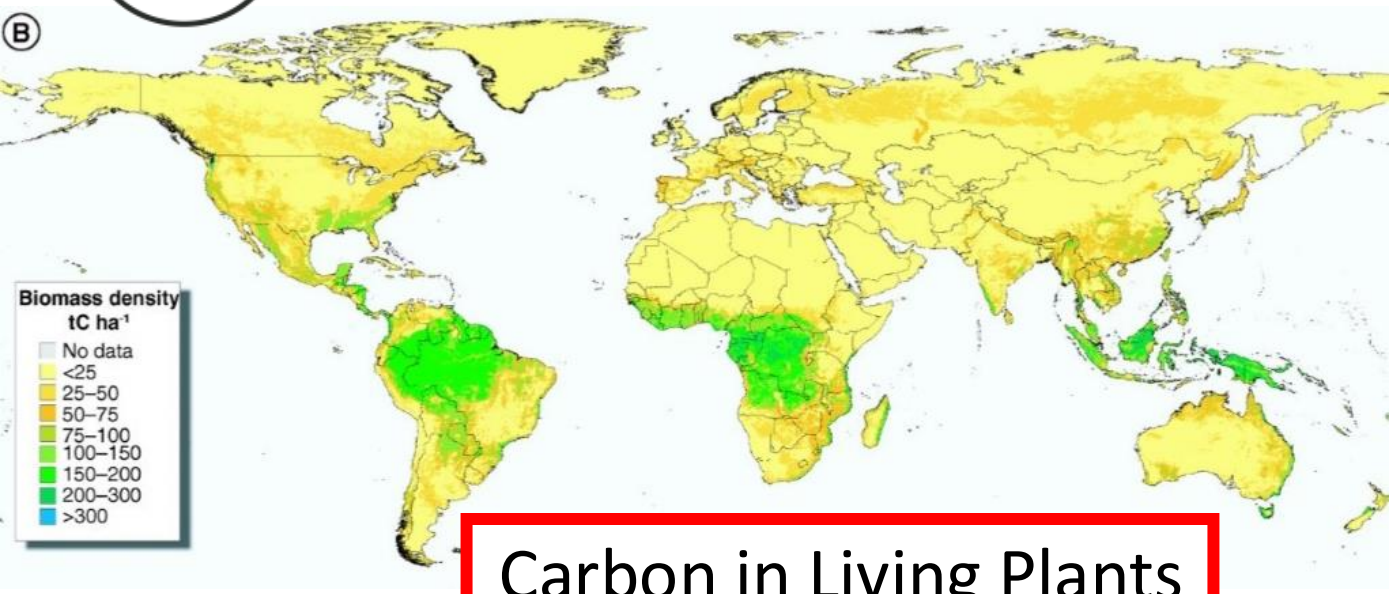
Information

Energy

Complexity !

Beierkuhnlein, C., Pugh, B., Justice, S., Schrodt, F., El Serafy, G., Jenerowicz-Sanikowska, M., Karnieli, A., Lillebø, A., Mallast, U., Manakos, I., Mirtl, M., Nietsch, L., Peñas de Giles, J., Peterek, A., Poursanidis, D., Wozniak, E., Field, R., Provenzale, A. (2025) Towards a Comprehensive Geodiversity - Biodiversity Nexus. Earth Science Reviews 264, 105075.

Earth Critical Zone

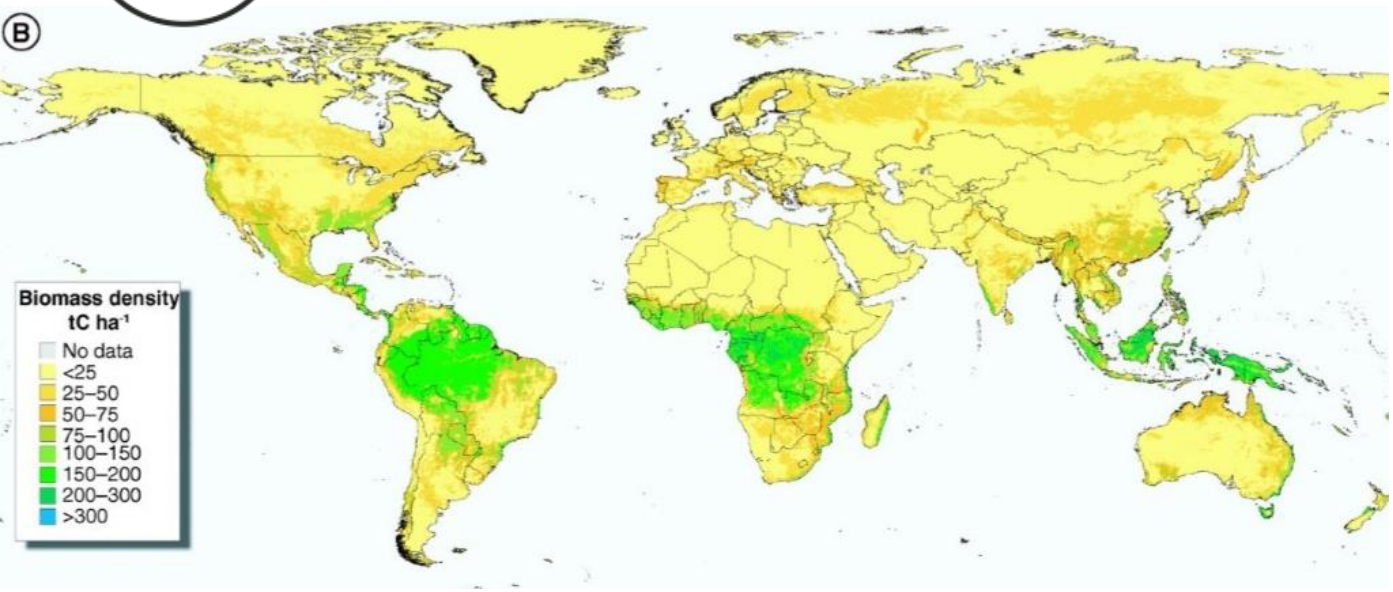


Carbon density (tC ha -1) stored in above and belowground **vegetation biomass**

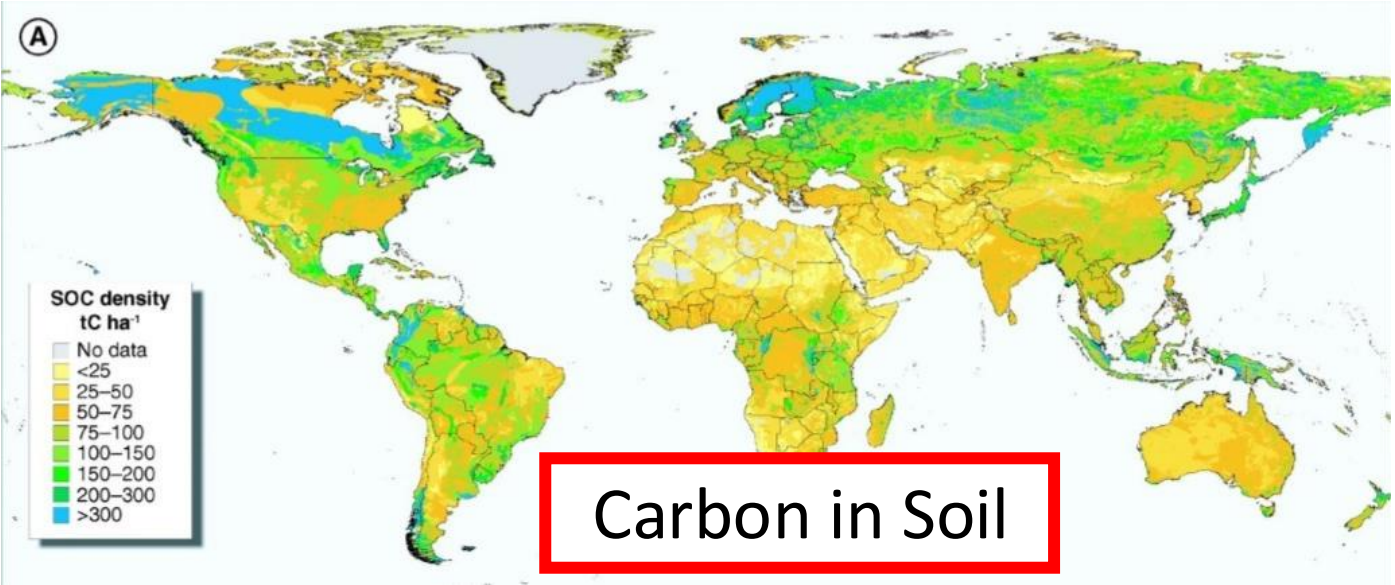
Carbon in Living Plants

Beierkuhnlein & Shrestha 2024: The Biogeography of the Earth Critical Zone. In: White & Provenzale (eds) Critical Zone and Ecosystem Dynamics, Springer Nature, 51-77.

Earth Critical Zone



Carbon density (tC ha -1) stored in above and belowground **vegetation biomass**



Carbon density (tC ha -1) stored in soils as **Soil Organic Carbon** (SOC) within 1m soil depth

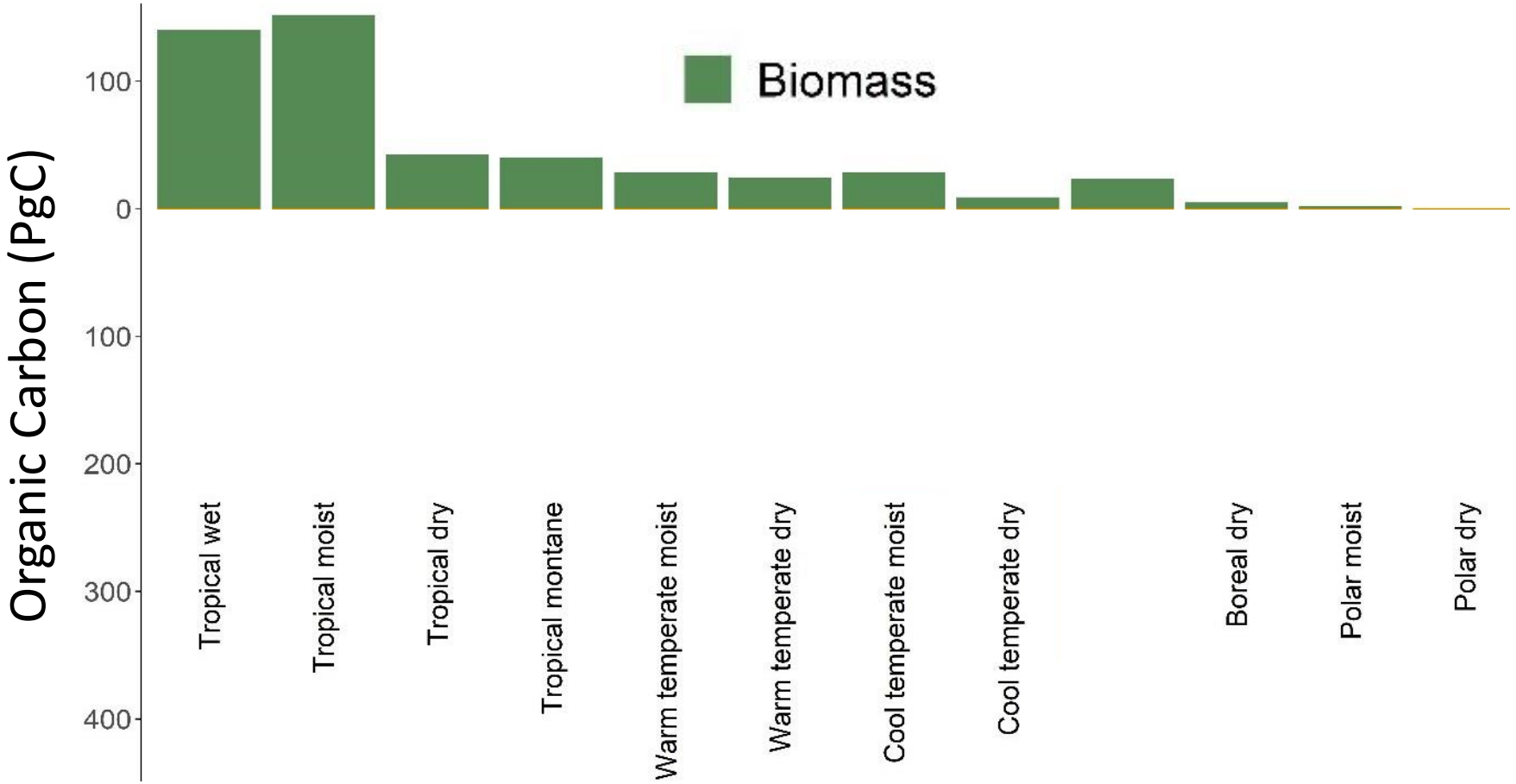
Carbon in Soil

Beierkuhnlein & Shrestha 2024: The Biogeography of the Earth Critical Zone. In: White & Provenzale (eds) Critical Zone and Ecosystem Dynamics, Springer Nature, 51-77.

Earth Critical Zone

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Distribution of organic carbon stocks across IPCC climatic regions subdivided into sub-soil, top-soil and above / belowground biomass.



Beierkuhnlein & Shrestha 2024: The Biogeography of the Earth Critical Zone.
In: White & Provenzale (eds) Critical Zone and Ecosystem Dynamics, Springer Nature, 51-77.

Earth Critical Zone

Climate change and biodiversity loss cannot be seen in isolation. Interactions are scale dependent.

- **Nature Conservation**
- **Land Use**
- **Human Health**

Case Studies



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Case Study

Nature Conservation and Protected Areas

Nature Conservation

… is confronted with fundamental **challenges** through biodiversity loss and climate change!

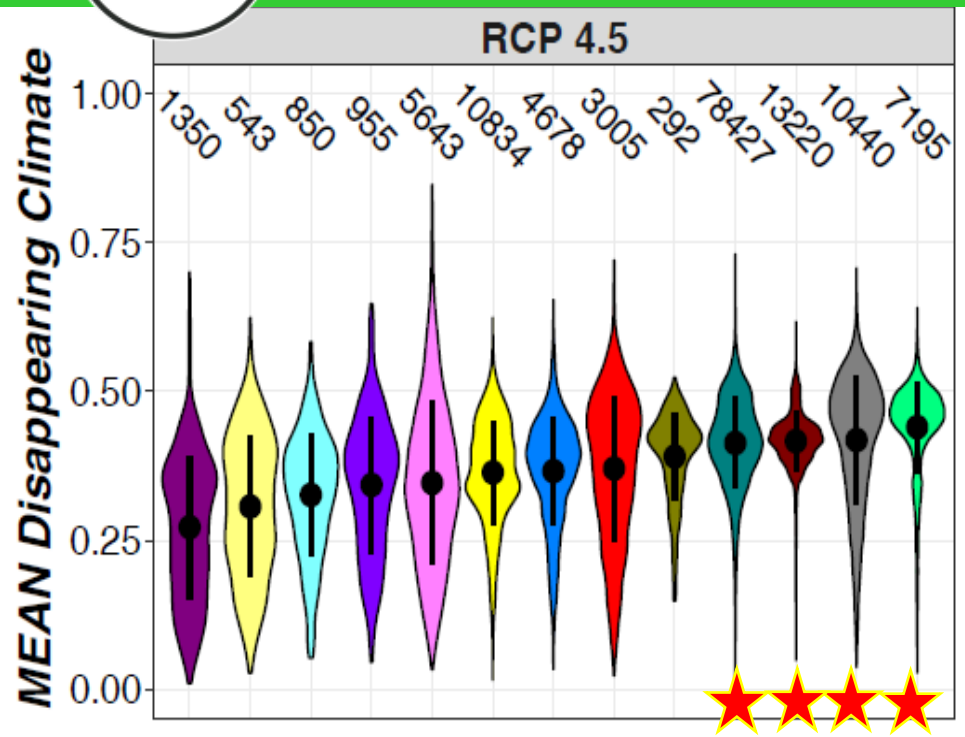
- Populations of **rare and already threatened species** are at the brink of extinction.
- Communities are changing and the legal status of defined **static EU habitat types** can be lost.
- **Protected area** do no longer offer the environmental conditions and value from their **historic origin**.
- And more…

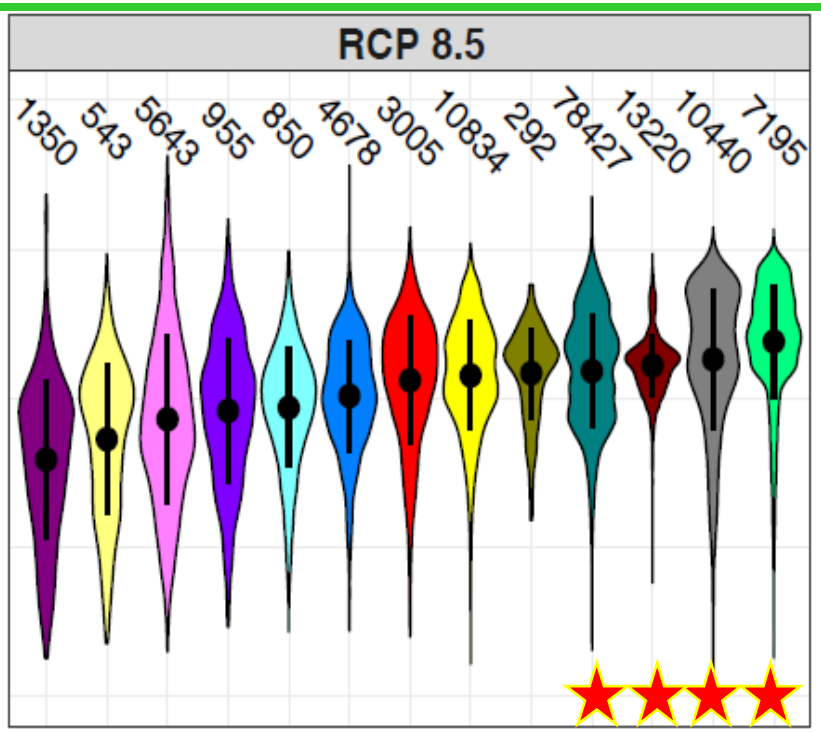
Nature Conservation

… must benefit from big data about species occurrences, remote sensing, and climatic information and forecasts !

- to assess the current and future **limitations and perspectives** for the preservation of biodiversity.
- to develop **spatial strategies and priorities** for protected areas in face of 30 x 30.

Protected Areas





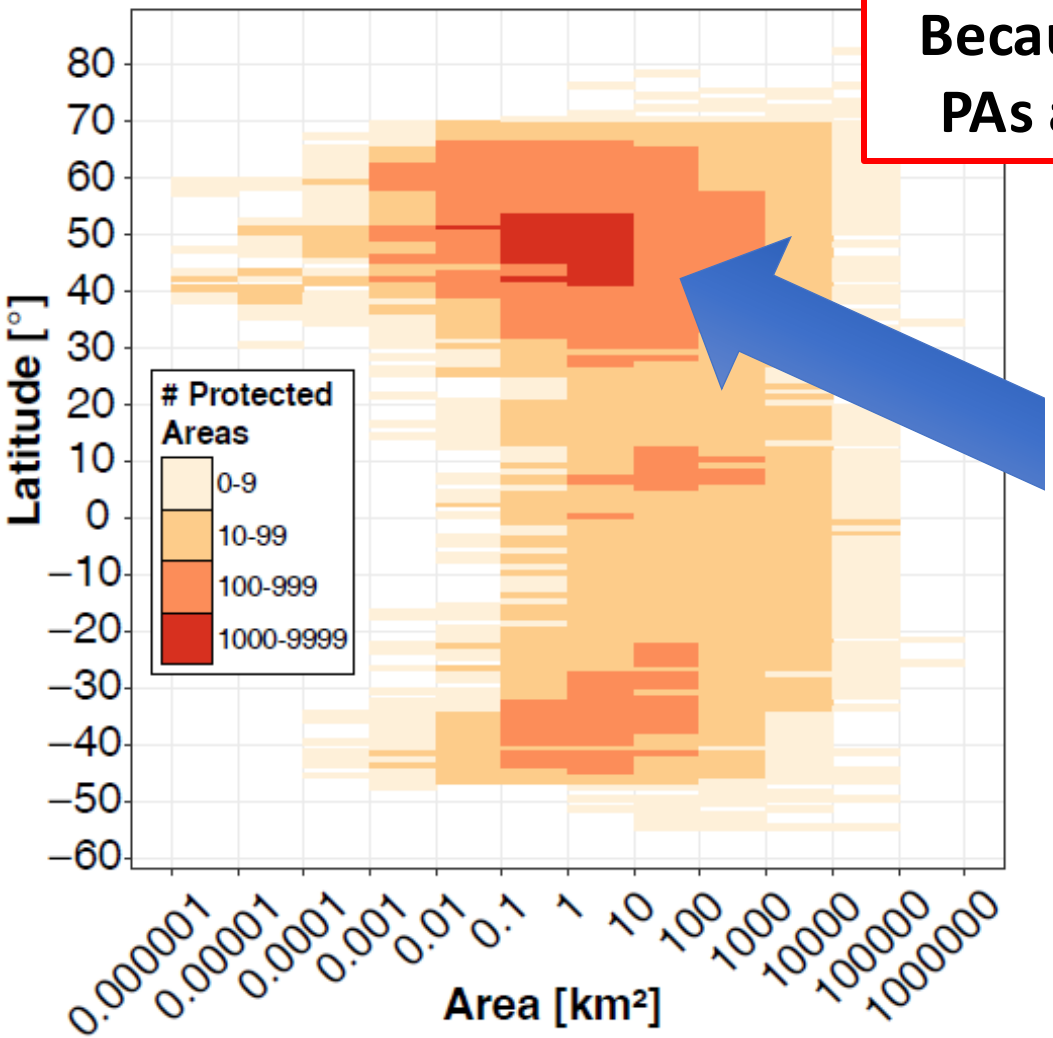
- Boreal Forests/Taiga
- Deserts & Xeric Shrublands
- Flooded Grasslands & Savannas
- Mediterranean Forests, Woodlands & Scrub
- Montane Grasslands & Shrublands
- Temperate Broadleaf & Mixed Forests
- Temperate Conifer Forests
- Temperate Grasslands, Savannas & Shrublands
- Tropical & Subtropical Coniferous Forests
- Tropical & Subtropical Dry Broadleaf Forests
- Tropical & Subtropical Grasslands, Savannas & S
- Tropical & Subtropical Moist Broadleaf Forests
- Tundra

Temperate and boreal protected areas most affected!

Hoffmann, Irl, Beierkuhnlein 2019. Predicted climate shifts within terrestrial protected areas worldwide. Nature Communications, 10, 4787 doi.org/10.1038/s41467-019-12603-w

Protected Areas

Because of small sizes, European PAs are particularly threatened



Many **small** PAs in the temperate zone of the northern hemisphere (e.g. Natura 2000)

World Database On Protected Areas
incorporating the UN List of Protected Areas

Hoffmann, Irl, Beierkuhnlein 2019. Predicted climate shifts within terrestrial protected areas worldwide. Nature Communications, 10, 4787 doi.org/10.1038/s41467-019-12603-w

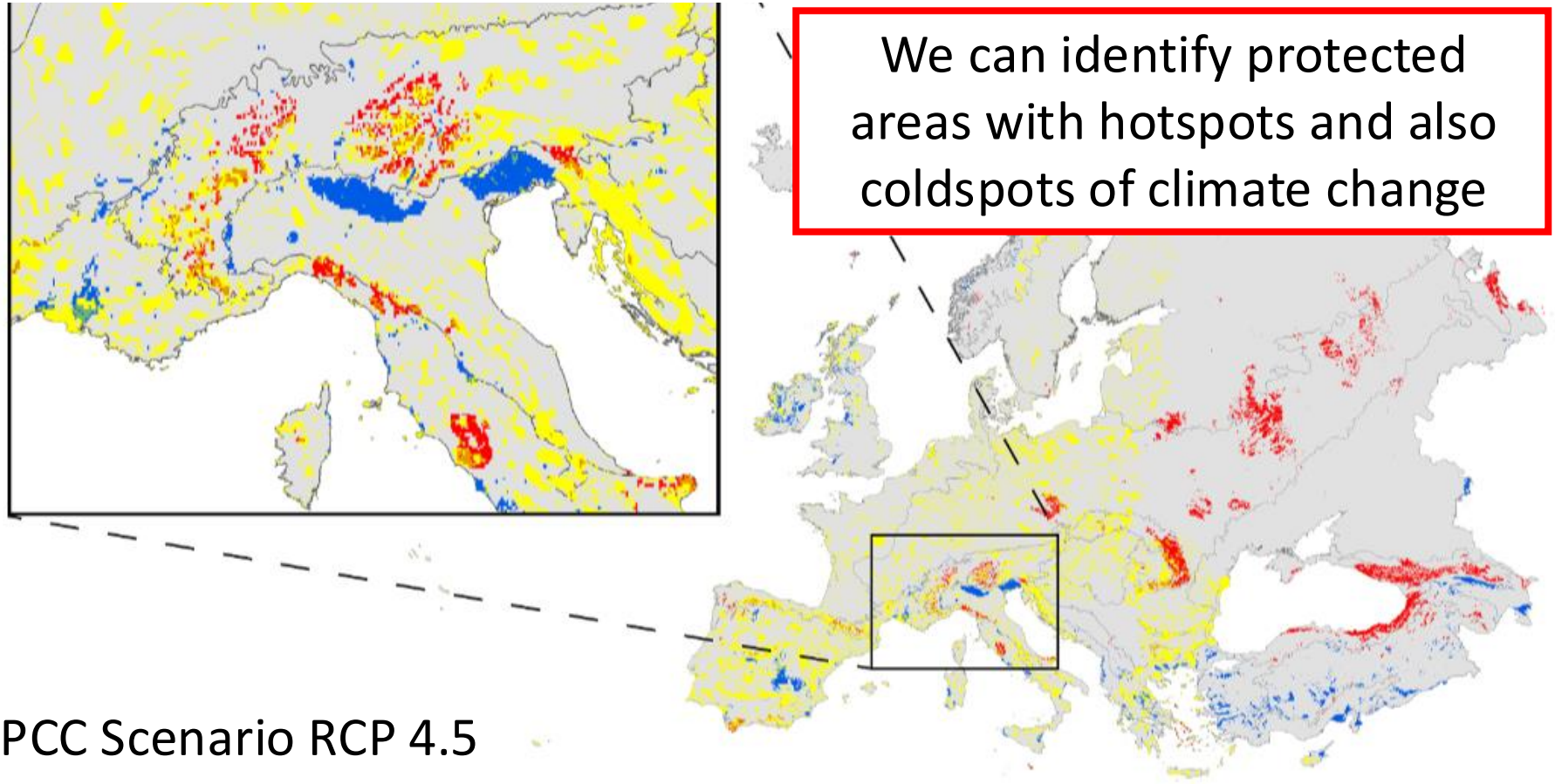
Protected Areas

Climate change coldspots within Natura 2000

Climate change hotspots within Natura 2000

Climate change coldspots

Climate change hotspots



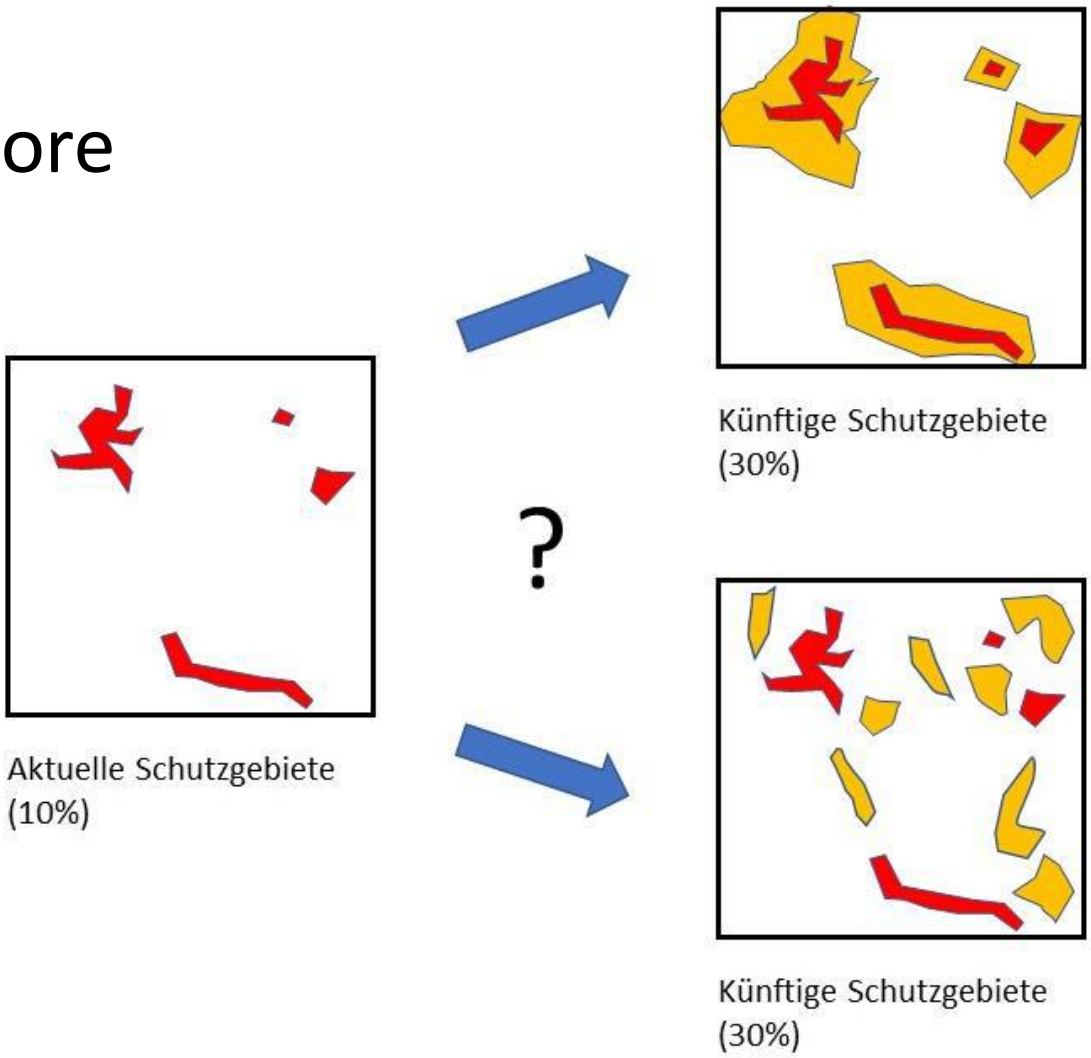
We can identify protected areas with hotspots and also coldspots of climate change

IPCC Scenario RCP 4.5

Lai, Hoffmann, Jaeschke, Beierkuhnlein 2022. Emerging spatial prioritization for biodiversity conservation indicated by climate change velocity. Ecological Indicators, 138(108829), 1-14

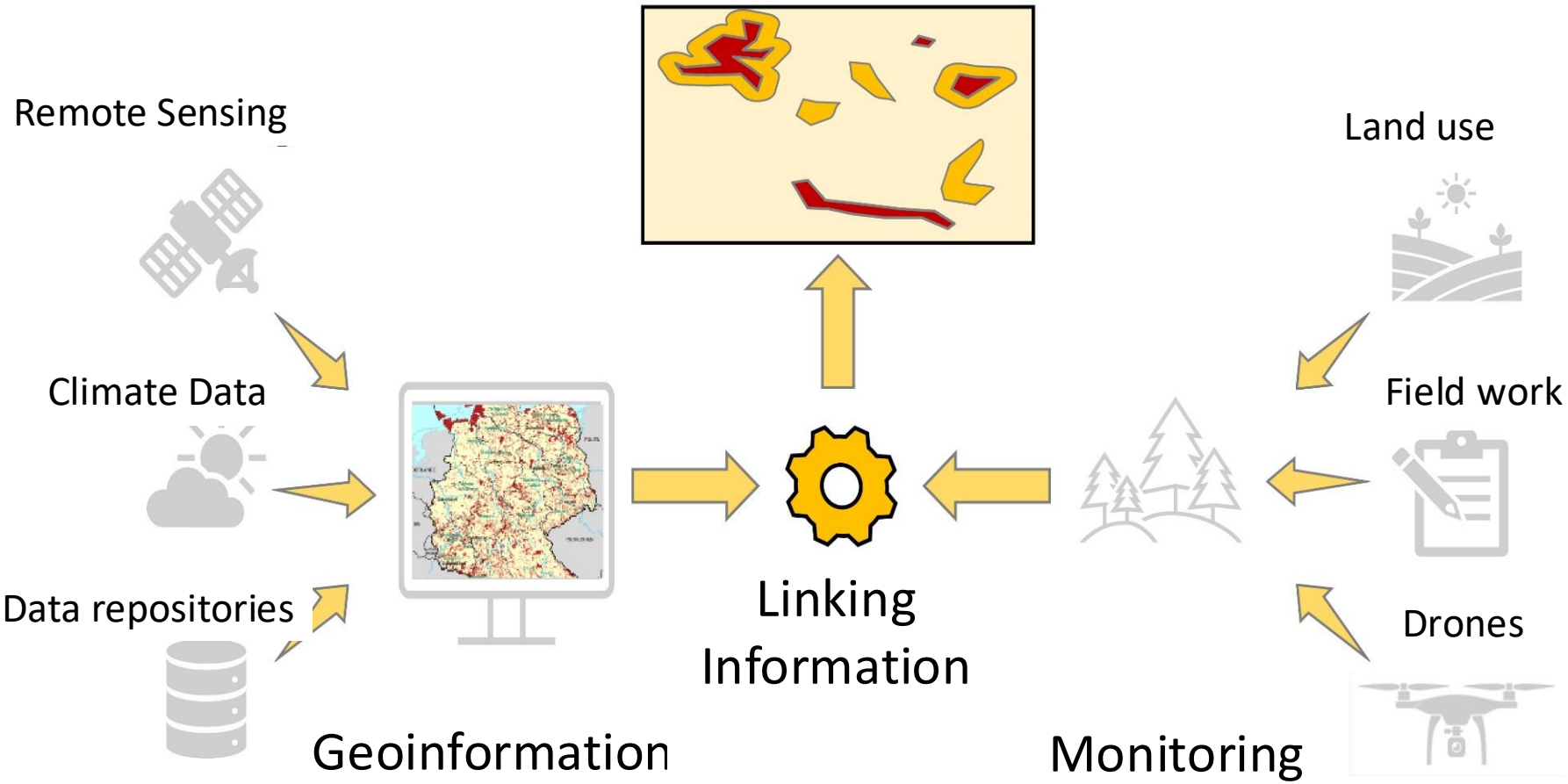
Protected Areas

Bigger – OR – More



Beierkuhnlein, C. 2023. Auswirkungen des Klimawandels in Schutzgebieten im globalen und kontinentalen Kontext. BfN Schriften 675, 12-25. Schutzgebiete im Klimawandel. doi.org/10.19217/skr675

Protected Areas



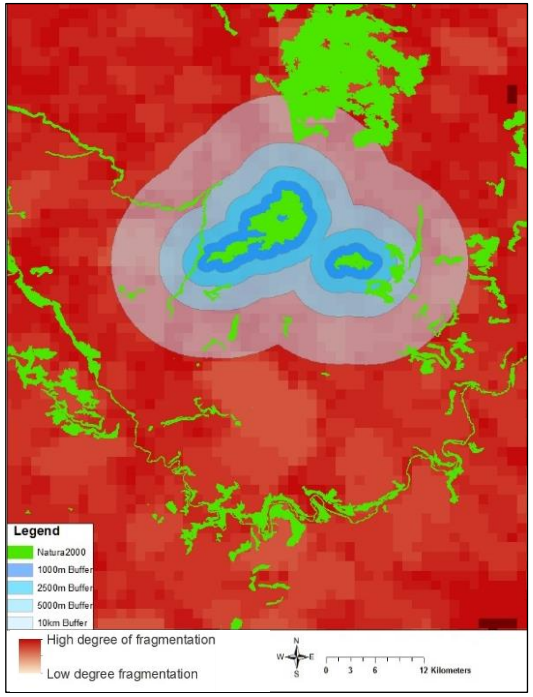
Beierkuhnlein C, Stahlmann R, Geist J (2023) Erfüllung der Ziele im Flächennaturschutz bis zum Jahr 2030 - Kriterien und Prioritäten. Naturschutz und Landschaftsplanung, 55(7), 16-21

Protected Areas

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NATURA 2000

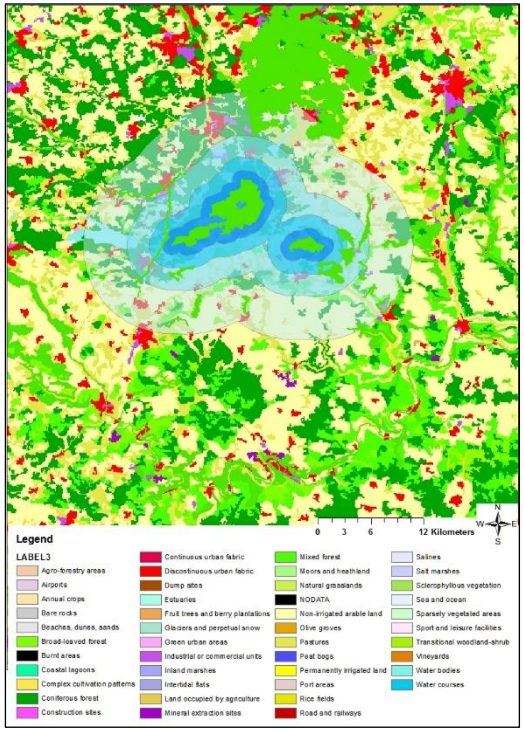
Fragmentation



Natura 2000 Frankenalb

(EEA)

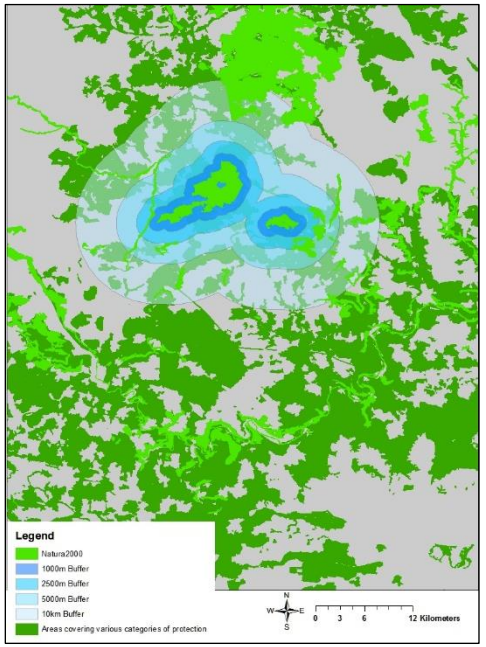
Land Cover



Corine landcover classification (CLC 2012)

Reference: EEA 2012. Corine Land Cover (CLC) 2012. Version 18.5.1 [01/2018] Available at: https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012?tab=metadata.

Other Protection Status

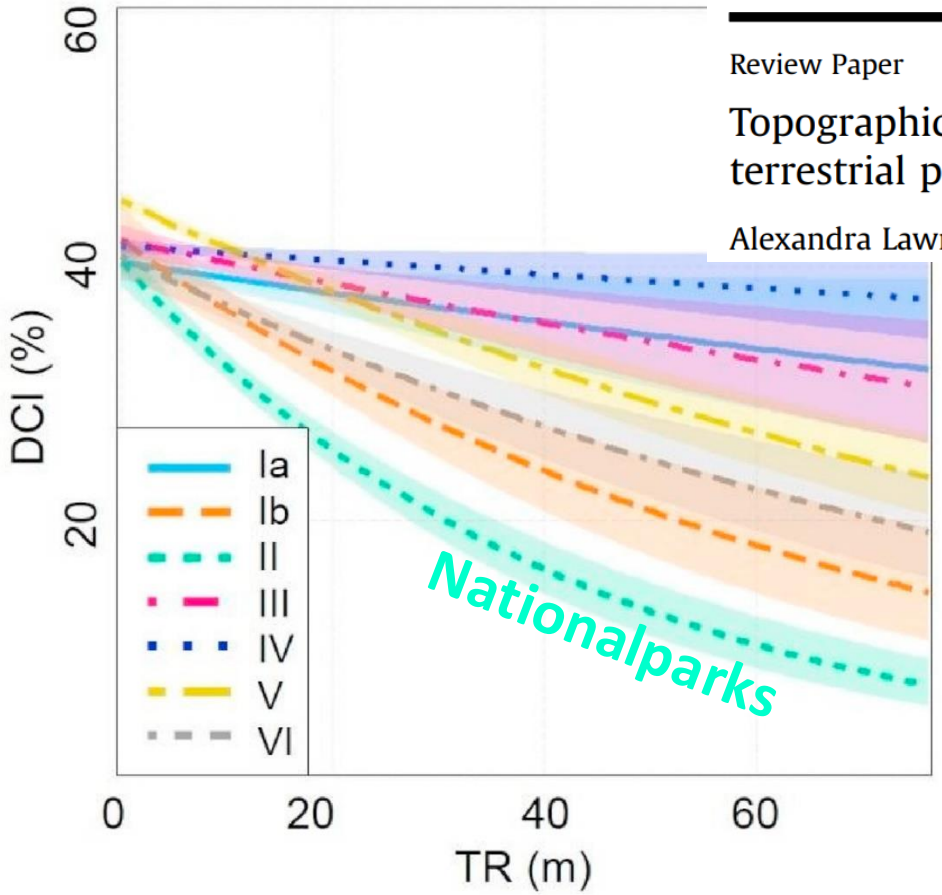


World Database on Protected Areas (WDPA)

Reference: IUCN and UNEP-WCMC 2017. The World Database on Protected Areas (WDPA) [09/2017]. Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net.

RCP 4.5 bis 2070 (+- 10 a)

Verloren gehende Klimabedingungen



Topographische Rauigkeit

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Review Paper

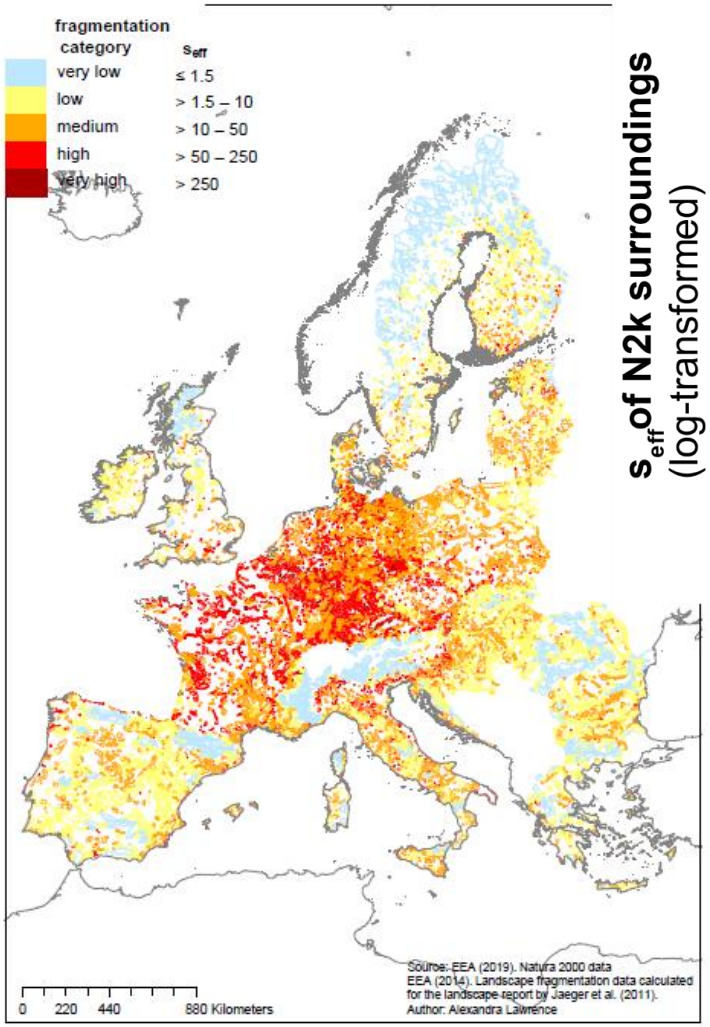
Topographic diversity as an indicator for resilience of terrestrial protected areas against climate change

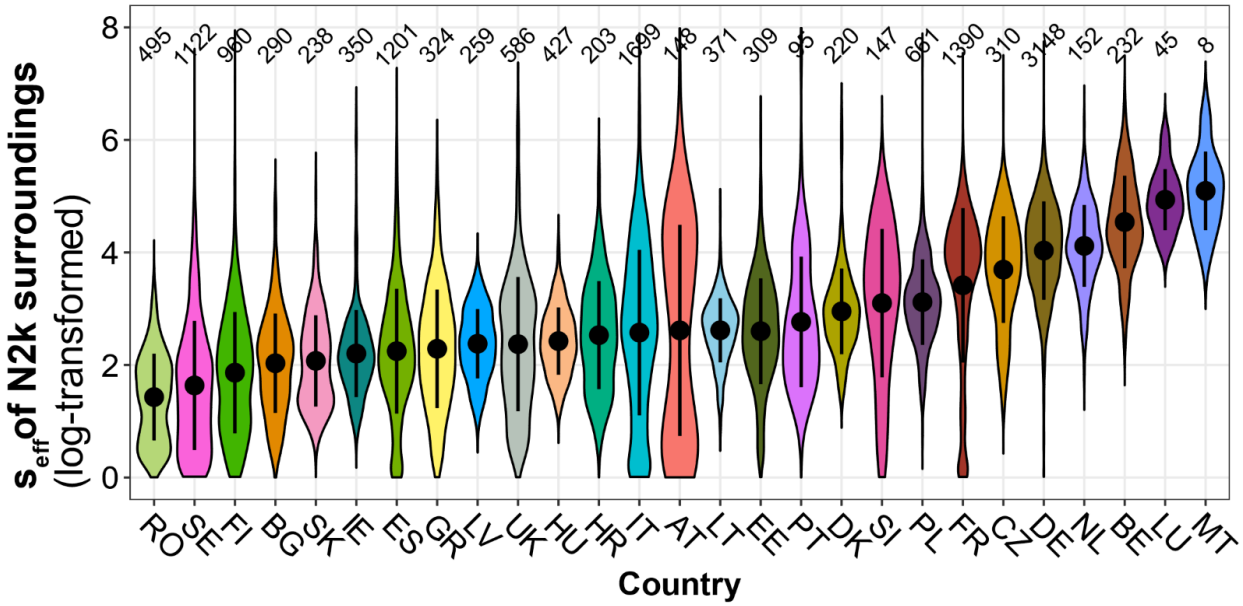
Alexandra Lawrence [a, *], Samuel Hoffmann [a], Carl Beierkuhnlein [a, b, c]

Heterogeneous Topography means less habitat loss

Lawrence, Hoffmann, Beierkuhnlein 2021. Topographic diversity as an indicator for resilience of terrestrial protected areas against climate change. Global Ecology and Conservation, 25, e01445

Fragmentation

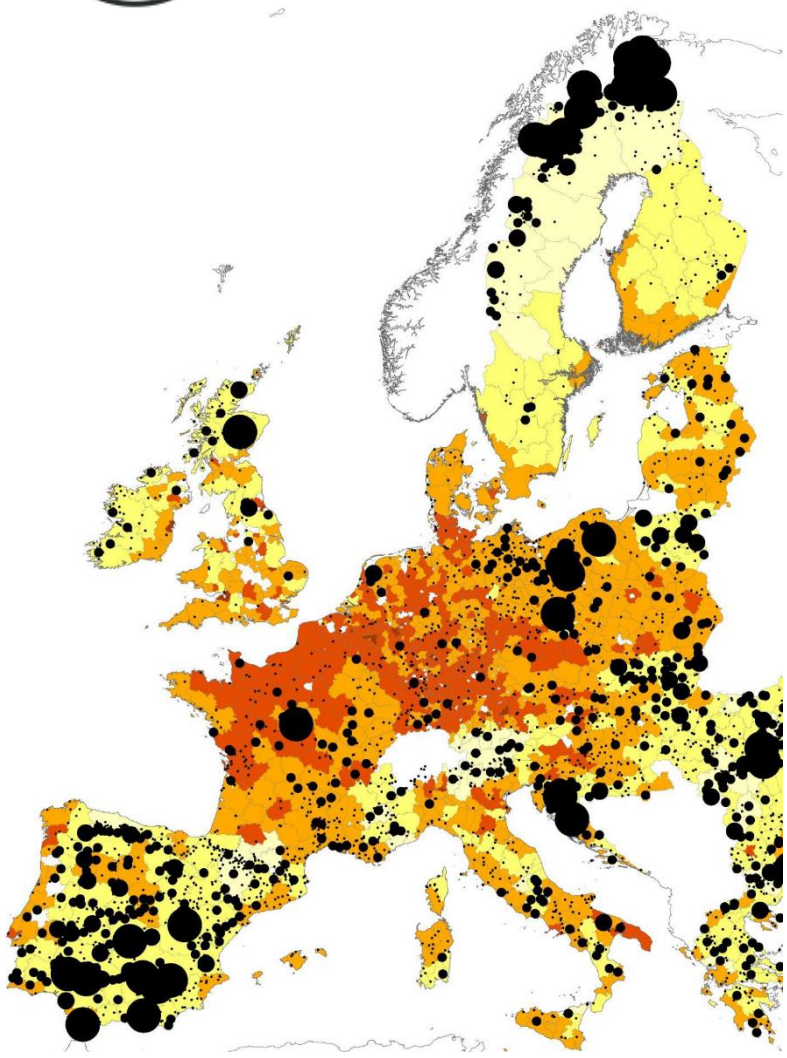




Fragmentation in surroundings of N2000 protected areas.

Lawrence, Beierkuhnlein (2023) Detecting low fragmented sites surrounding European protected areas – Implications for expansion of the Natura 2000 network. Journal for Nature Conservation 73, 126398.

Fragmentation

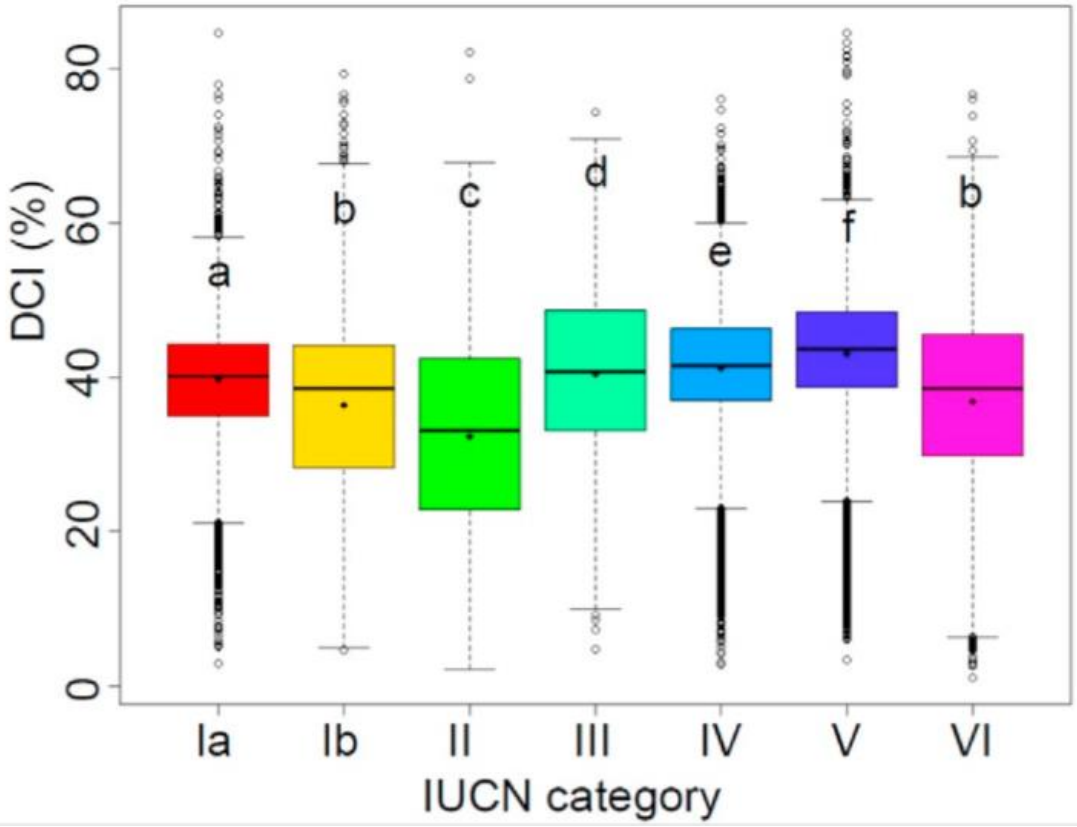


Highly fragmented landscapes host mainly very small PAs

Lawrence, Friedrich, Beierkuhnlein (2021) Landscape fragmentation of the Natura 2000 network and its surrounding areas, PLoS ONE, 16(10), e0258615, 1-22

Fragmentation

Disappearing Climate Index (DCI) for global Protected Areas in IUCN Categroies



All Categories are equally affected

137,432 PAs comprising a total area of 20,658,583 km2

14% of the global terrestrial surface and 99.9% of all PAs

World Database On Protected Areas
incorporating the UN List of Protected Areas

Lawrence, Hoffmann, Beierkuhnlein 2021. Topographic diversity as an indicator for resilience of terrestrial protected areas against climate change. Global Ecology and Conservation, 25, e01445

Nature Conservation

Conservation in the face of climate change and biodiversity loss

…needs to identify, which **protected areas** will fulfil their aims also in the future

- by suggesting regional priorities.

…requires spatial concepts for the appropriateextension of the European network of protected areas

- by identifying areas for larger and new protected areas.

…must consider fragmentation in densely populated landscapes

- to realize limits and options for biological networks.



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Case Study

Land Use and Grasslands

Land Use

… is confronted with fundamental **challenges** through biodiversity loss and climate change!

- Ecosystem functioning can be declining due to species loss.
- Spatial patterns and seasonal phenology of plant communities are expected to be homogenized.

Land Use

… can be assesed based on remote sensing for land use and cover, experimental treatments, and weather data and Global Circulation Models !

- Knowledge on these interactions is useful to design management related to the EU Restoration Law

Grasslands



Grassland in Aosta Valley, Italy

Grasslands

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Mowing 6 times per year
Fertilizer added

The loss of species richness is expected to have negative effects on ecosystem services.

Grassland close to Bayreuth

Grasslands

European grasslands are important components of cultural landscapes and exhibit **high species diversity**.









Grasslands

European grasslands are important components of cultural landscapes and habitat for many species.

Like forests, these managed grasslands (pastures, hay meadows) are **permanent ecosystems** that persist even without fertilization.





Grasslands

European grasslands are important components of cultural landscapes and habitat for many species.

Like forests, these managed grasslands (pastures, hay meadows) are permanent ecosystems that persist even without fertilization.

Managed grasslands are excellent tools for **experimental research**. They can easily be established, manipulated, and **harvested**.


Bayreuth


Jena

Lindenhof Grassland Experiment

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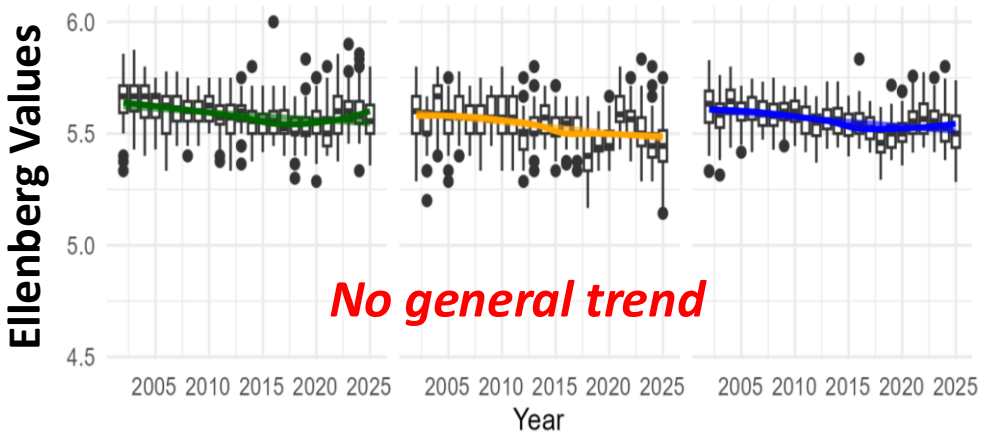
64 plots 2x2 m
Species specific cover and biomass
Annual species recording since 1995
Since 1999 no manipulation of richness

Temperature Regime

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Presence

June September All Year

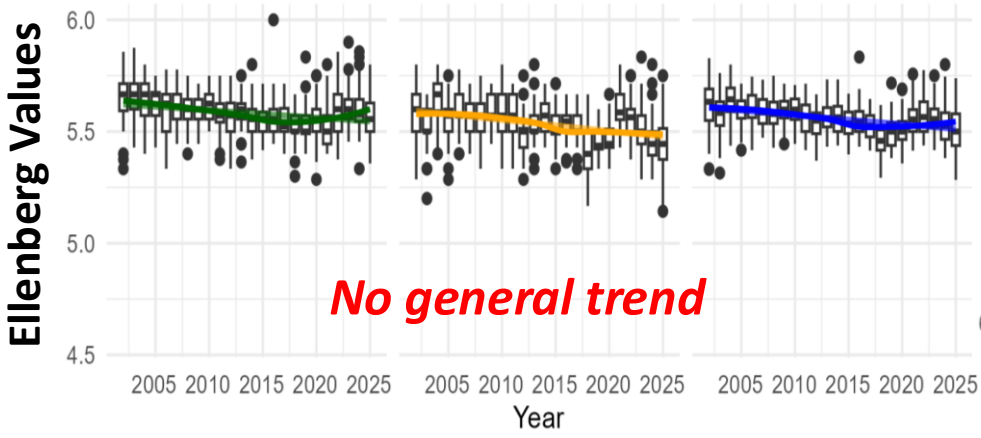


Temperature Regime

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Presence

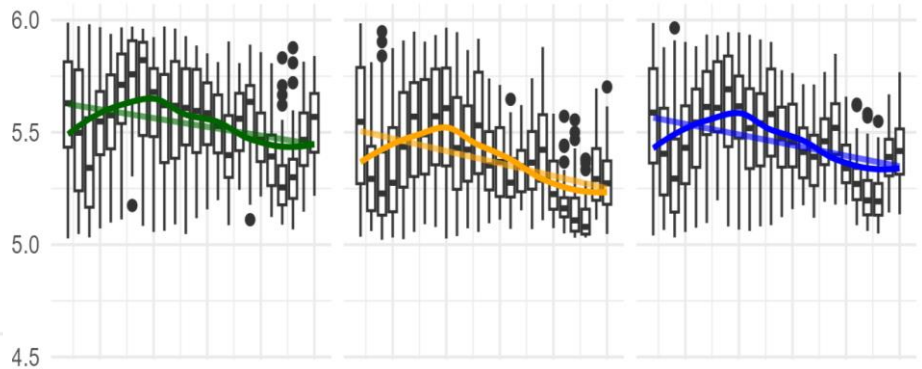
June | September | All Year



No general trend

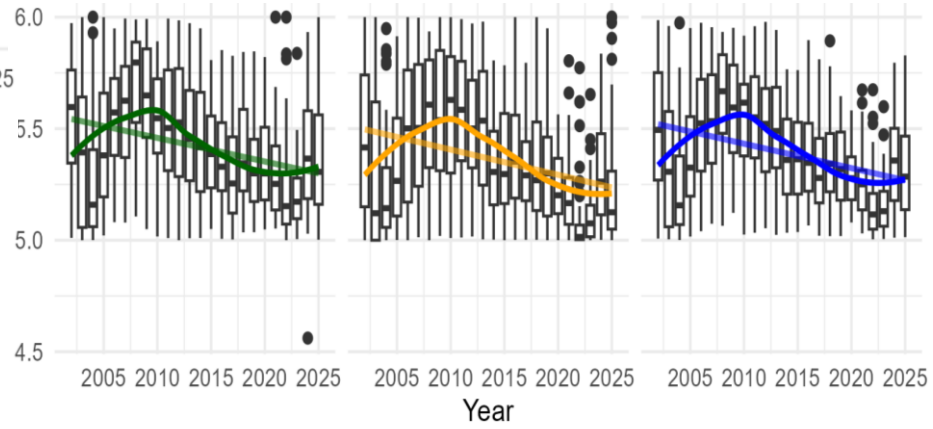
Cover

June | September | All Year



Same fluctuating pattern

Biomass



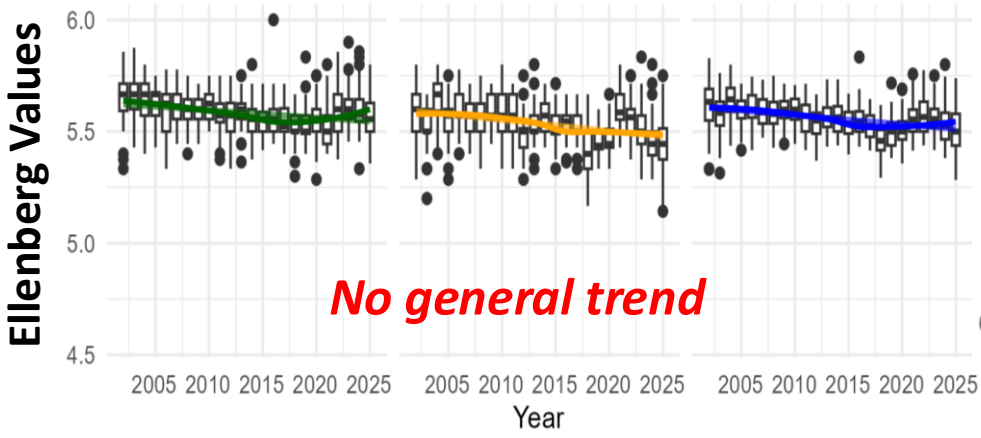
Temperature Regime

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No short-term establishment of thermophilic plant species

Presence

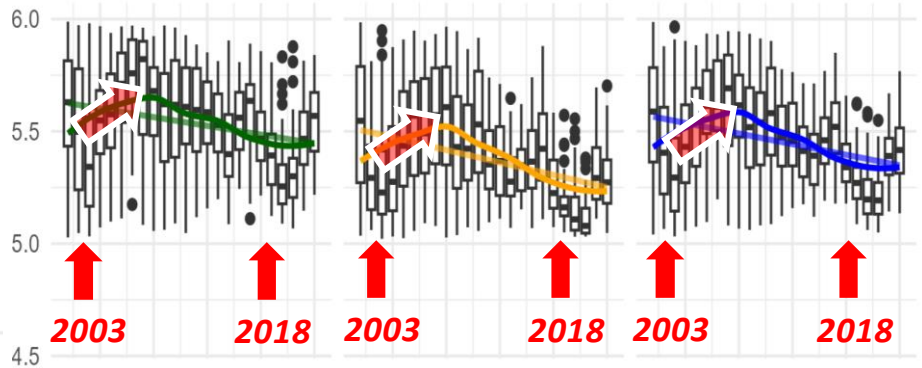
June September All Year



No general trend

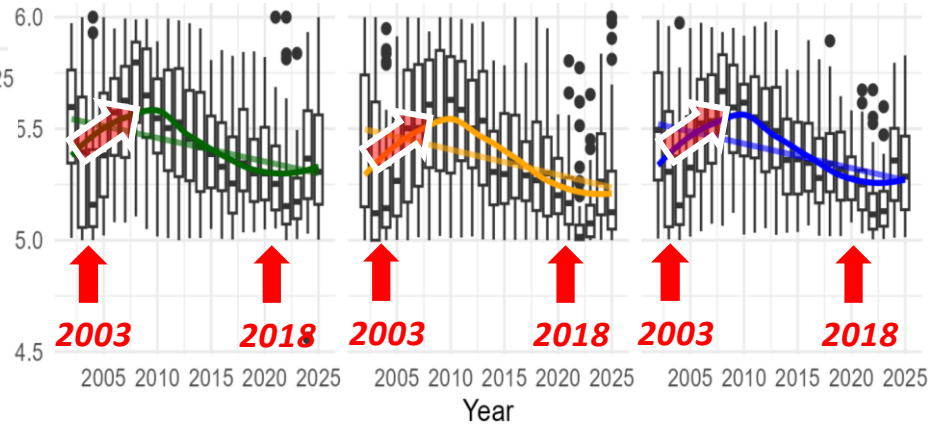
Cover

June September All Year



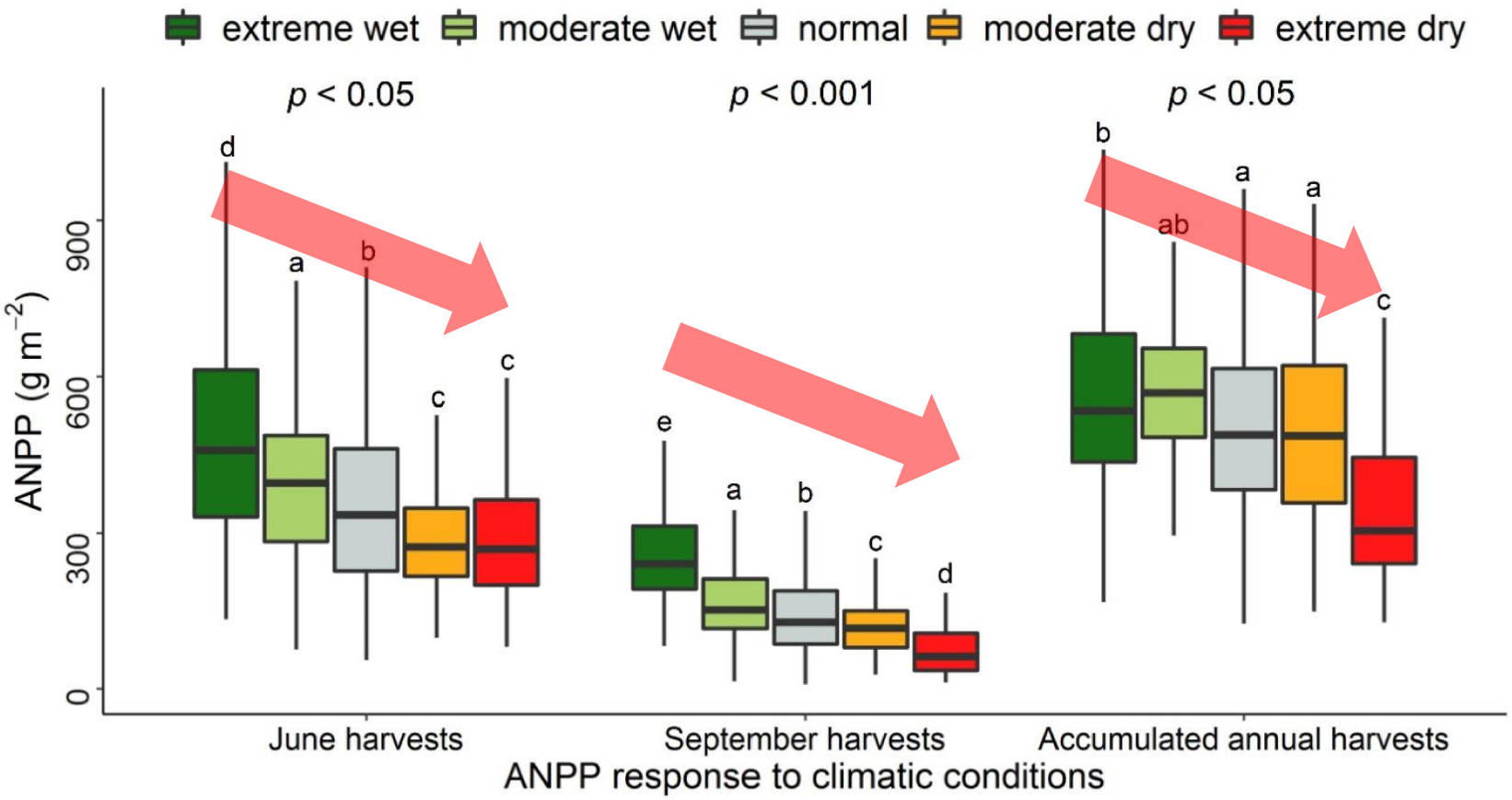
Shifting dominance patterns after drought and heat waves

Biomass



Extreme Weather

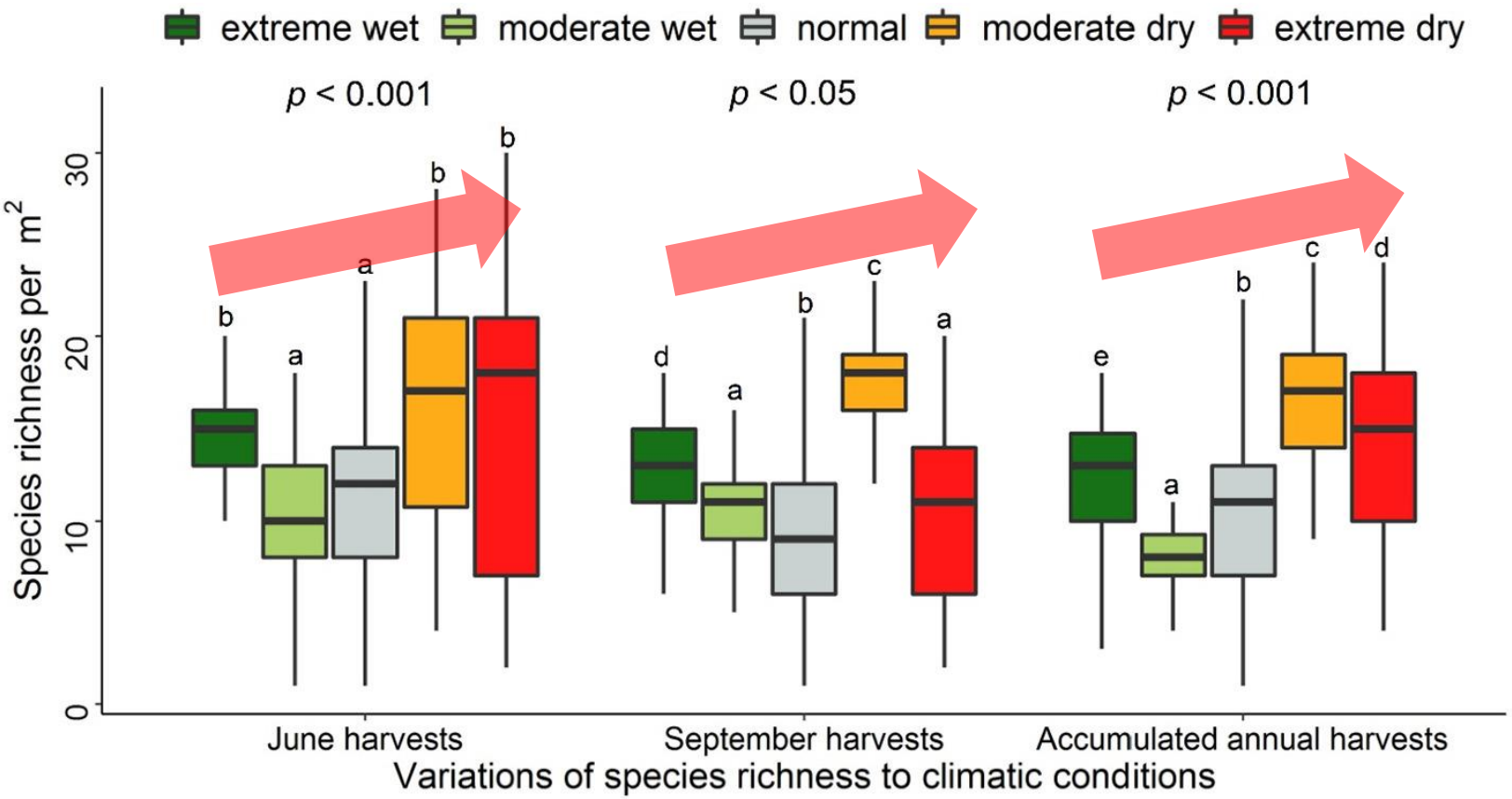
No surprise: Drought results in less biomass



Hossain, Li, Hoffmann, Beierkuhnlein 2022. Biodiversity showed positive effects on resistance but mixed effects on resilience to climatic extremes in a long-term grassland experiment. Science of The Total Environment, 827, 154322.

Extreme Weather

Surprise: Drought increases species richness

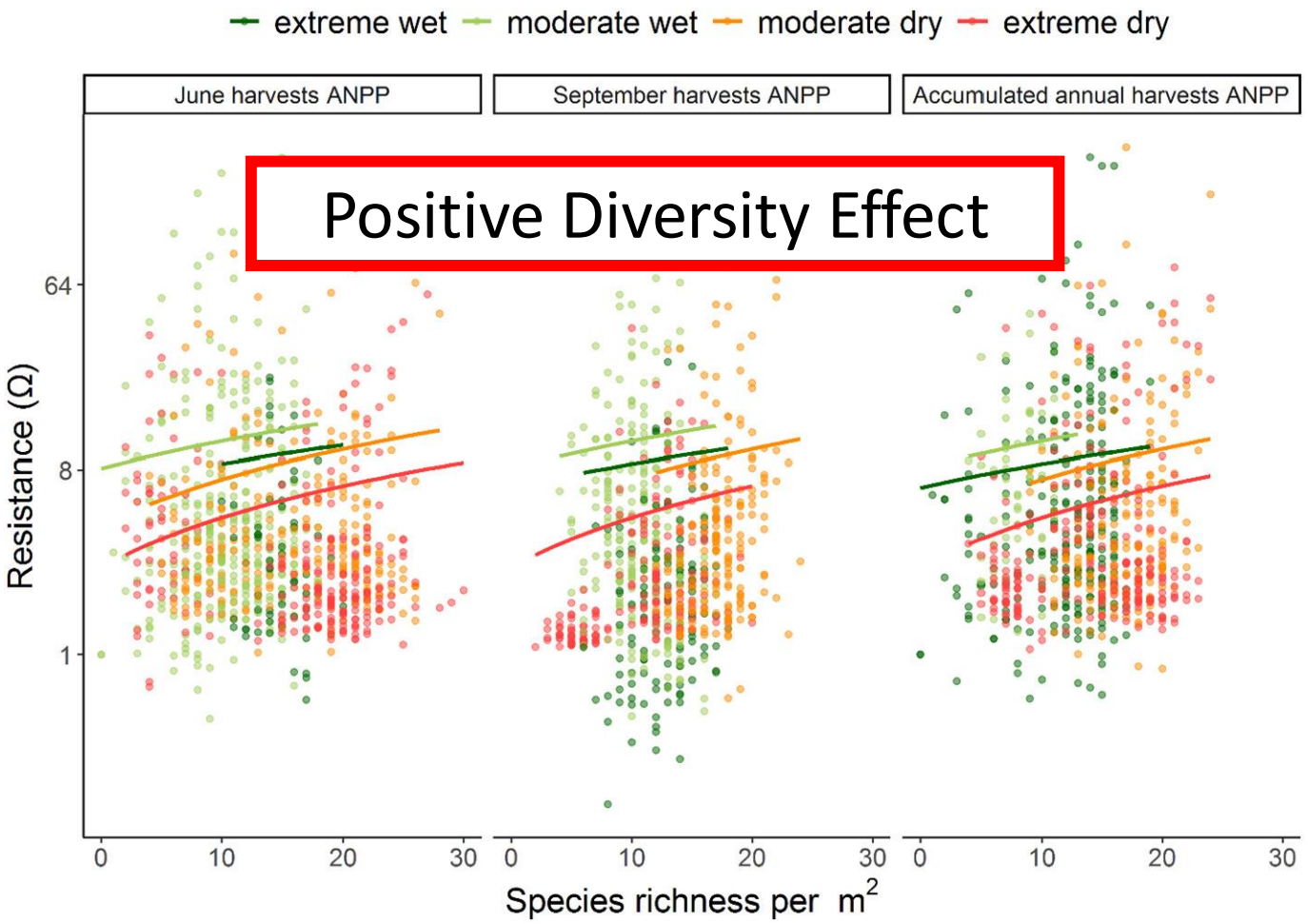


Hossain, Li, Hoffmann, Beierkuhnlein 2022. Biodiversity showed positive effects on resistance but mixed effects on resilience to climatic extremes in a long-term grassland experiment. Science of The Total Environment, 827, 154322.

Extreme Weather

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Resistance



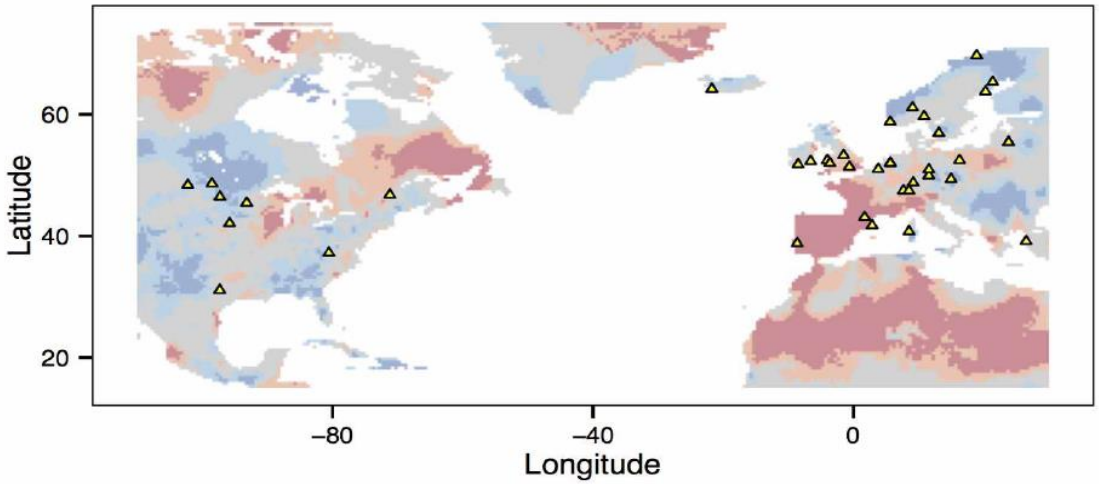
Hossain, Li, Hoffmann, Beierkuhnlein 2022. Biodiversity showed positive effects on resistance but mixed effects on resilience to climatic extremes in a long-term grassland experiment. Science of The Total Environment, 827, 154322.

Extreme Weather

nature

Biodiversity increases the resistance of ecosystem productivity to climate extremes

Forest Isbell[1], Dylan Craven[2,3], John Connolly[4], Michel Loreau[5], Bernhard Schmid[6], Carl Beierkuhnlein[7], T. Martijn Bezemer[8], Catherine Bonin[9], Helge Bruelheide[2,10], Enrica de Luca[6], Anne Ebeling[11], John N. Griffin[12], Qinfeng Guo[13], Yann Hautier[14], Andy Hector[15], Anke Jentsch[16], Jürgen Kreyling[17], Vojtěch Lanta[18], Pete Manning[19], Sebastian T. Meyer[20], Akira S. Mori[21], Shahid Naeem[22], Pascal A. Niklaus[6], H. Wayne Polley[23], Peter B. Reich[24,25], Christiane Roscher[2,26], Eric W. Seabloom[1], Melinda D. Smith[27], Madhav P. Thakur[2,3], David Tilman[1,28], Benjamin F. Tracy[29], Wim H. van der Putten[8,30], Jasper van Ruijven[31], Alexandra Weigelt[2,3], Wolfgang W. Weisser[20], Brian Wilsey[32] & Nico Eisenhauer[2,3]



46 biodiversity experiments in grasslands

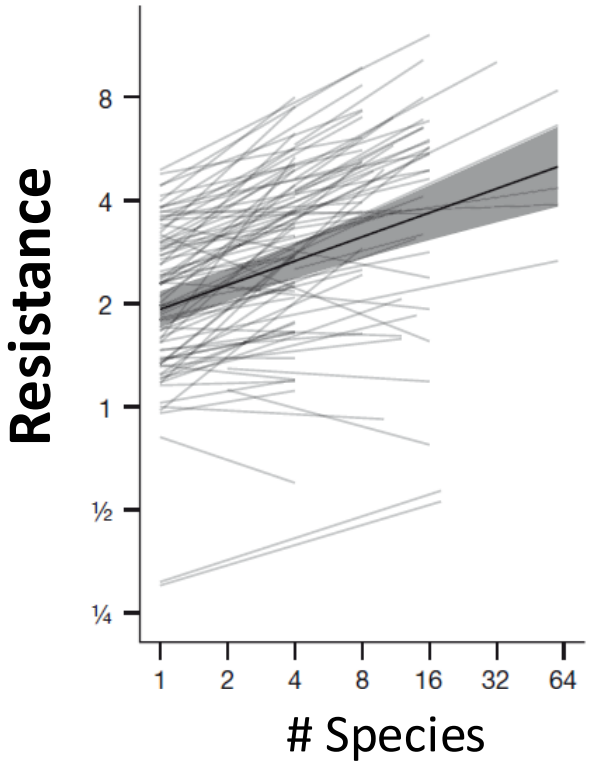
Extreme Weather

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LETTER

doi:10.1038/nature15374

Biodiversity increases the resistance of ecosystem productivity to climate extremes



Positive Diversity Effect

Land Use

Grasslands in face of climate change and biodiversity loss

…show that species **richness supports stability**

- However, **restricted resilience** can lead to state changes

…show that there is **no local homogenization**

- And **extreme years stimulate dissimilarity** between plots

…hint at increasing numbers and dominance of **xeric species**

- Coinciding with a **decrease in nitrophilic species**

…confirm that there is **no short-term thermophilisation**

- But, **shifts in dominance patterns** (insurance effect)

Land Use

Grasslands in face of climate change and biodiversity loss

…may possibly provide **positive feed-back loops** if extreme climatic conditions enhance biodiversity and biodiversity stabilizes ecosystem functioning.

This could be an efficient mechanism of **natural adaptation** to climate change.

However, this regulation is only possible, if the **species pool** (gamma diversity) at the landscape scale **is maintained**!

Loosing species at regional levels **means loosing** options for nature based solutions in face of climate change!



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Case Study

Human Health and Vector-borne Diseases

Human Health

… is confronted with fundamental **challenges** through biodiversity loss and climate change!

- Heat waves and water shortage will pose physical threats to human health.
- Invasive species will increase exposure to allergenic pollen and poisonous plants.
- Invasion of non-native mosquitos and climate change will create new risks related to vector-borne diseases.

Human Health

… can be assesed based on remote sensing for land use and cover, experimental treatments, and weather data and Global Circulation Models !

- This can create awarness towards emerging diseases.
- European deficits in biosecurity in harbours and airports can be addressed.

Human Connectivity

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Airline Connections

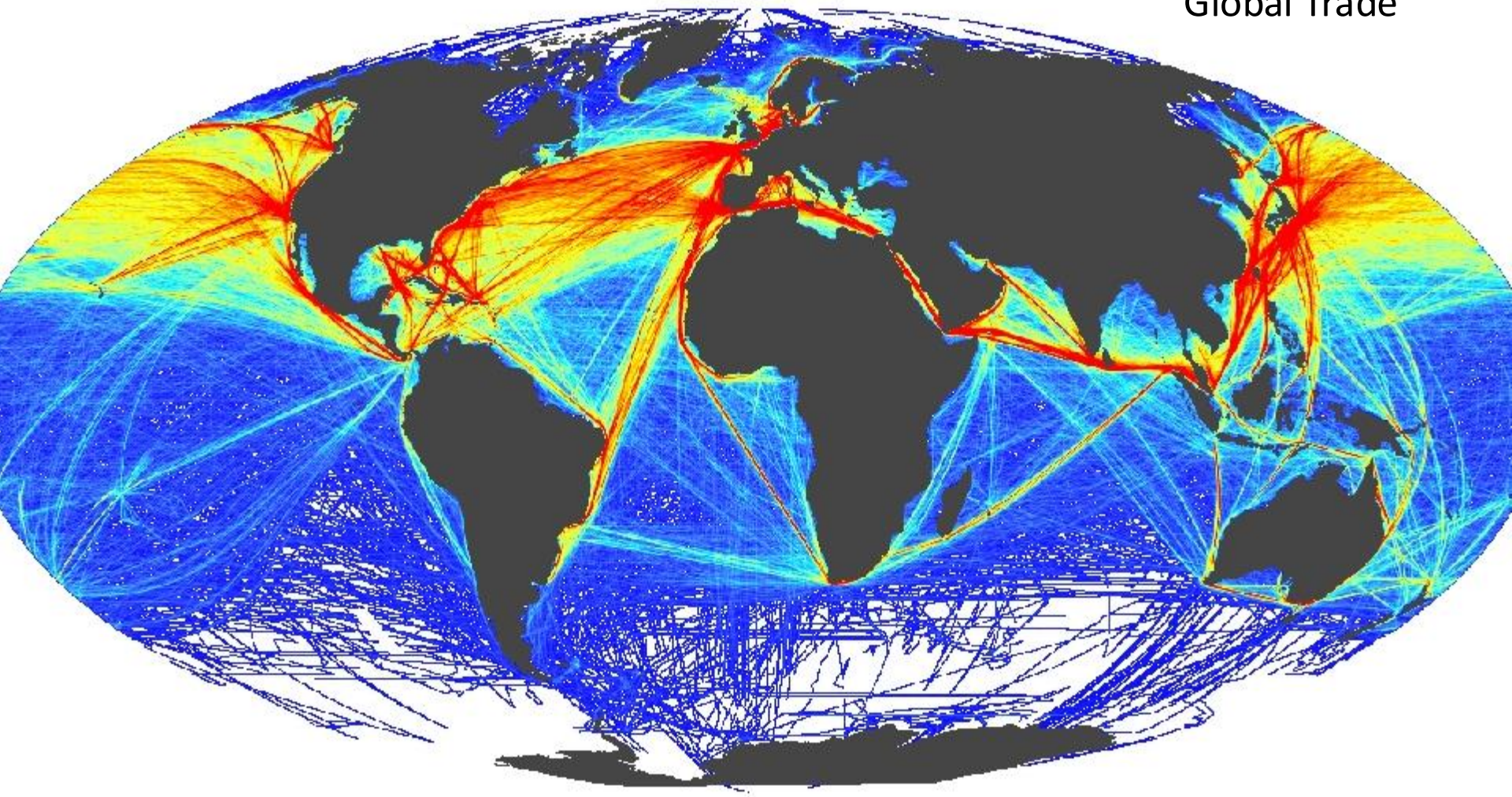


Within hours, infected people can travel between continents.

Transport of Goods

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Global Trade



Invasive species can cross continental borders in a matter of days.

Invasive Species & Pathogens

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Insects are **ecothermal**, warming has direct effects on them!

Climate warming enables to **establish and reproduce** beyond historic ranges of mosquitos!

Global **transportation** supports invasion processes!

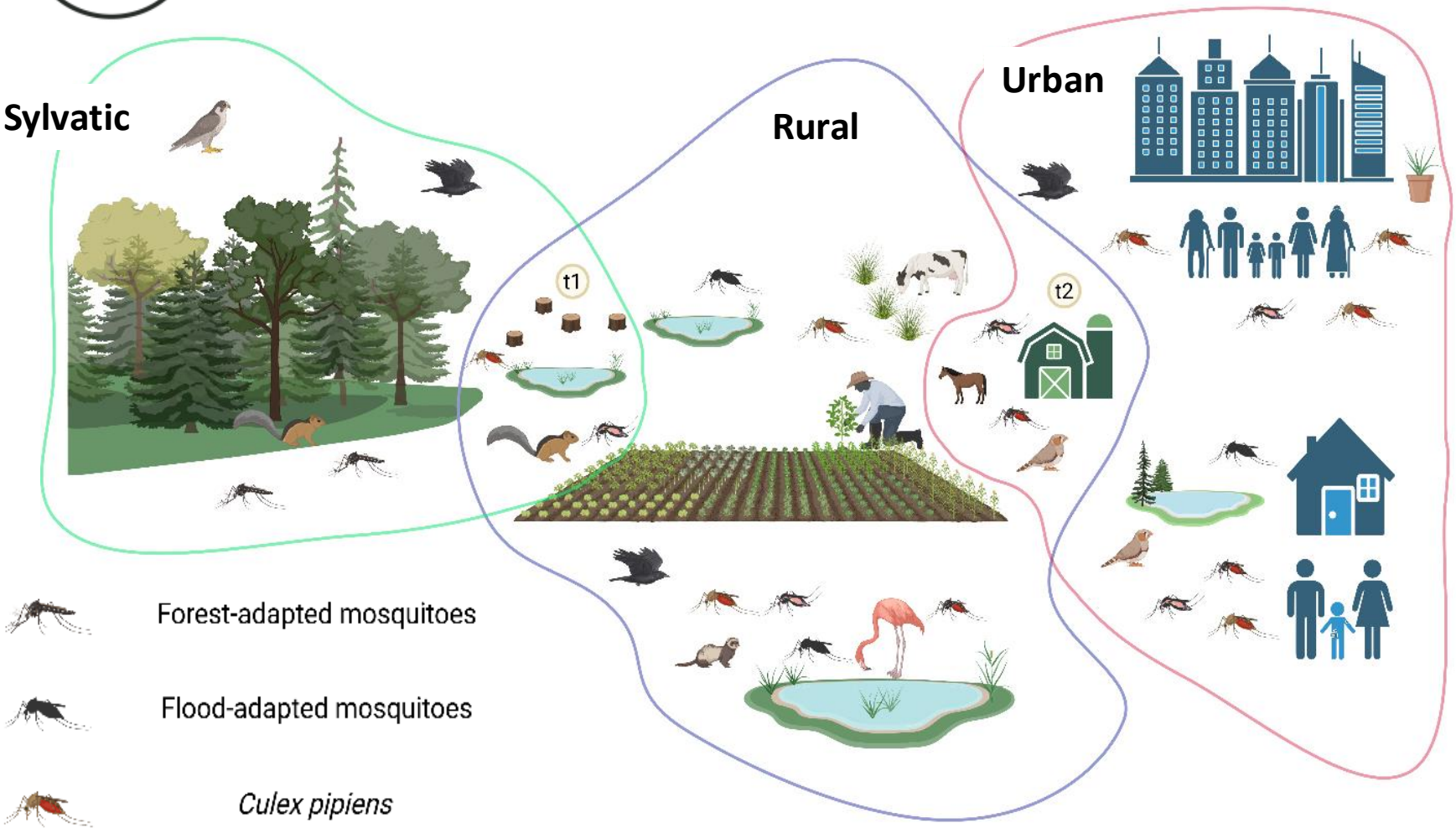
Survival of eggs during winter establishes populations!

Warming enables **longer activity** during the year!

Infected humans **spread** pathogens accross continents.

Warming allows **pathogens** in insects to replicate and be transmitted to other people that never travelled!

Vectors and Ecosystems

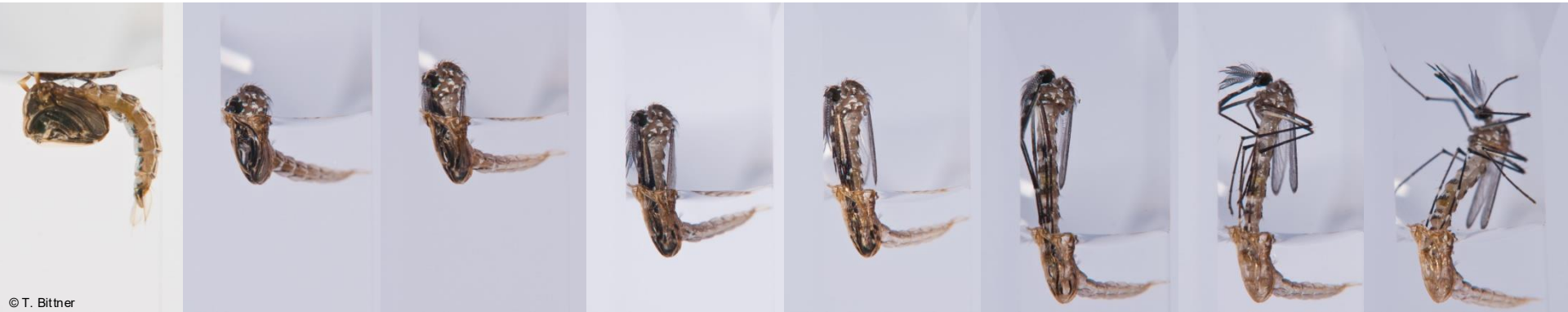


Naturalness gradient and
vector mosquito eco-epidemiology

Invasive Tiger Mosquito



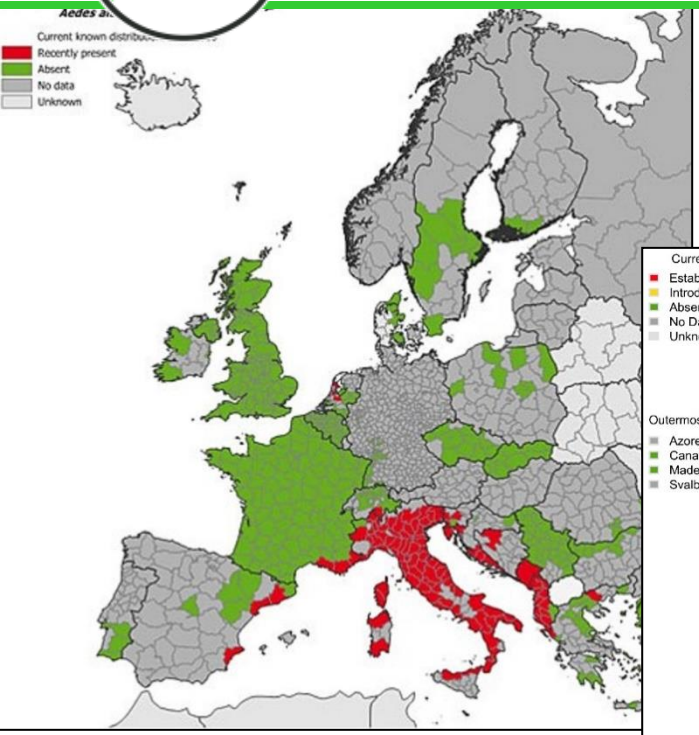
- *Aedes albopictus* syn *Stegomya albopicta*
- Originally from South-East Asia
- Introduced to Europe by transport
- Aggressive, day-active mosquito
- Competent vector of more than 25 pathogens such as Dengue, Chikungunya und Zika



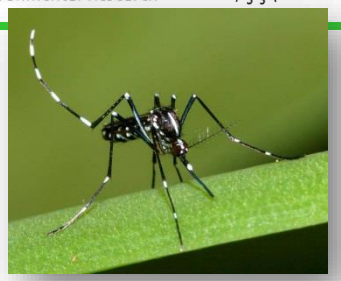
© T. Bittner

Invasive Tiger Mosquito

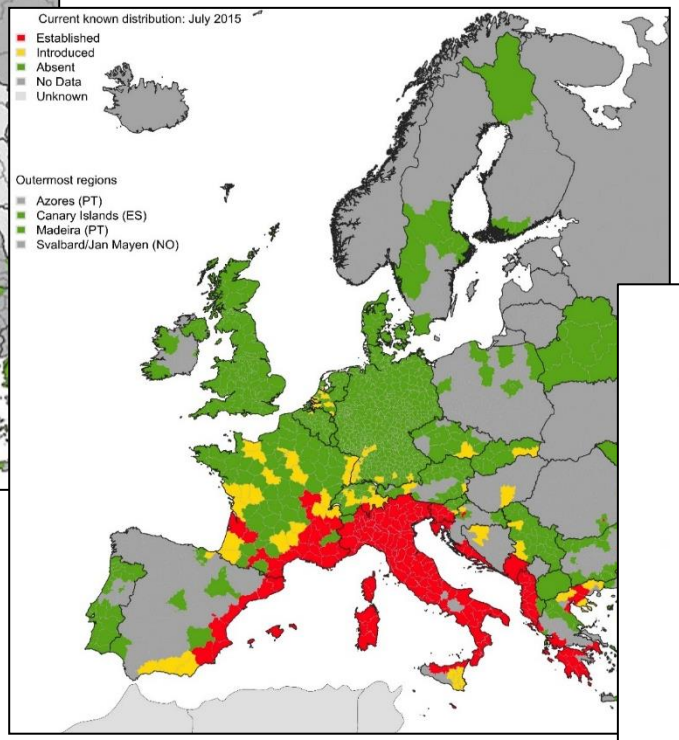
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Established
Introduced
Absent
No Data
Unknown



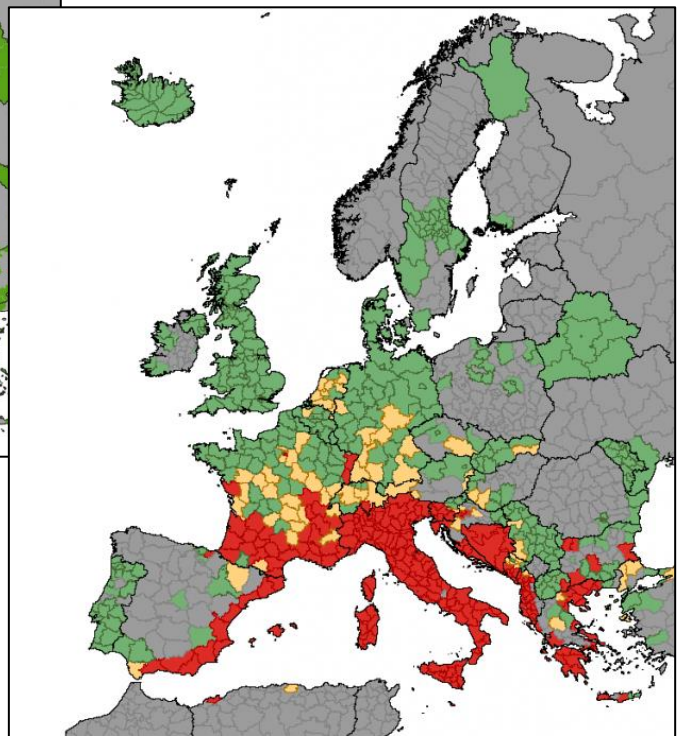
Aedes albopictus



9/2017

6/2010

7/2015

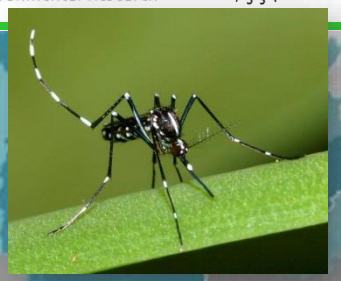


European Center for Disease Control ECDC

Invasive Tiger Mosquito

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April 2026



Aedes albopictus



ecdc
EUROPEAN CENTRE FOR DISEASE PREVENTION AND CONTROL

European Center for Disease Control ECDC

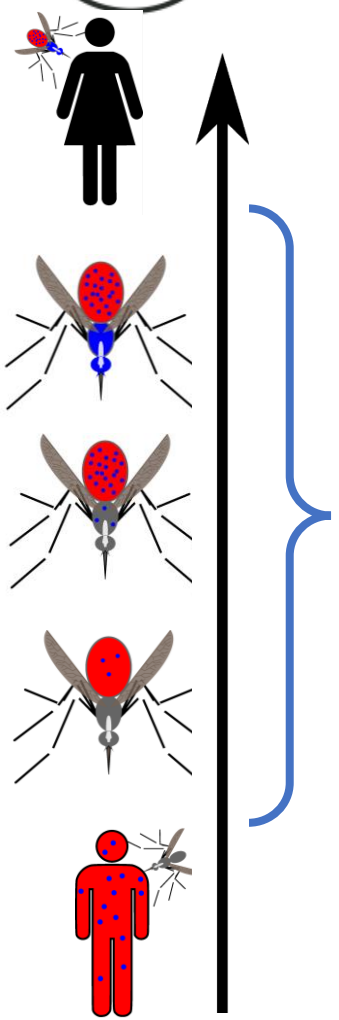
Dengue

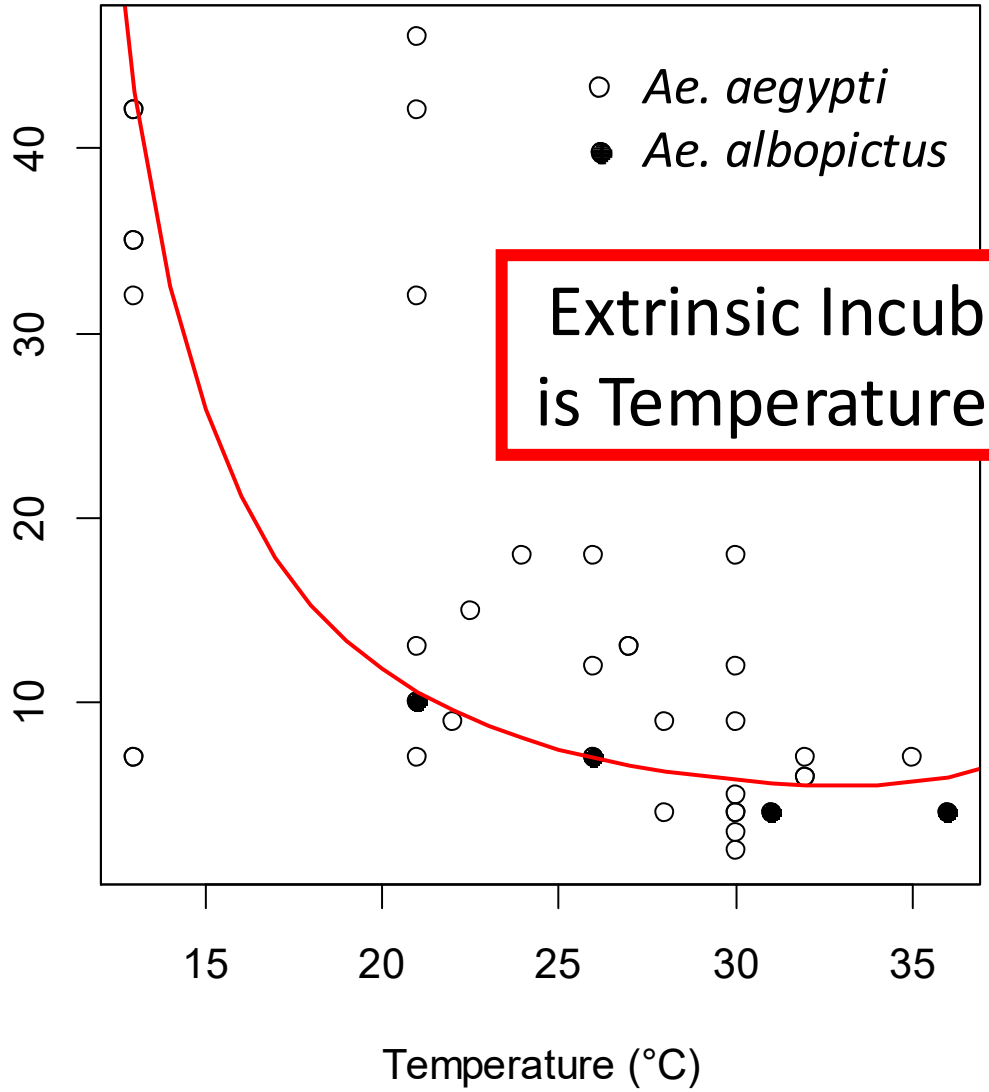


From 2010 to 2024 there are **579 cases of autochthonous transmission** reported in Europe

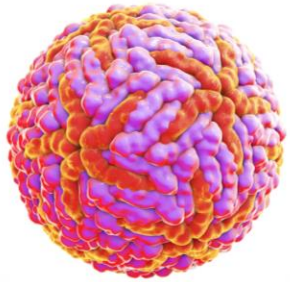
https://www.ecdc.europa.eu/en/all-topics-z/dengue/surveillance-and-disease-data/autochthonous-transmission-dengue-virus-eueea-previous-years

Dengue





Extrinsic Incubation Period is Temperature-dependent!

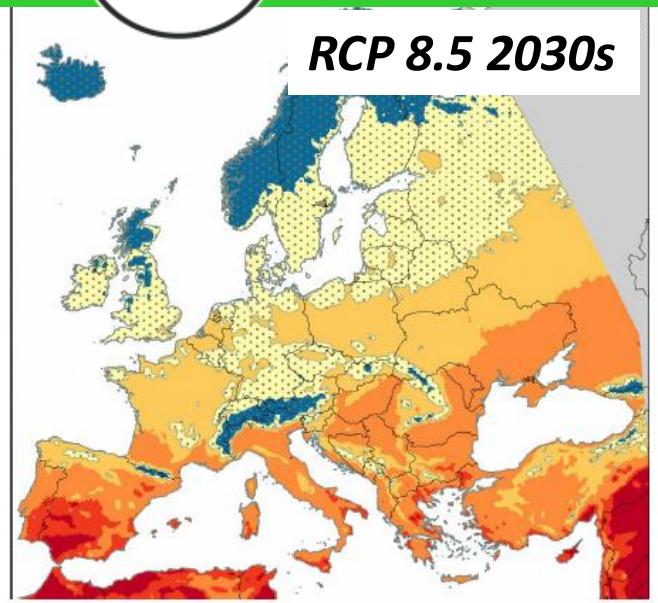


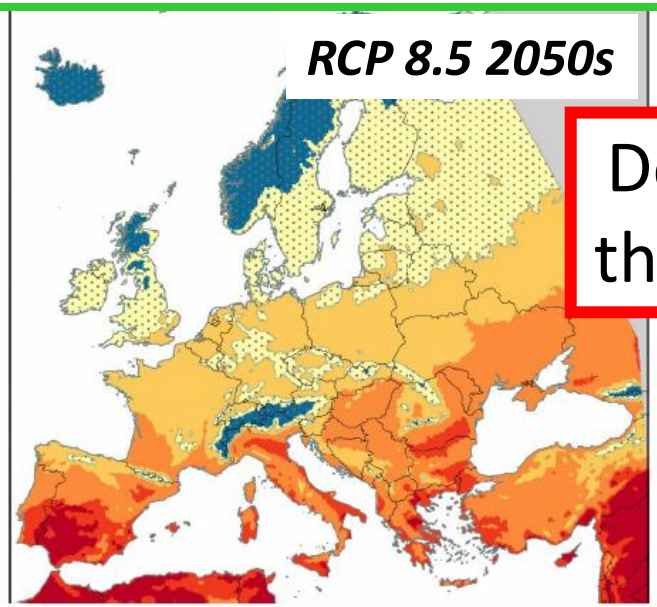
Dengue Virus

Tjaden N, Thomas SM, Fischer D, Beierkuhnlein C (2013) Extrinsic Incubation Period of Dengue: Knowledge, Backlog, and Applications of Temperature Dependence. PLoS Negl Trop Dis 7(6): e2207.

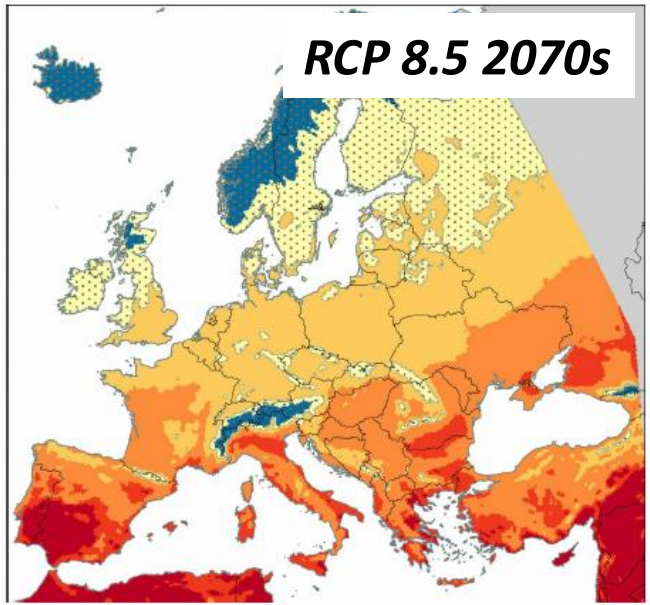
Dengue

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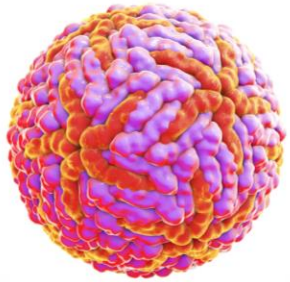
Decreasing lenght of the EIP with warming



EIP (d)
5.0 - < 6.0
6.0 - < 7.0
7.0 - < 11.0
11.0 - < 21.0
21.0 - < 60.0
≥ 60.0
no data

Unfulfilled flying condition

Required # days for multiplication and transmission of DENV

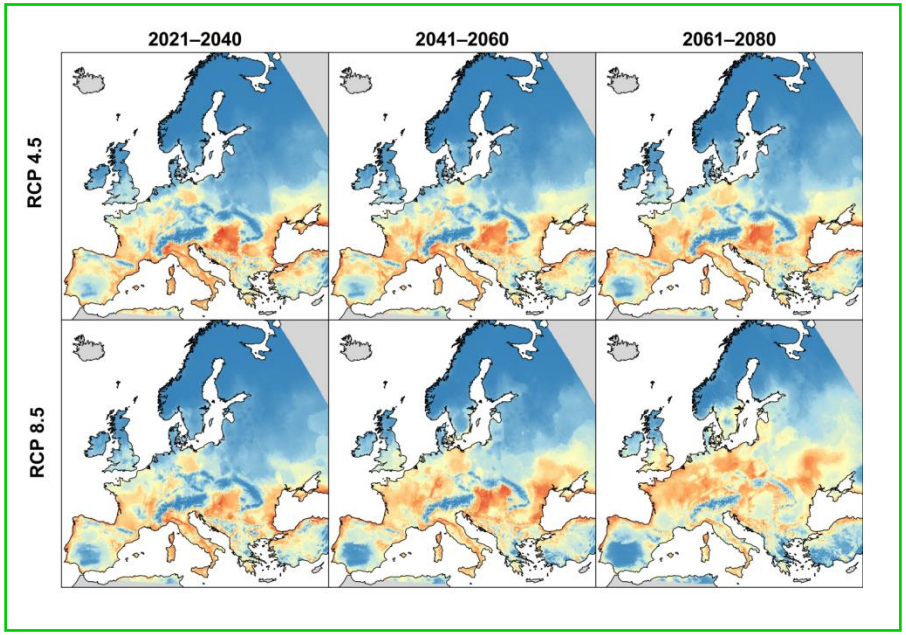


Dengue Virus

Dengue

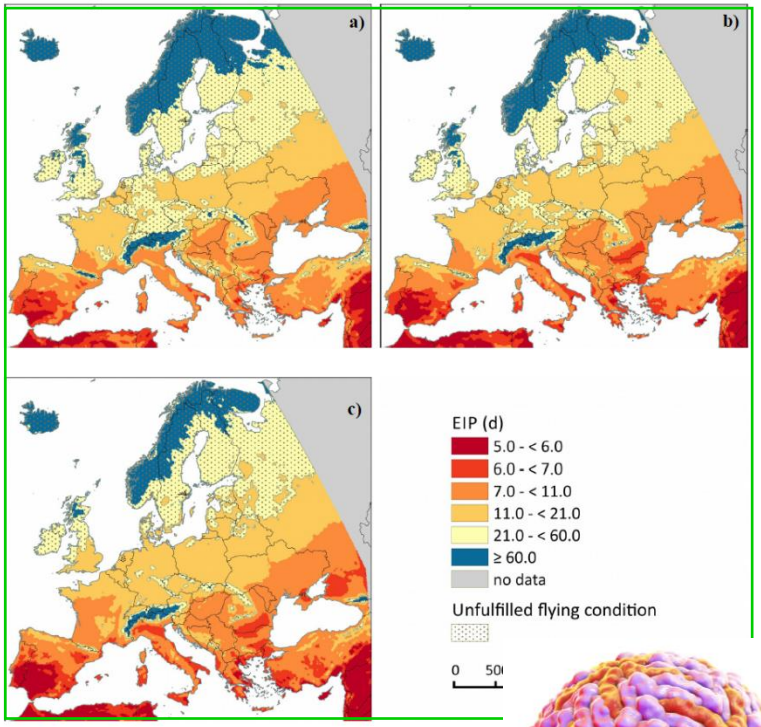
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Aedes albopictus
biogeographical modelling



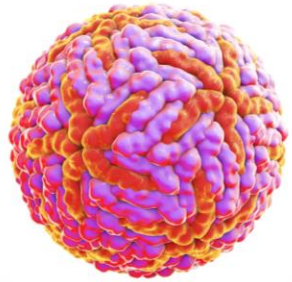
+

Dengue
Extrinsic Incubation Period





Combined Models



Dengue Virus

Dengue

Travel Medicine and Infectious Disease 71 (2026) 102979

Contents lists available at ScienceDirect

Travel Medicine and Infectious Disease

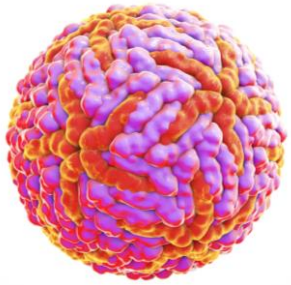
journal homepage: www.elsevier.com/locate/tmaid



Autochthonous dengue outbreak in Northern Italy, September 2024: epidemiological, microbiological, entomological investigation and public health response

Jasleen Singh [a,b,*,1], Tiziana Lazzarotto [c,d,1], Christin
Maurilia Marcacci [e], Guido Di Donato [e], Rodolfo Veron
Marco Di Luca [a], Arianna Puggioli [f], Ilaria Pati [g], Raffa
Nicola Alvaro [j], Alessandra Fantuzzi [k], Flavia Riccardo [a,l], Giacomo Creola [k], Paola Angelini [m],
Giulio Matteo [m], Mattia Calzolari [n], Michele Dottori [n], Patrizio Pezzotti [a], Chiara Sacco [a,2],
Martina Del Manso [a,2], Working group

Increasing Evidence !



Dengue Virus

An autochthonous outbreak of dengue in Spain in 2024

PN Patricia Nadal-Barón MB Mª Assumpció Bou-Monclus GS Glòria Ferrús Serra SG Sergio Pardo Granell SV Sofia Minguell Vergés SL Susana Cerdán López
AS Ana Bocio Sanz AM Ana I Martínez Mateo IC Itziar Martínez Calleja RV Rosa Mercè Vileu Vallverdú BN Beatriz Villar Navas EB Elena García Bueno See more

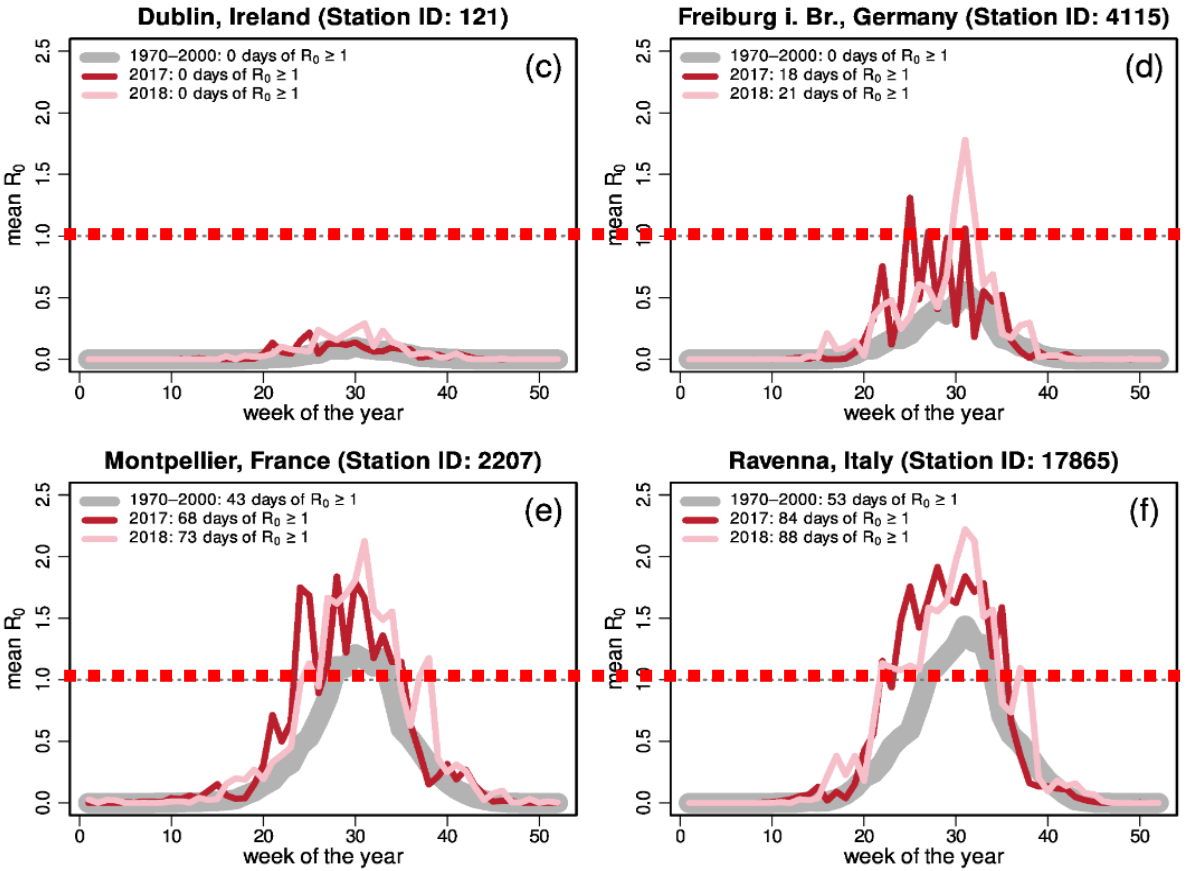
Singh J et al. 2026 Autochthonous dengue outbreak in Northern Italy, September 2024… Travel Medicine and Infectious Disease 71, 102979.

Nadal-Barón P et al. 2026, An autochthonous outbreak of dengue in Spain in 2024. *Journal of Travel Medicine*, 33, taag030.

Chikungunya

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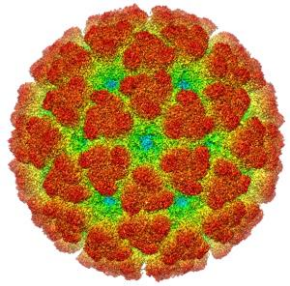
Extreme warm conditions allow the local transmission of tropical diseases in **European cities**



R0 = 1

R0 = 1

Epidemiological Model for the years **2017 / 18**



Chikungunya Virus

Tjaden N, Cheng Y, Beierkuhnlein C, Thomas SM (2021) Chikungunya Beyond the Tropics: Where and When Do We Expect Disease Transmission in Europe? Viruses, 13, 1024.

Chikungunya

570 cas autochtones de chikungunya : faut-il craindre un emballement ?

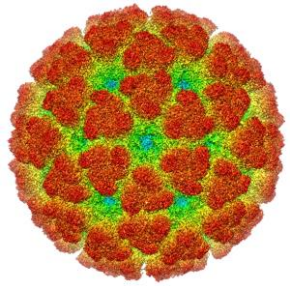
Par **Marie Briel** - 29 septembre 2025 à 12h09



Le moustique tigre est désormais implanté dans 81 départements français en 2025, contre 42 en 2019. © Freepik

Jamais la France métropolitaine n'avait connu une telle flambée. 570 cas de chikungunya transmis localement ont été recensés depuis le début de la surveillance par Santé Publique France. En cause, le moustique-tigre, désormais bien installé sur presque tout le territoire. Alors, simple alerte sanitaire ou signe avant-coureur d'un bouleversement durable ?

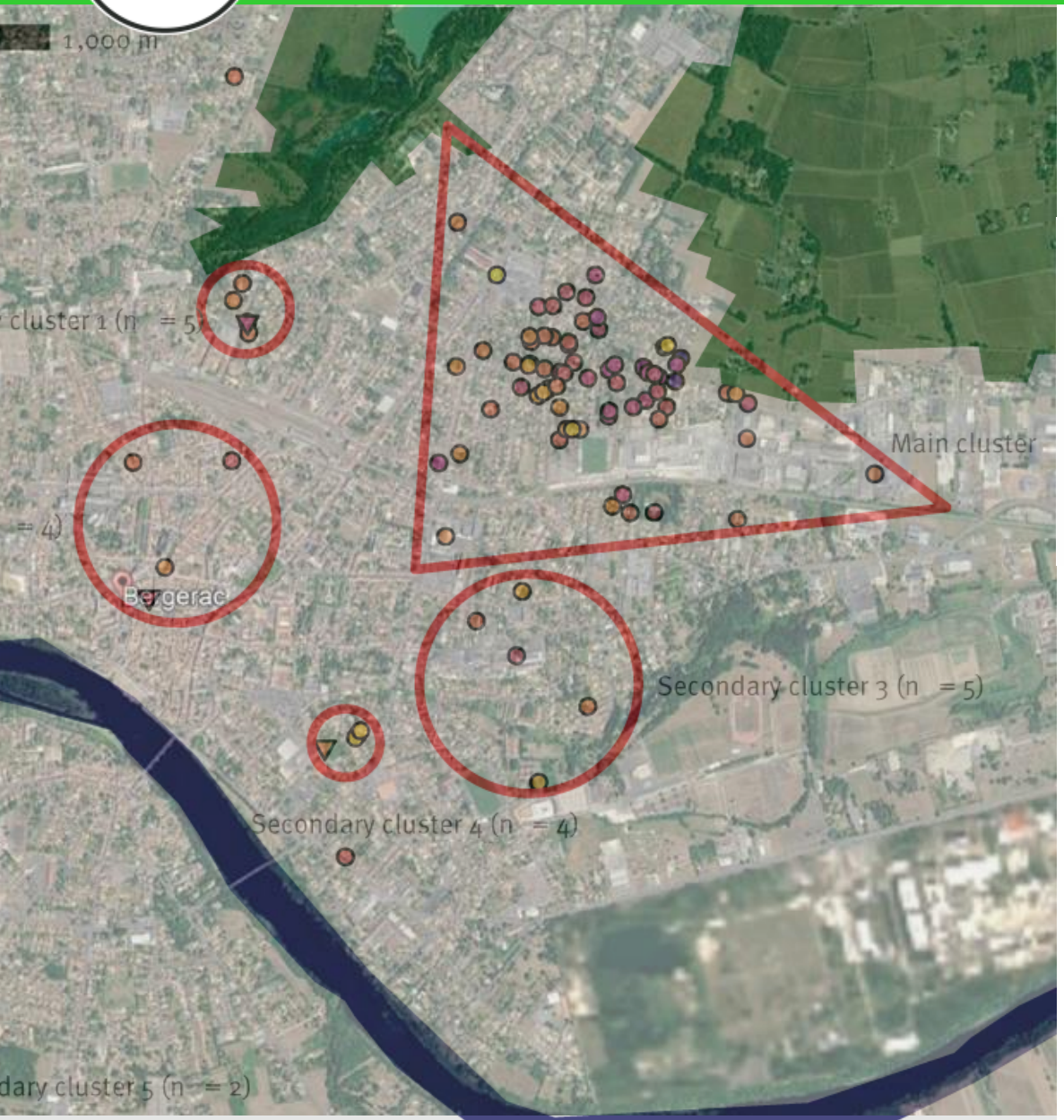
29. September 2025 !



Chikungunya Virus

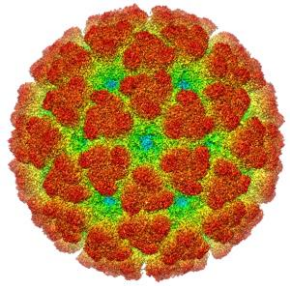
https://ma-sante.news/570-cas-autochtones-de-chikungunya-faut-il-craindre-un-emballement/

Chikungunya



Outbreak in the city of Bergerac, France, 2025

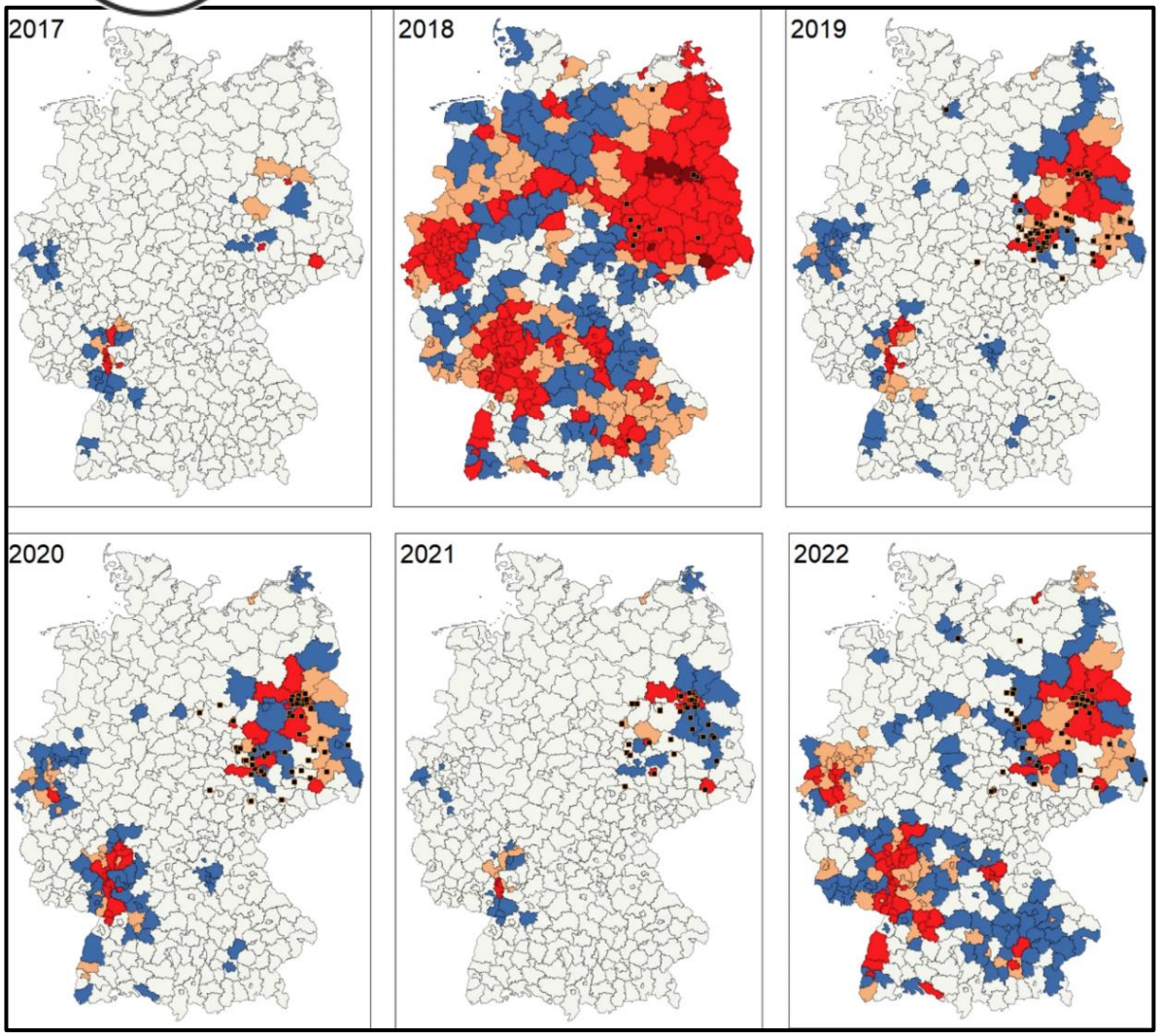


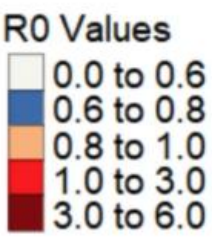


Chikungunya Virus

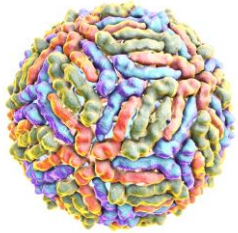
Creuse R et al. 2025. Lessons from an investigation of an autochthonous chikungunya outbreak in Bergerac, mainland France, June to October 2025. Euro Surveillance 39, 2500871.

West-Nile





Risks are different between years



West-Nile-Virus

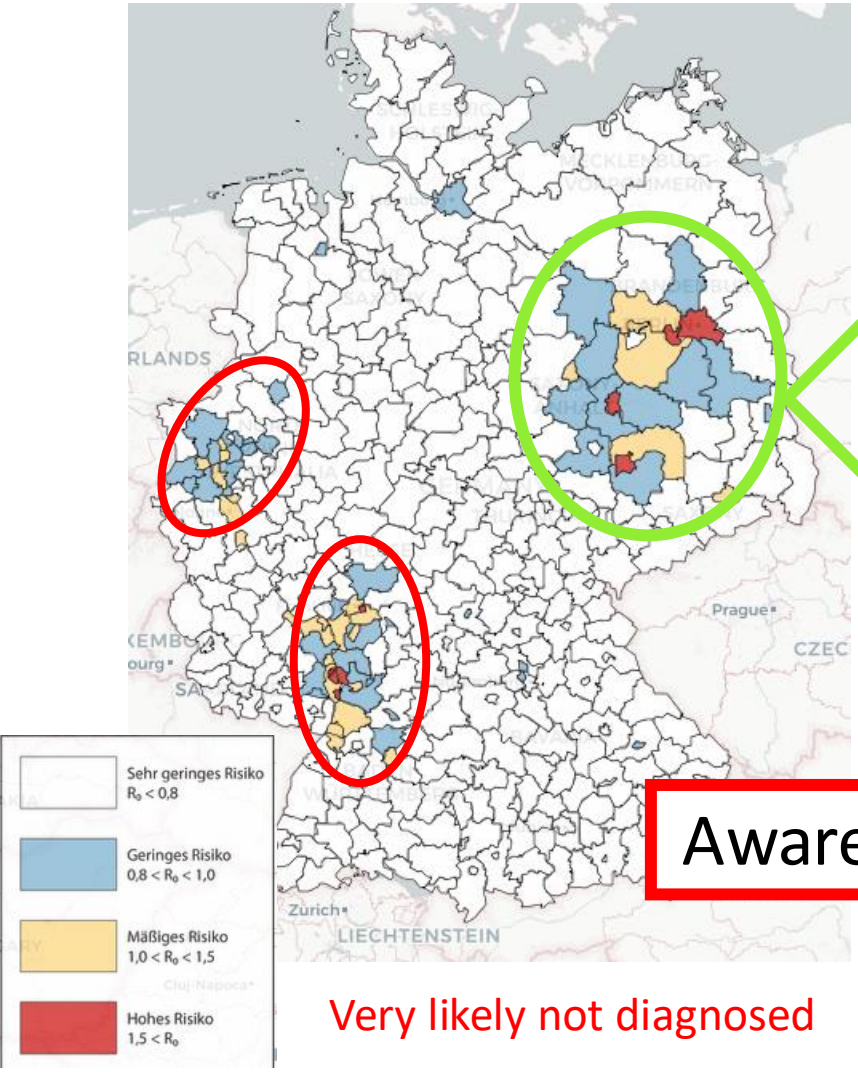
Mbaoma OC, Thomas SM, Beierkuhnlein C 2024. Spatiotemporally explicit epidemic model for West Nile Virus outbreak in Germany: An inversely calibrated approach. *J Epidemiol Glob Health* **14**, 1052–1070.

West-Nile

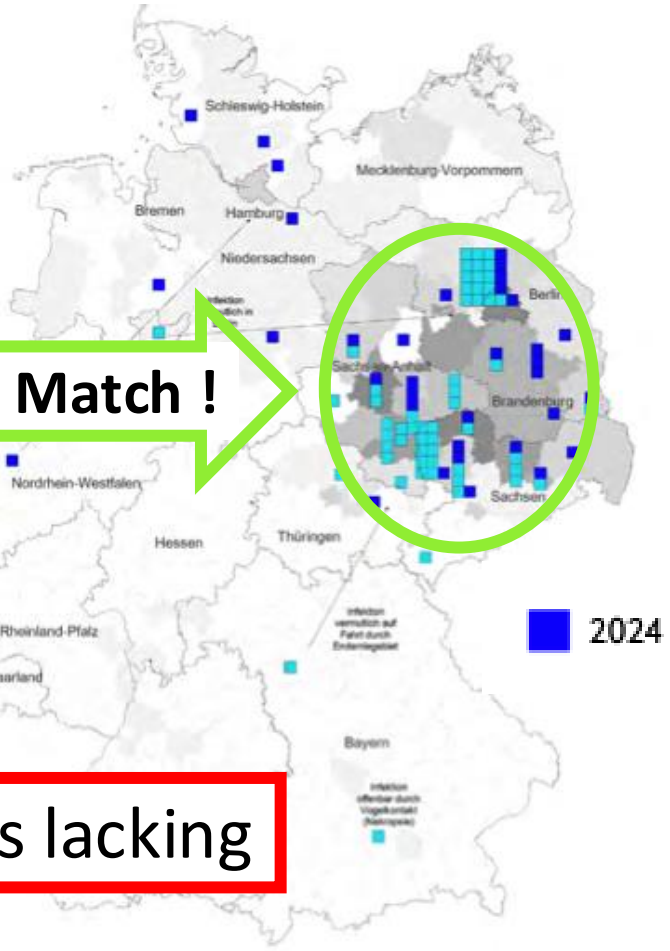
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Our **Model Prediction** for 2024

Reported Human **Cases** for 2024



Good Match !



Awareness is lacking

Very likely not diagnosed

Human Health

Changes in climate and biodiversity

…cause emerging **tropical diseases** outside of the tropics

- Chikungunya Virus (CHIKV), Dengue virus (DENV), transmitted by invasive non-native mosquitos

…enable transmission of pathogens that are **new to Europe**

- West-Nile-Virus (WNV), transmitted in warm periods by native mosquitos.

…create new risks for the **urban** human population

- High human population density and living in urban heat islands.



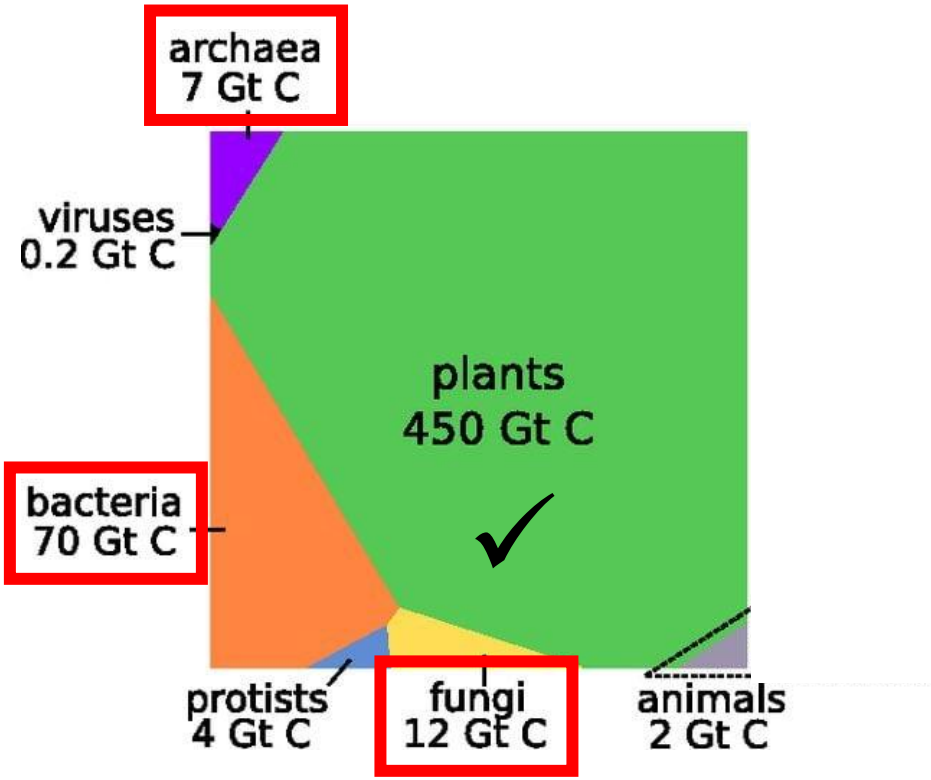
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Uncertainty

Uncertainty

Global Biomass (Gt C) for all taxa



Bar-On, Y.M., Phillips, R., Milo, R. 2018. The biomass distribution on Earth. PNAS 115, 6506-6511.

Uncertainty

Estimates for global (terrestrial and marine) bacterial biomass are 70 Gt C but **range between 7 and 700 Gt** of Carbon.

In terrestrial topsoils bacterial biomass is estimated to 4.3 Gt C (**0.5 to 10.3 Gt**).

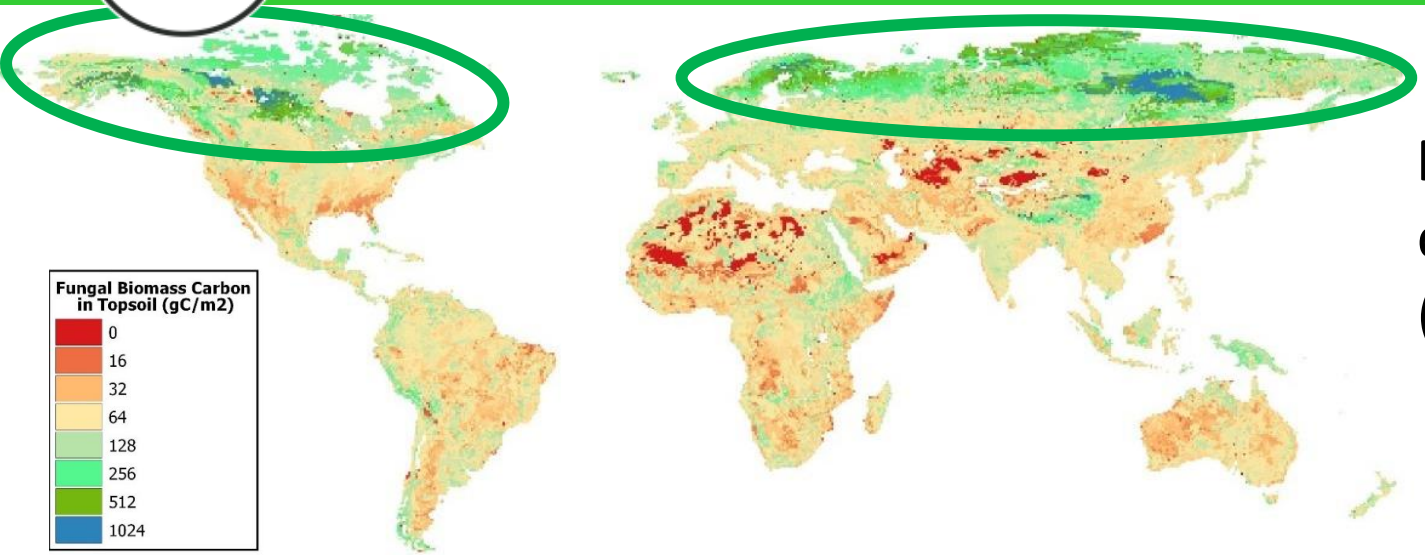
The biomass of Archaea is more difficult to estimate because of inaccessibility in deep bedrock.

Terrestrial fungal biomass is estimated to 12.6 Gt C (with an uncertainty range of **6.6 – 16.4 Gt C**).

Bar-On, Y.M., Phillips, R., Milo, R. 2018. The biomass distribution on Earth. PNAS 115, 6506-6511.

Takele L. et al. 2025. Contribution of microbial necromass to soil organic carbon in profile depths exhibited opposite patterns across ecosystems: A global meta-analysis. Soil Biology and Biochemistry 207, 109842.

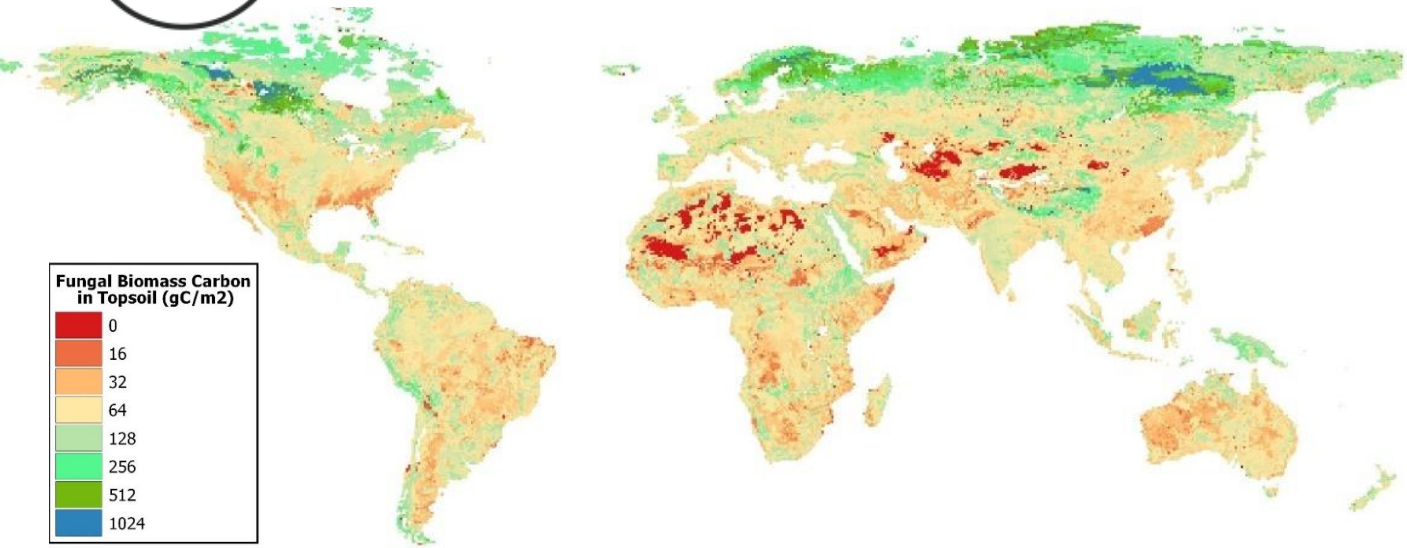
Uncertainty



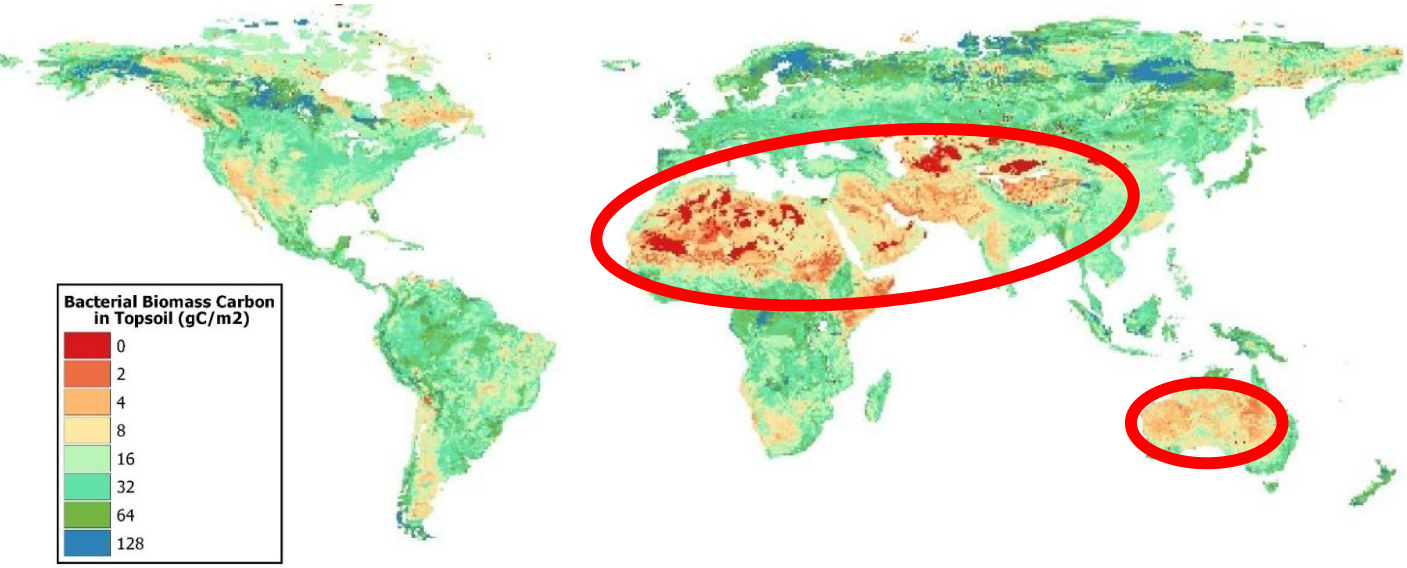
Fungal biomass carbon in topsoil (10kgC ha^{-1})

Beierkuhnlein C & Shrestha S (2024) Biogeography of the Earth Critical Zone.
In: White T & Provenzale A (eds): Critical Zone and Ecosystem Dynamics, Springer Nature

Uncertainty



Fungal biomass carbon in topsoil (10kgC ha^{-1})

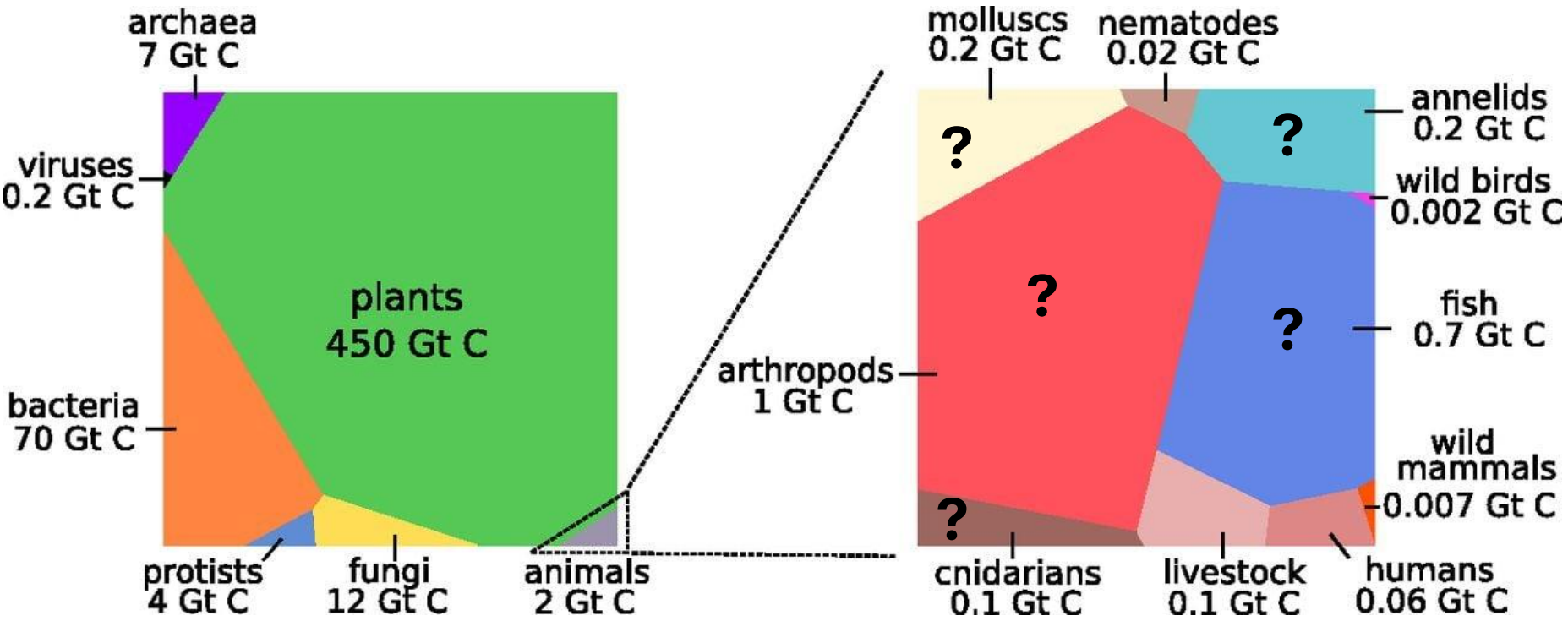


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Uncertainty

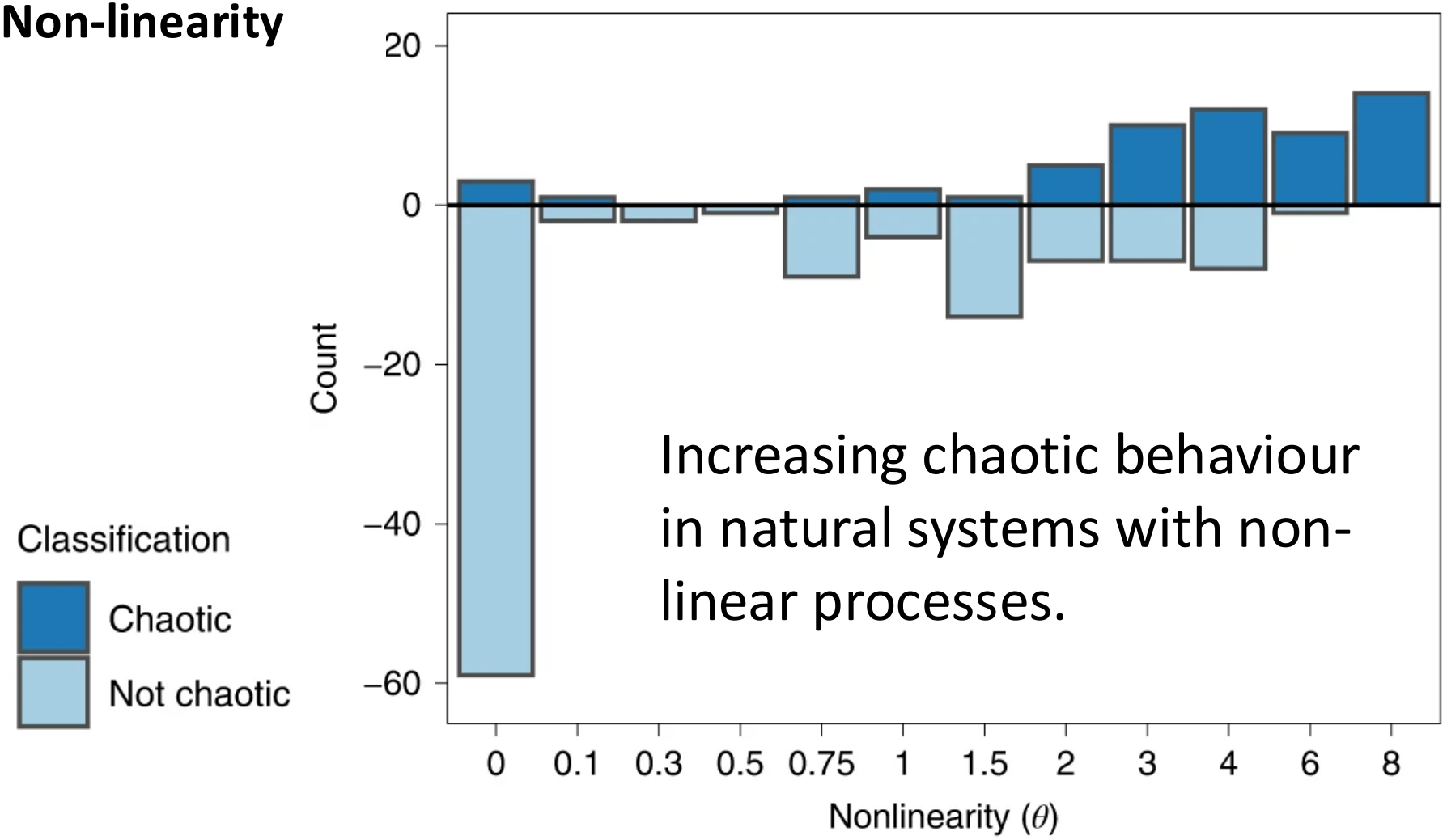
Global Biomass (Gt C) for all taxa



Bar-On, Y.M., Phillips, R., Milo, R. 2018. The biomass distribution on Earth. PNAS 115, 6506-6511.

Uncertainty

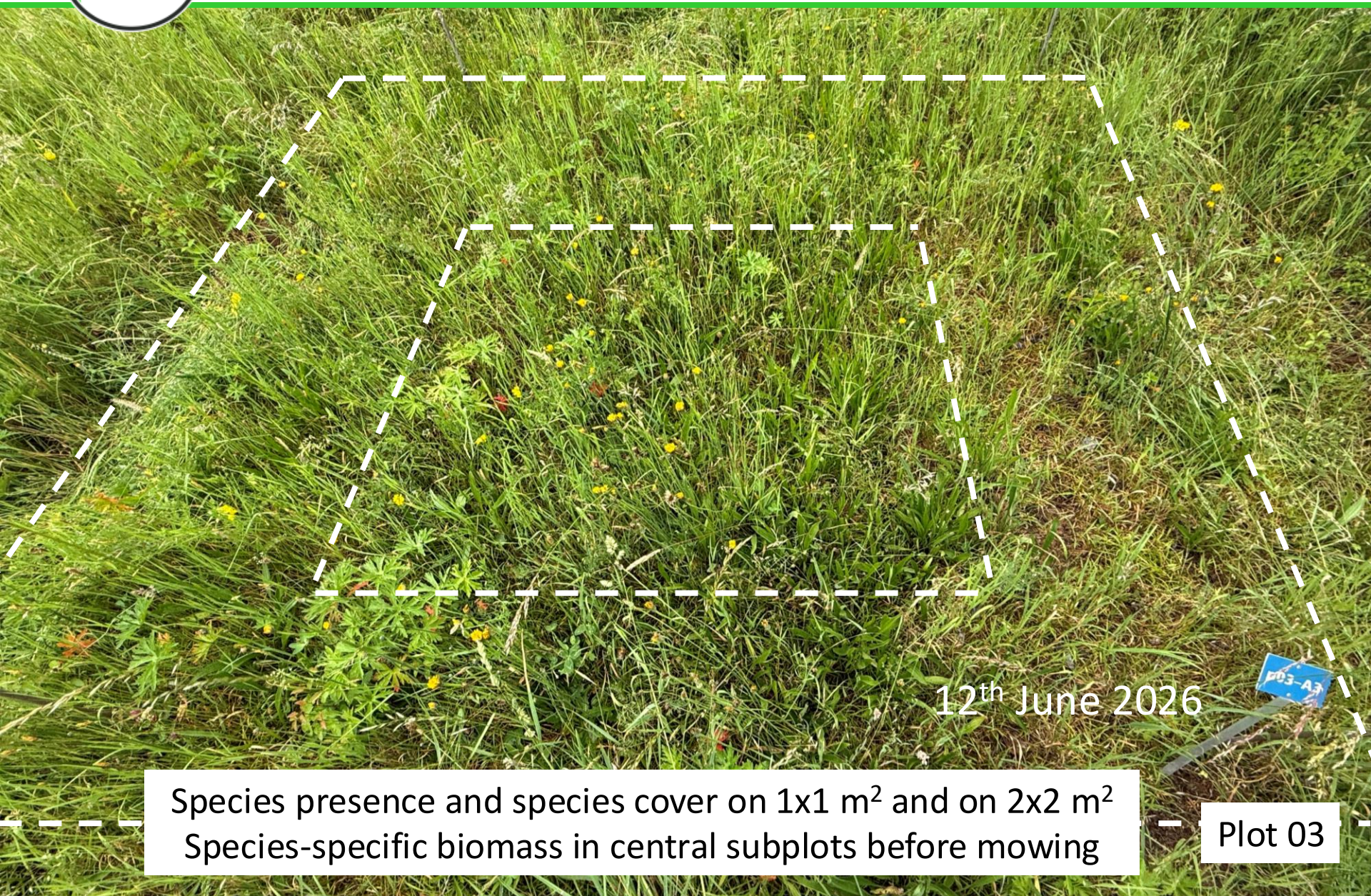
Non-linearity



Increasing chaotic behaviour in natural systems with non-linear processes.

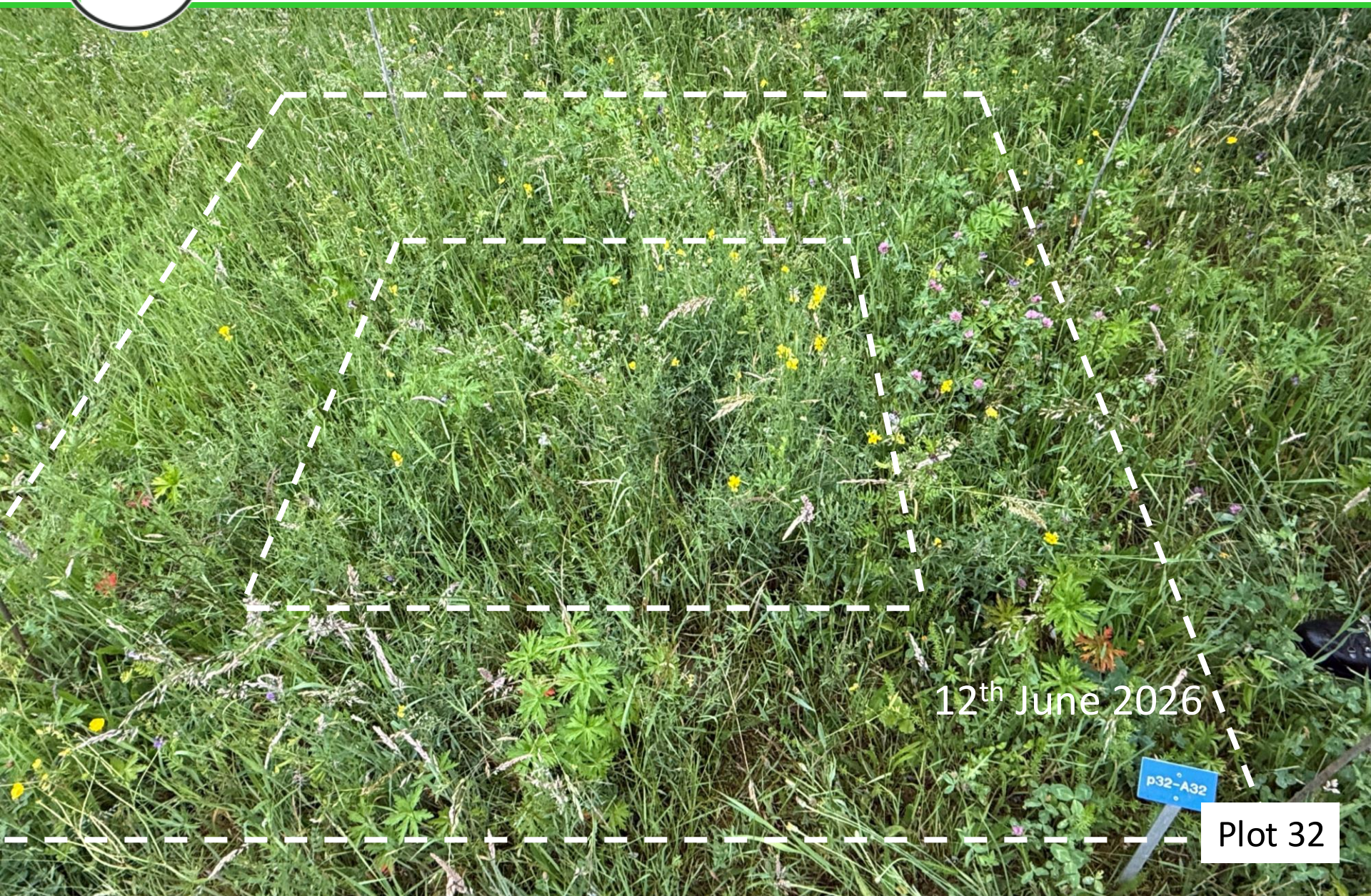
Rogers et al. (2022): Chaos is not rare in natural ecosystems. Nat Ecol Evol 6, 1105–1111

Spatial Heterogeneity

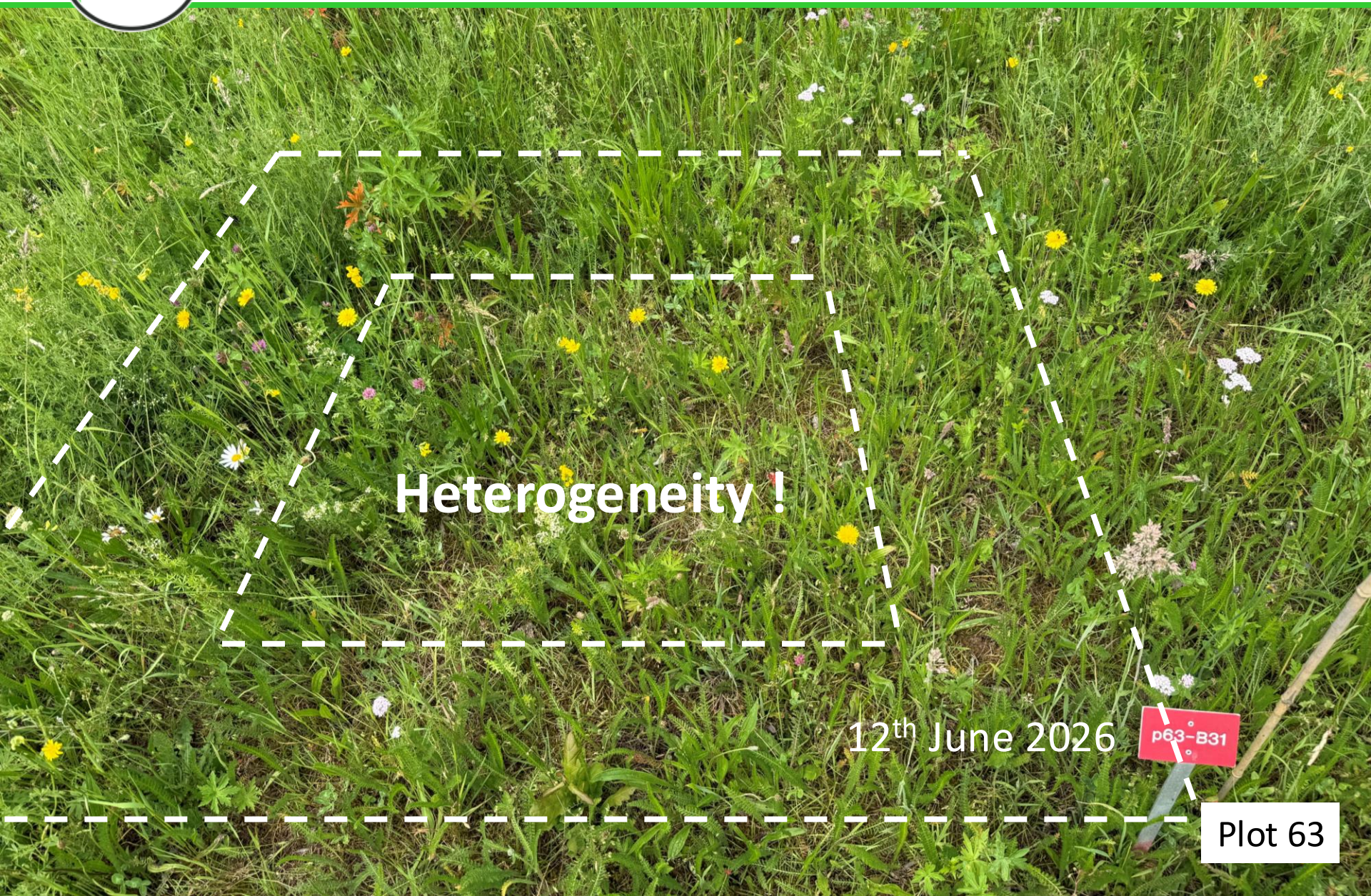


Species presence and species cover on 1x1 m^2 and on 2x2 m^2
Species-specific biomass in central subplots before mowing

Spatial Heterogeneity



Spatial Heterogeneity





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Conclusions

Climate Change

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Projected warming in the 21st century

- can be modified through **political decisions** (scenarios),
- **differs regionally** (latitude, elevation, continentality),
- is not a constant trend but **differs between years,**
- is pronounced in different **seasons,**
- has implications on the **precipitation regime,**
- comes along with increasing **climatic extremes…**

In consequence, it is not the global trend or average that matters but the **regional consequences in specific years.**

Biodiversity Conservation

Must be

- **Diverse** (taxa, management, etc.)
- **Complex** (including processes and functioning)
- **Multidisciplinary** (biota, soil, water, carbon, air…)
- **Large** (no cherry picking)
- **Ambitious** (not defensive)
- **Modern** (including Earth Observation and repositories)
- **Flexible** (consider uncertainty)

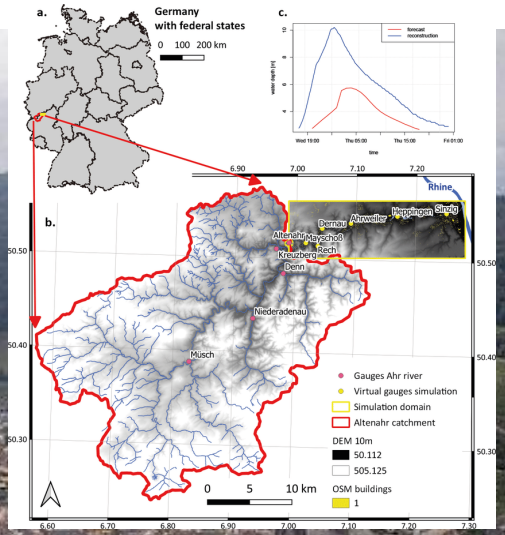
Biodiversity Conservation

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Negative consequences of the combination of extreme weather and land use change are getting more and more critical !

Foto imago images/Future Image

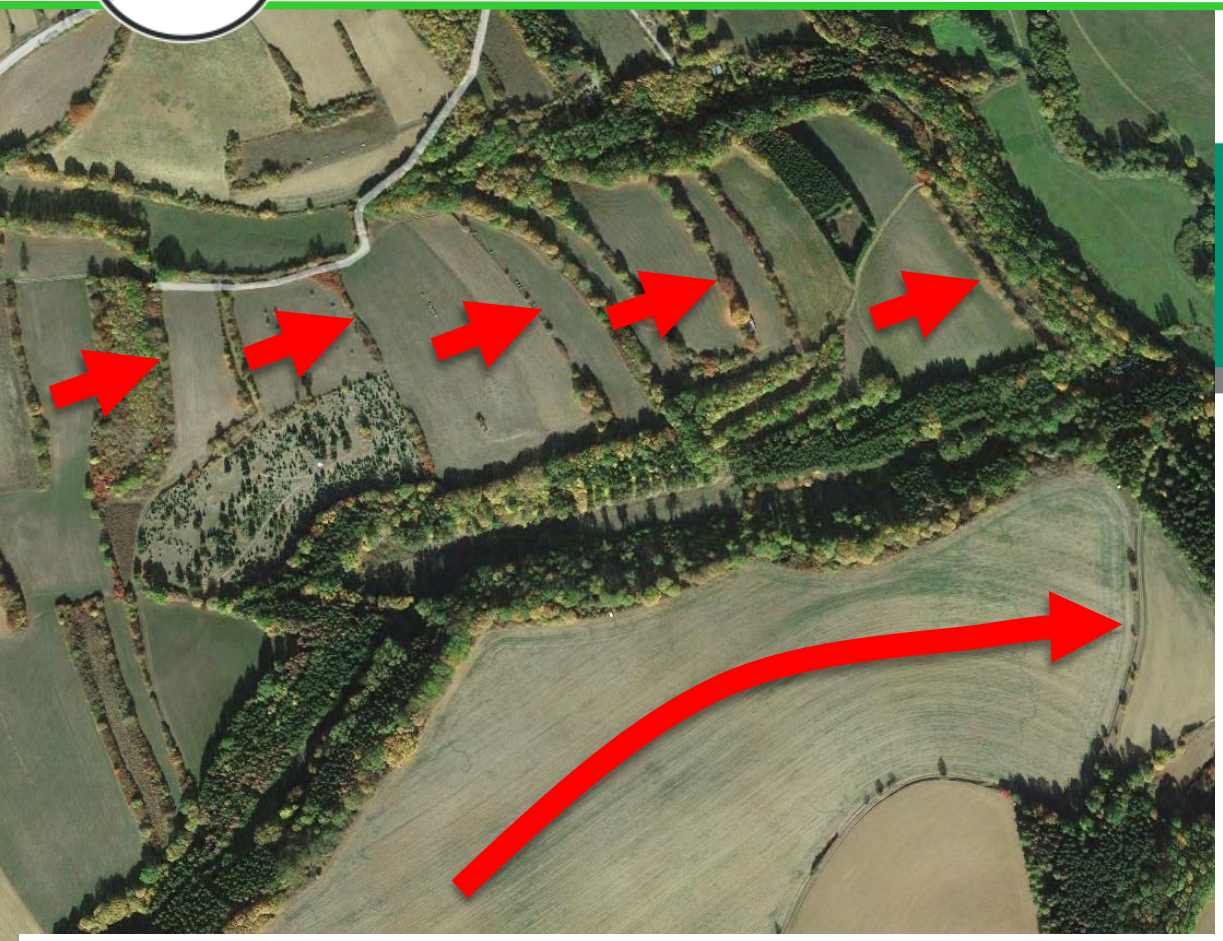
Protecting nature means protecting people



Beierkuhnlein, C. (2021) Nature-based solutions must be realized – not just proclaimed – in face of climatic extremes. Erdkunde 75(3): 225-244.

Biodiversity Conservation

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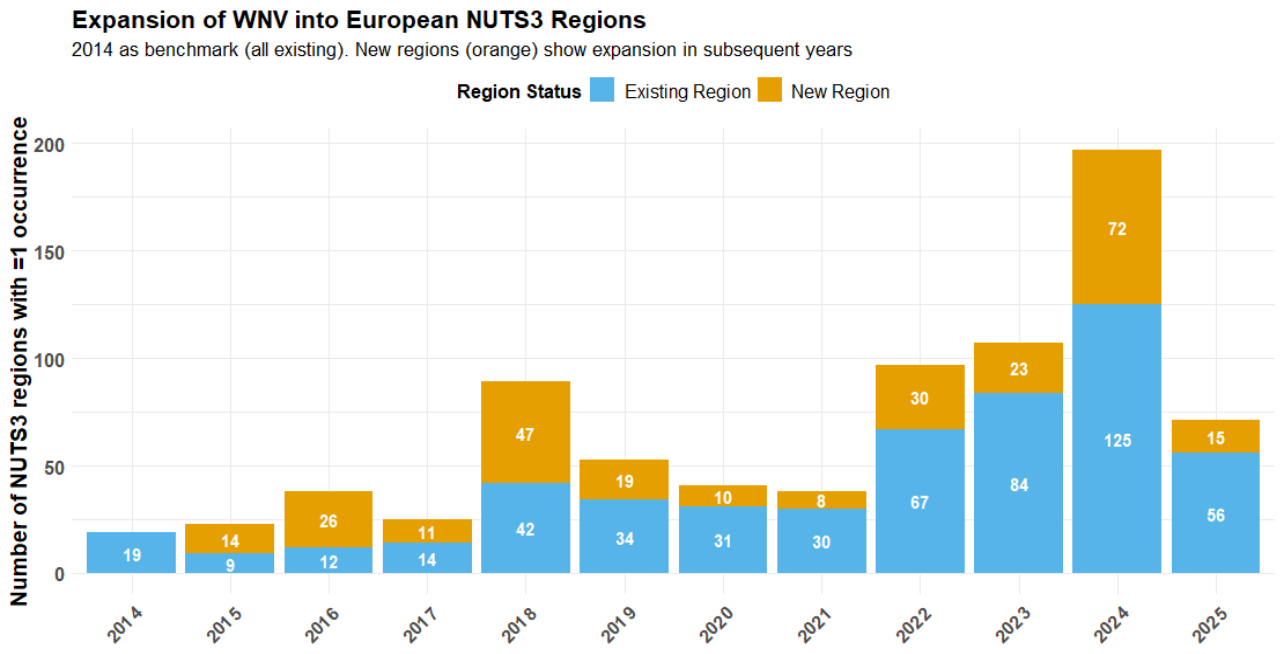


Surface runoff, erosion, and groundwater recharging are affected by land use and habitat diversity !

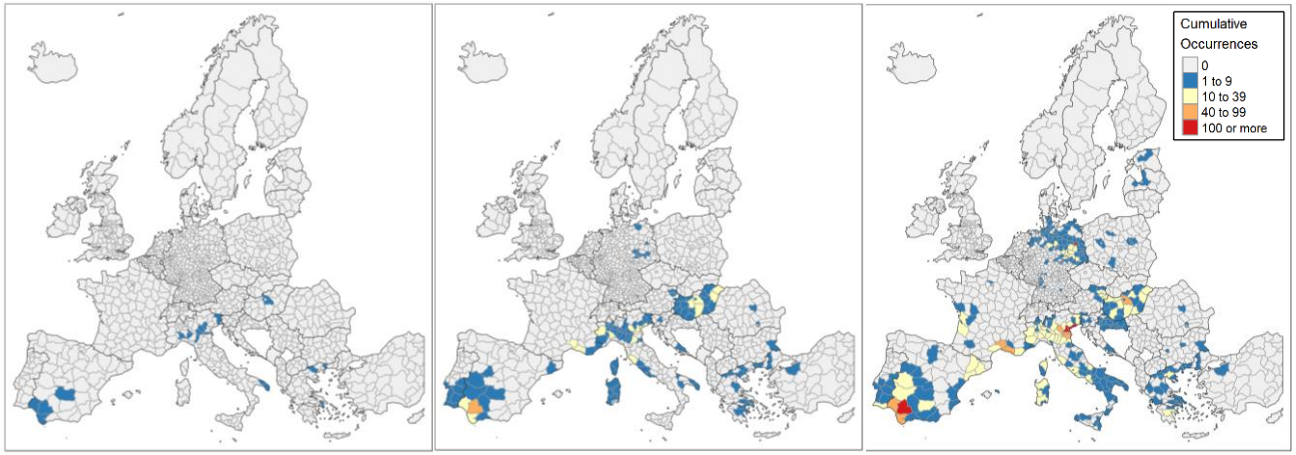


Beierkuhnlein, C. 2021. Nature-based solutions must be realized - not just proclaimed - in face of climatic extremes. Erdkunde 75(3), 225-244.

A


Expansion of WNV into European NUTS3 Regions
2014 as benchmark (all existing). New regions (orange) show expansion in subsequent years
Region Status
Existing Region
New Region
Number of NUTS3 regions with =1 occurrence
0
50
100
150
200
19
14
9
26
12
11
14
47
42
19
34
10
31
8
30
30
67
23
84
72
125
15
56
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025

B


Cumulative
Occurrences
0
1 to 9
10 to 39
40 to 99
100 or more

α Diversity and Extremes

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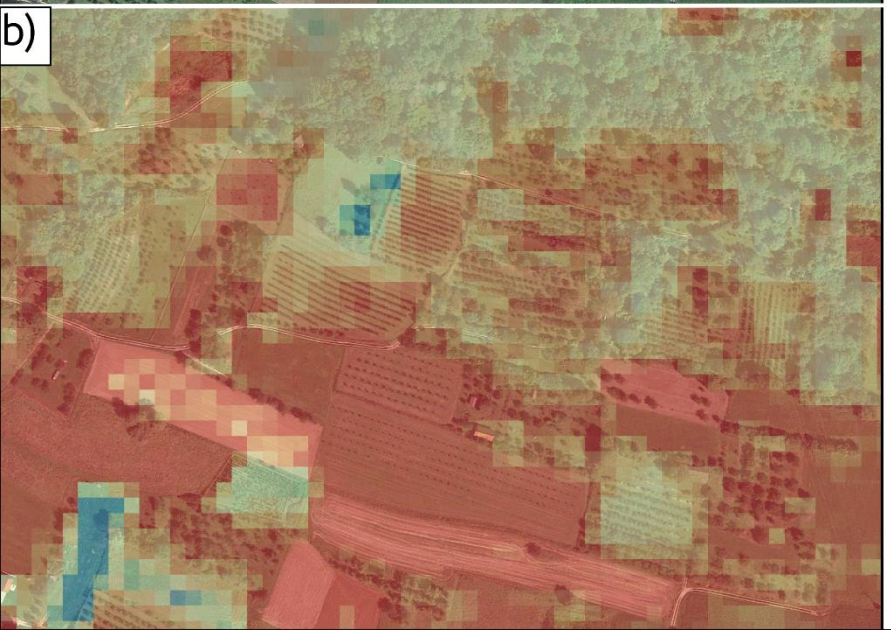
α Diversity and Extremes



α Diversity and Extremes

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Änderung der "Grünheit" (NDVI) zwischen 25.08.2017 und 20.08.2018

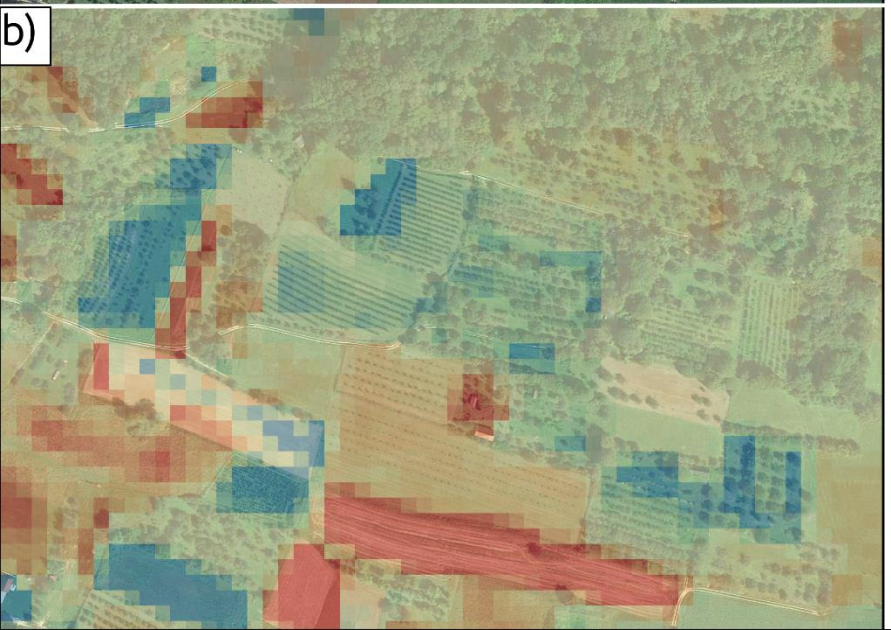
- -30%
- -15%
- 0%
- 15%
- 30%
- Ort von Bildausschnitt a) und b)

Hintergrundkarte: Google Earth

In summer 2018 clearly less drought impact in grassy orchards compared withpure grasslands and other land uses.

α Diversity and Extremes







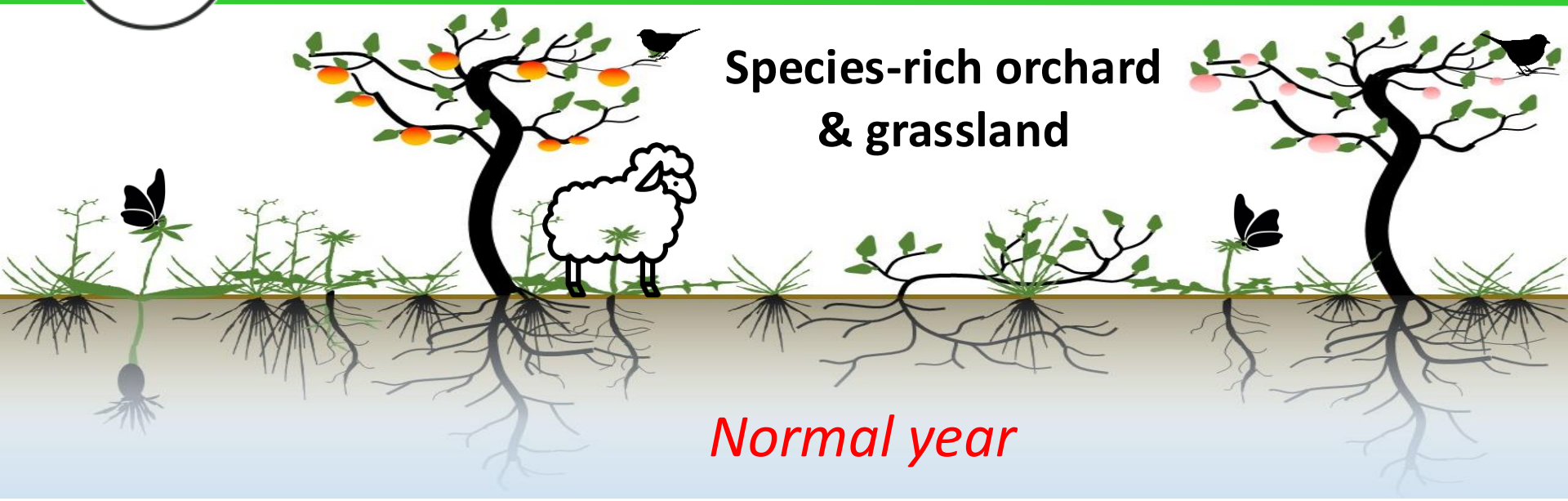
Änderung der "Grünheit" (NDVI) zwischen 25.08.2017 und 14.08.2021

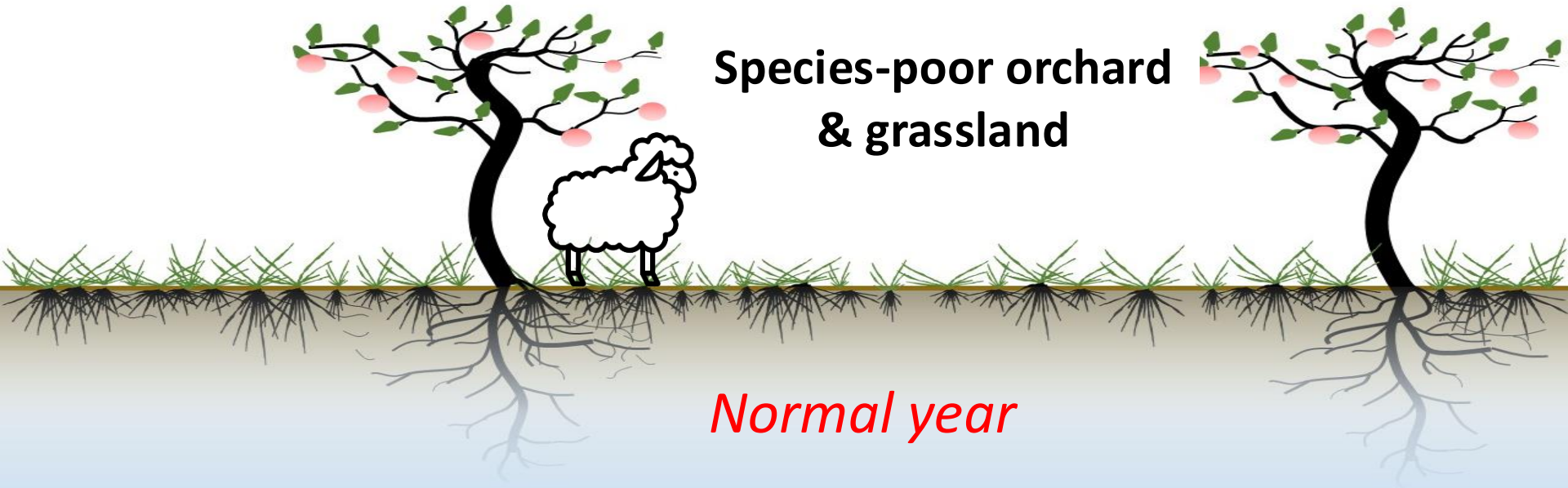
- -30%
- -15%
- 0%
- 15%
- 30%
- Ort von BIldausschnitt a) und b)

Hintergrundkarte: Google Earth

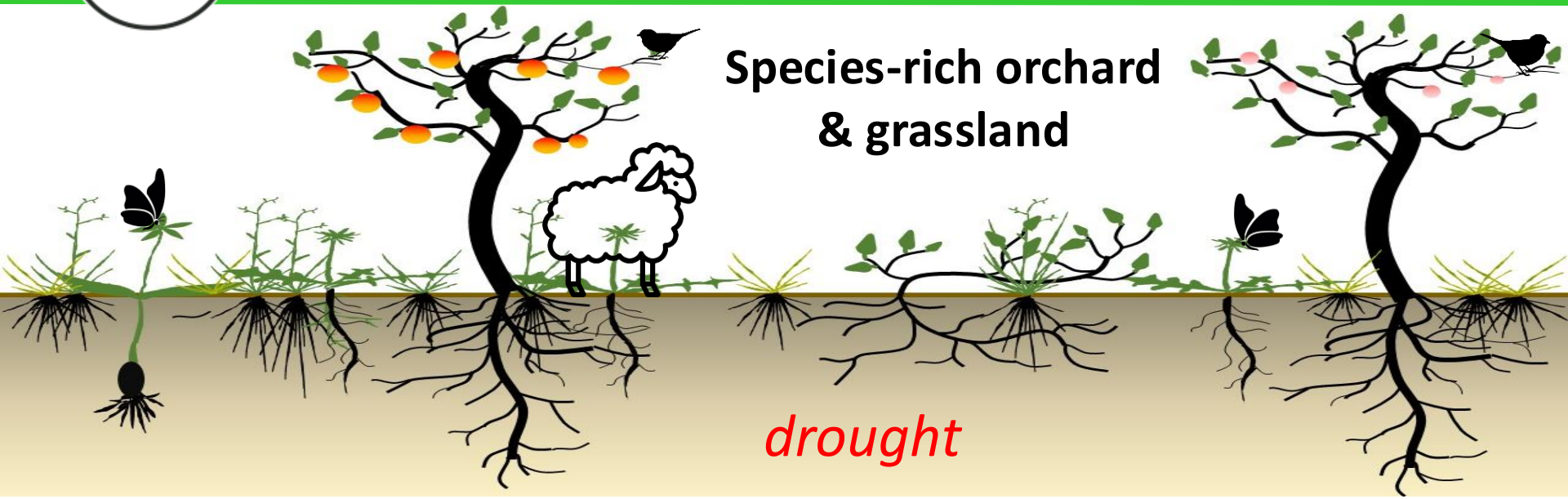
In comparison with before (2017) and after (2021) drought 2018/19 grassy orchards do best!

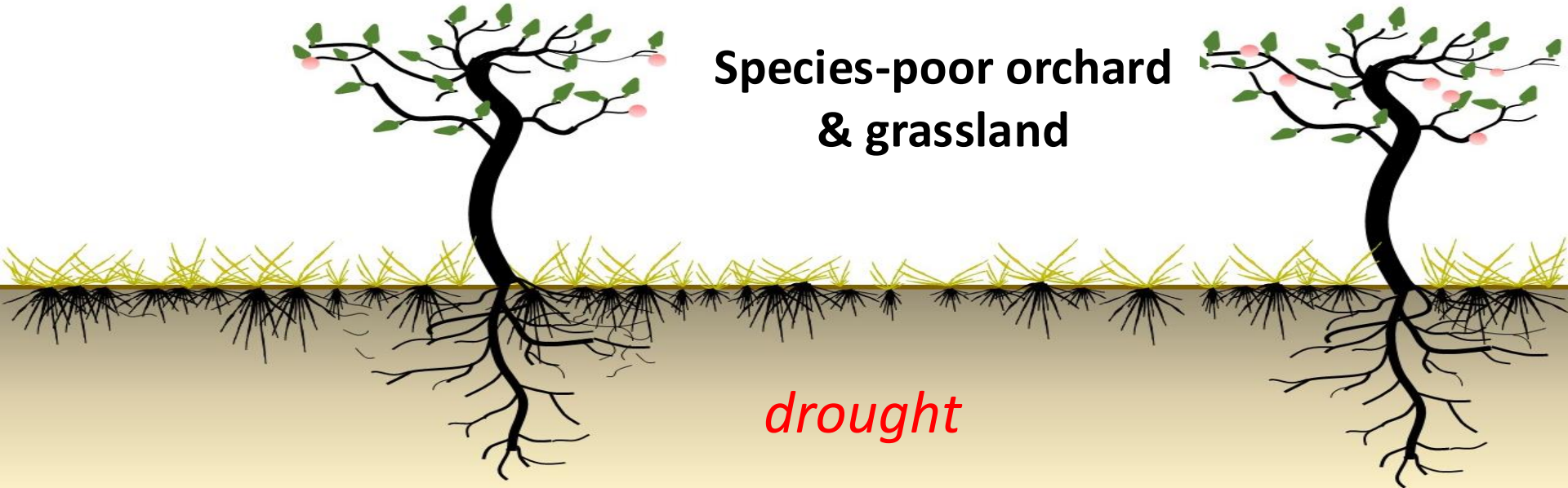
α Diversity and Extremes





α Diversity and Extremes

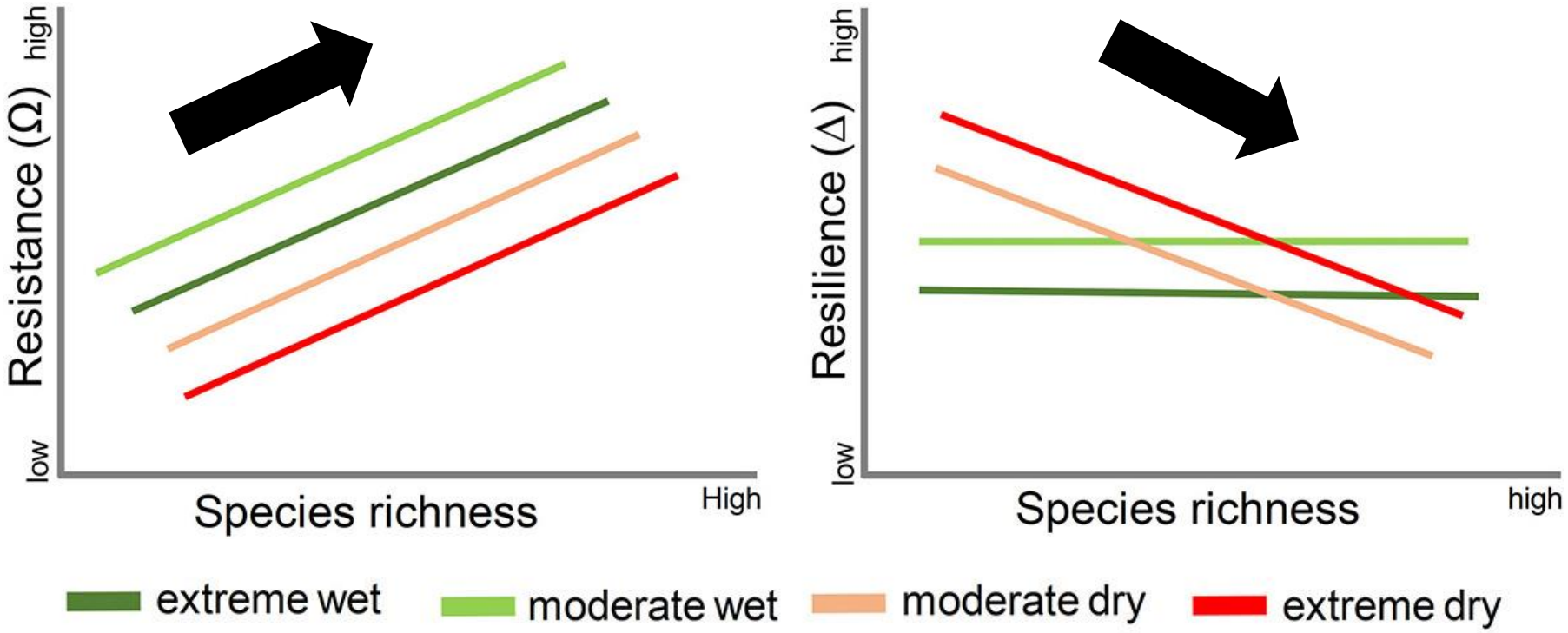




α Diversity and Extremes

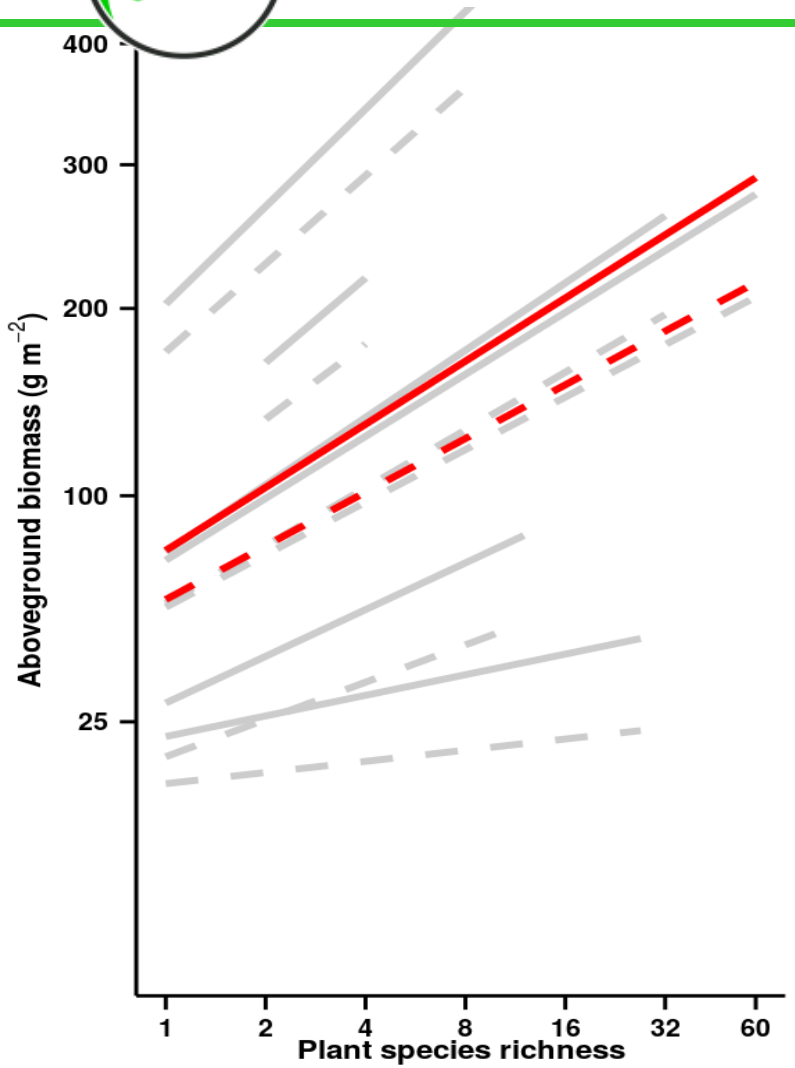
$$\text{Resistance } (\Omega) = \frac{\overline{Y_n}}{|Y_e - \overline{Y_n}|}$$

$$\text{Resilience } (\Delta) = \left| \frac{Y_e - \overline{Y_n}}{Y_{e+1} - \overline{Y_n}} \right|$$



Hossain, Li, Hoffmann, Beierkuhnlein 2022. Biodiversity showed positive effects on resistance but mixed effects on resilience to climatic extremes in a long-term grassland experiment. Science of The Total Environment, 827, 154322.

α Diversity and Extremes



16 Experiments in global grasslands.

Lower productivity because of drought but still a positive effect of biodiversity.

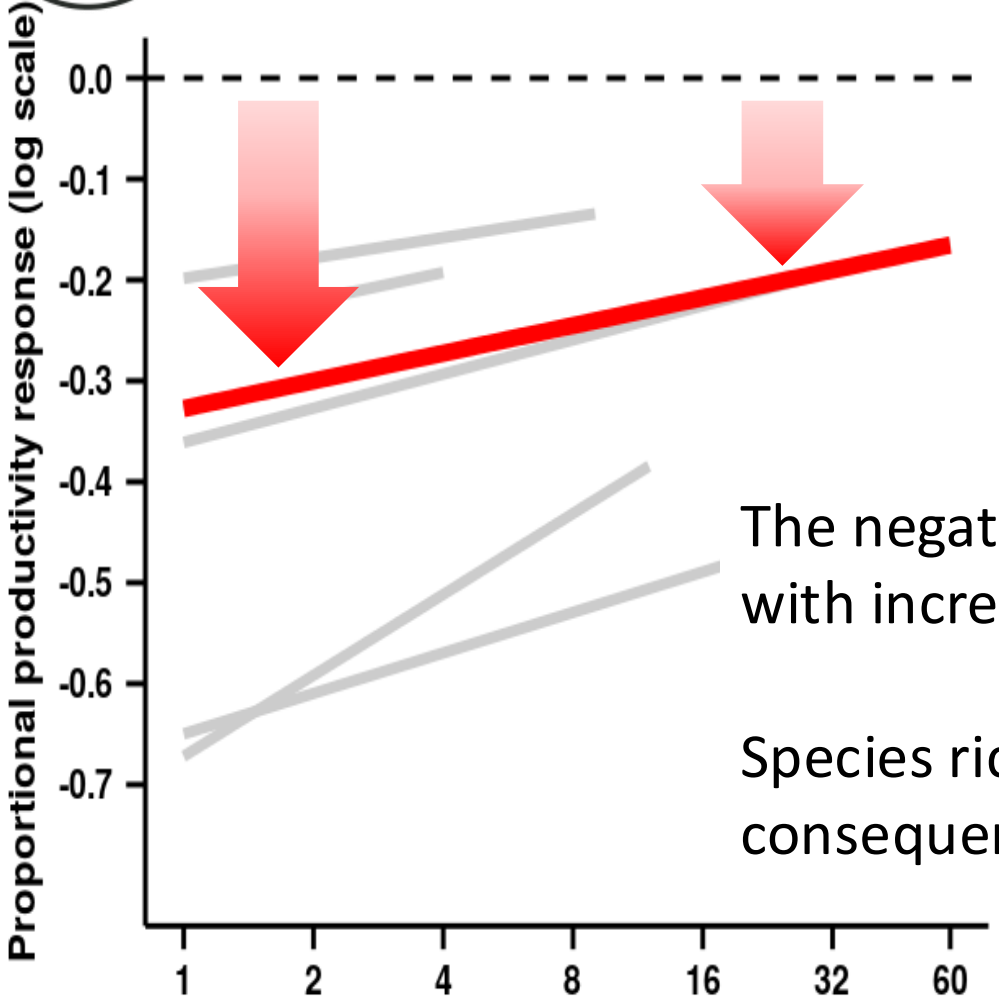
Species-rich grasslands grow better under drought than species-poor grasslands.

Drought

Control

Craven, Isbell, Manning, Conolly, Bruelheide, Ebeling, Roscher, van Ruijven, Weigelt, Wilsey, Beierkuhnlein et al. (2016) Plant diversity effects on grassland productivity are robust to both nutrient enrichment and drought. Philos Trans R Soc Lond B Biol Sci. 19; 20150277. doi: 10.1098/rstb.2015.0277

α Diversity and Extremes

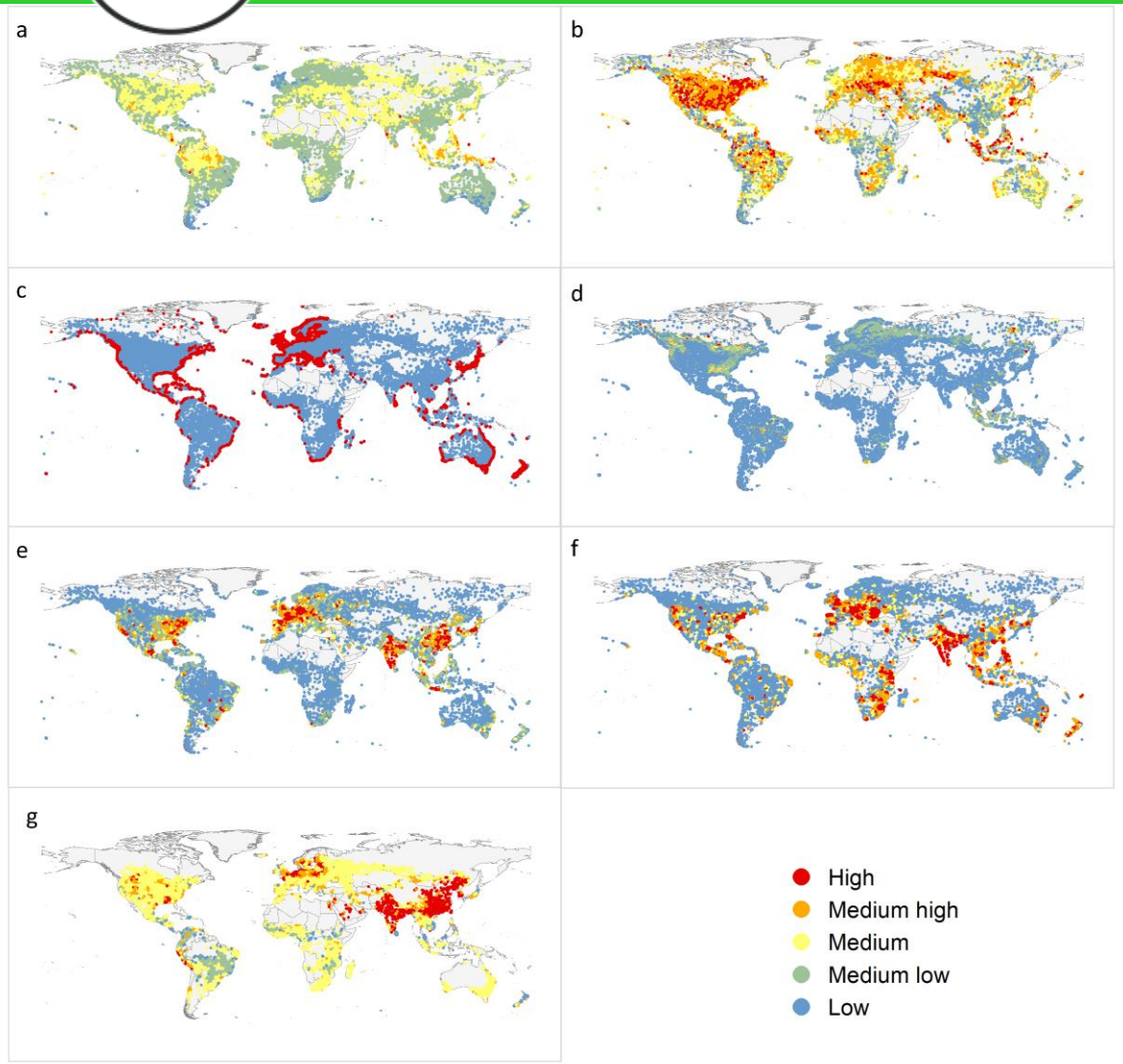


The negative effect of drought decreases with increasing number of species.

Species richness reduced the negative consequences of extreme climate.

Craven, Isbell, Manning, Conolly, Bruelheide, Ebeling, Roscher, van Ruijven, Weigelt, Wilsey, Beierkuhnlein et al. (2016) Plant diversity effects on grassland productivity are robust to both nutrient enrichment and drought. Philos Trans R Soc Lond B Biol Sci. 19; 20150277. doi: 10.1098/rstb.2015.0277

Protected Areas



Global threats to 137 735 **protected areas.**

Drivers of biodiversity loss.

a) Near-future projected climate exposure under RCP 4.5

b) Near-future projected proportion of disappearing climatic conditions

c) Mid-century sea level rise

d) Gross forest loss

e) Pressures through tourism (equal intervals);

f) Pressures through poaching

g) Pressures through pollution/deposition of nitrogen

Eco-Epidemiological Models

Process-Based Mechanistic Models

$$\boldsymbol{M}(T) = \frac{EV(T)pO(T)EFGC(T)pEA(T)MDR(T)}{\mu(T)^2}$$

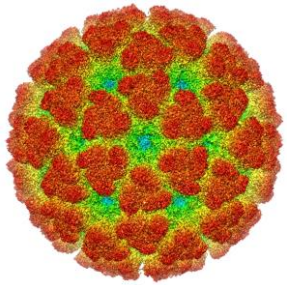
$\boldsymbol{M}$	Mückendichte
EV	Schlupfrate
pO	Anteil der Eiablage
pEA	Überlebensrate Eier, Larven, Puppen
MDR	Entwicklungsrate der Mücken
EFGC	Eier pro Weibchen pro gonotrophischem Zyklus



Aedes albopictus

$$\boldsymbol{R0}(T) = \frac{M(T)a^2bc(T)e^{-\mu EIP(T)}}{Nr\mu(T)}$$

$\boldsymbol{R0}$	Basisreproduktionszahl
$\boldsymbol{M}$	Mückendichte
a	Stechrate
bc	Vektorkompetenz
μ	Sterblichkeitsrate adulter Mücken
EIP	Extrinsische Inkubationsperiode
N	Anzahl der Wirte
r	Genesungsrate der Wirte



Chikungunya Virus

Spatial and Temporal Resolution

Bayceer
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Downscaling to the spatial resolution of the urban environment

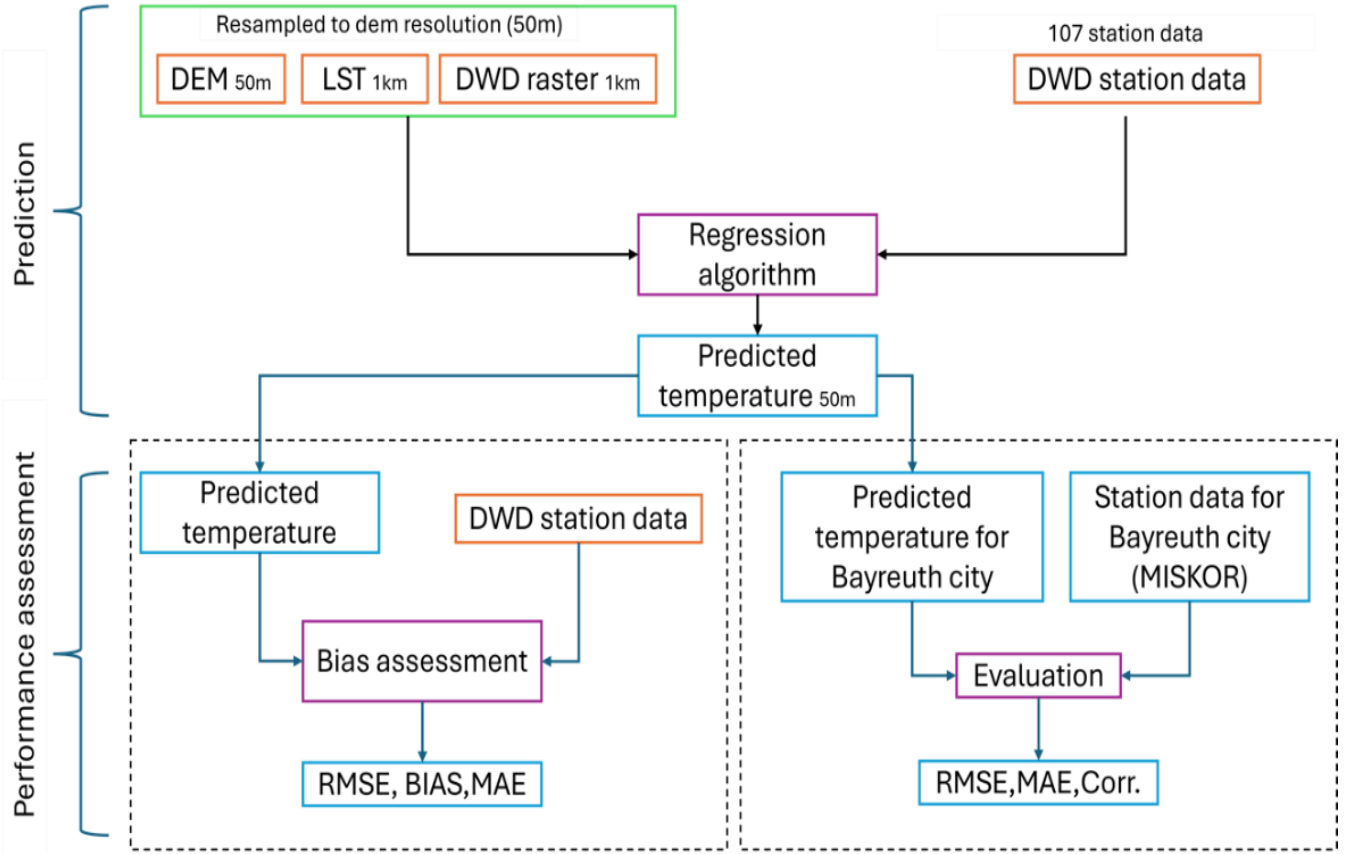
VIIRS LST: Visible Infrared Imaging Radiometer Suite

LST = Land Surface Temperature VIIRS

DEM = Digitales Geländemodell

DWD: Deutscher Wetterdienst

MISKOR: VKGI Projekt Mikrometeorologie UBT



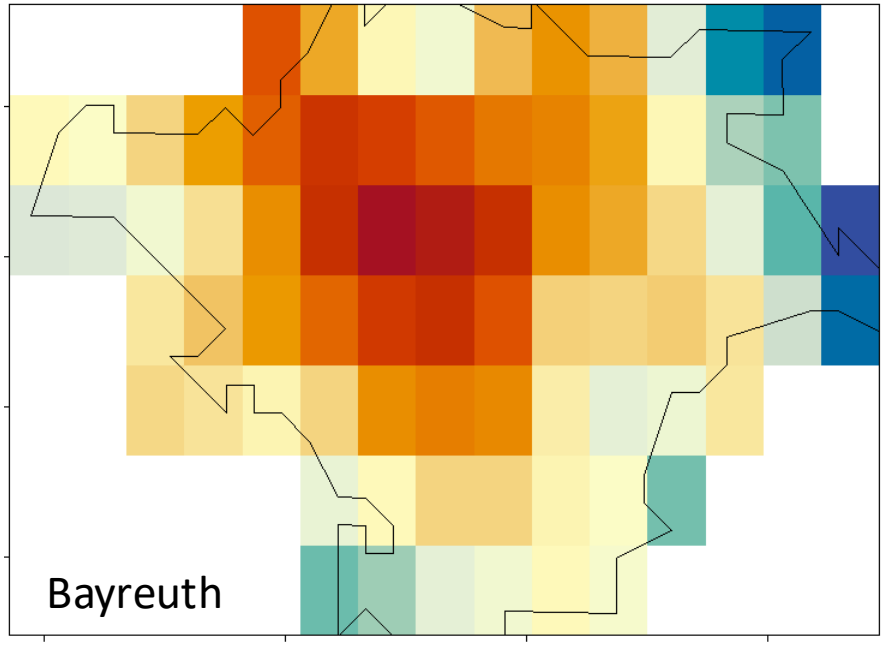
RMSE Root Mean Square Error
BIAS Systematic Error
MAE Mean Absolute Error

Spatial and Temporal Resolution

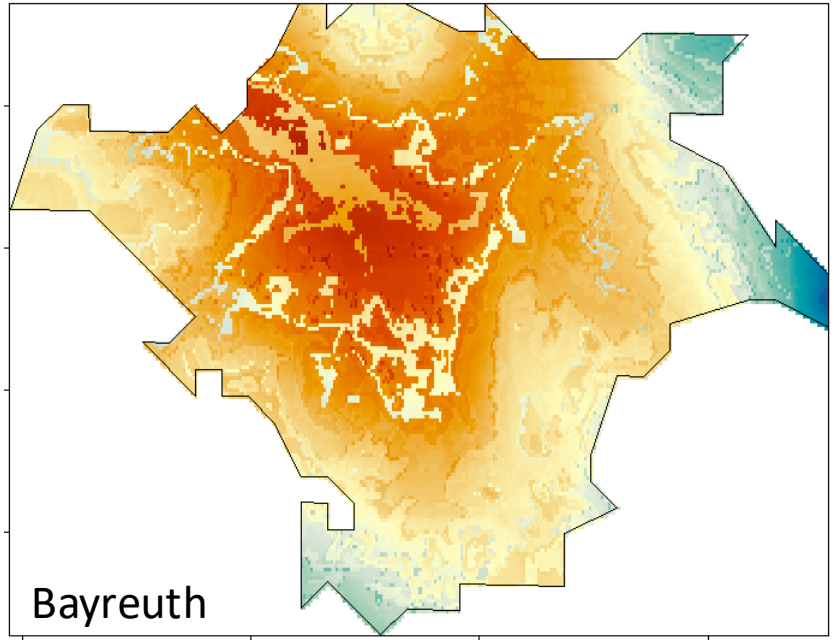
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Improved spatial resolution

DWD HYRAS temperature data (1km)



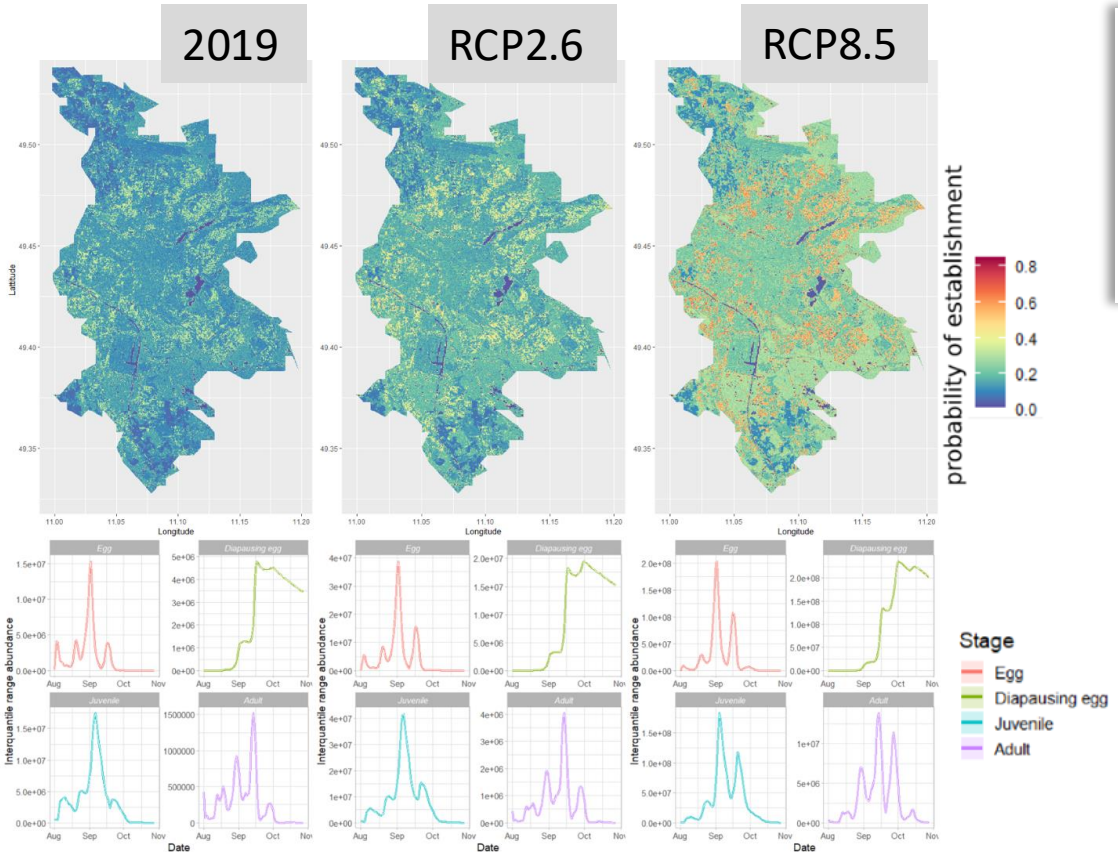
VIIRS modelled temperature (50m)



Spatial and Temporal Resolution

Bayceer
Bayreuth Center of Ecology and Environmental Research

Improved temporal resolution



Da Re *et al. Parasites & Vectors* (2022) 15:414
https://doi.org/10.1186/s13071-022-05414-4

Parasites & Vectors

METHODOLOGY Open Access

dynamAedes: a unified modelling framework for invasive *Aedes* mosquitoes

Daniele Da Re[1*†], Wim Van Bortel[2], Friederike Reuss[3,4], Ruth Müller[2], Sebastien Boyer[5], Fabrizio Montarsi[6], Silvia Ciocchetta[7], Daniele Arnoldi[8], Giovanni Marini[8], Annapaola Rizzoli[8], Gregory L'Ambert[9], Guillaume Lacour[10], Constantianus J. M. Koenraadt[11], Sophie O. Vanwambeke[1] and Matteo Marcantonio[12*†]



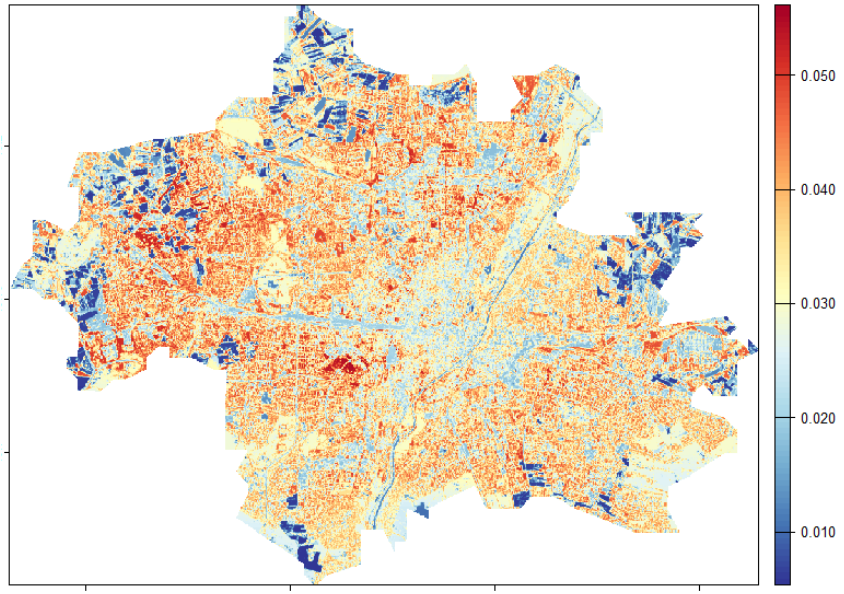
Aedes albopictus

Nürnberg, Germany

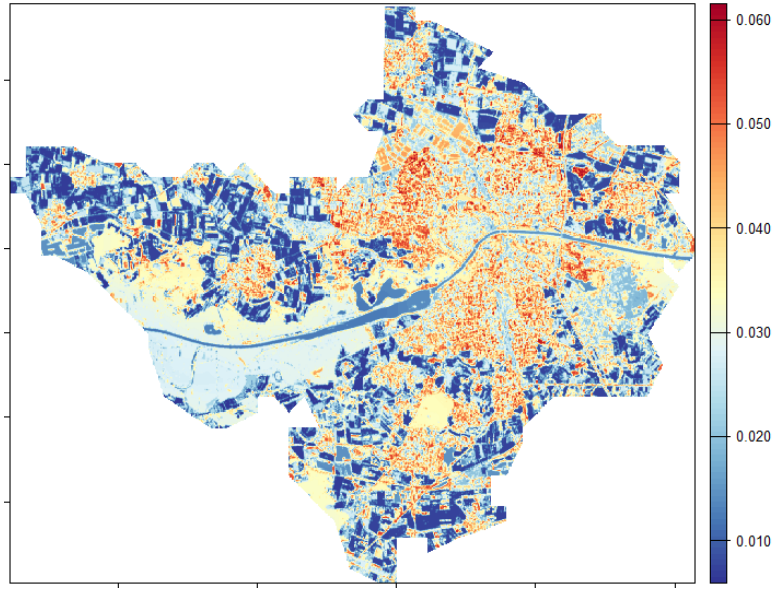
Chikungunya

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August to October 2019

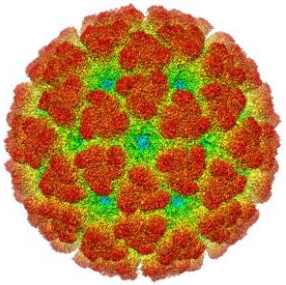


Munic



Ingolstadt

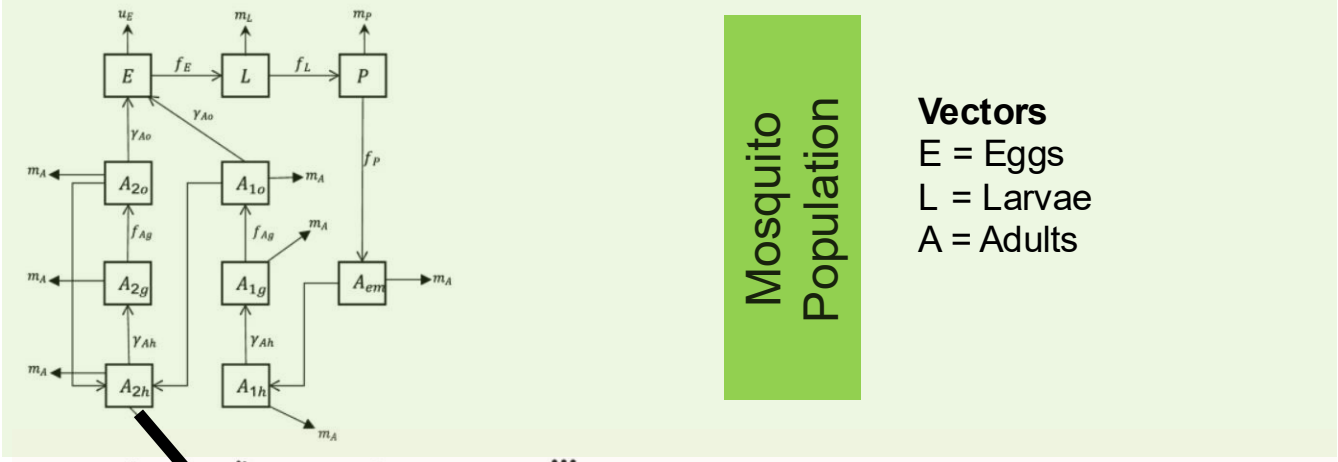
Risks are different between cities



Chikungunya Virus

Eco-Epidemiological Models

Process-Based Mechanistic Models



Mosquito Population

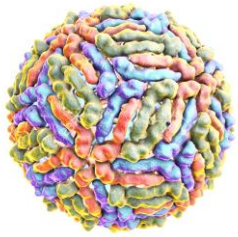
Vectors
E = Eggs
L = Larvae
A = Adults



Culex pipiens

Pathogen Transmission

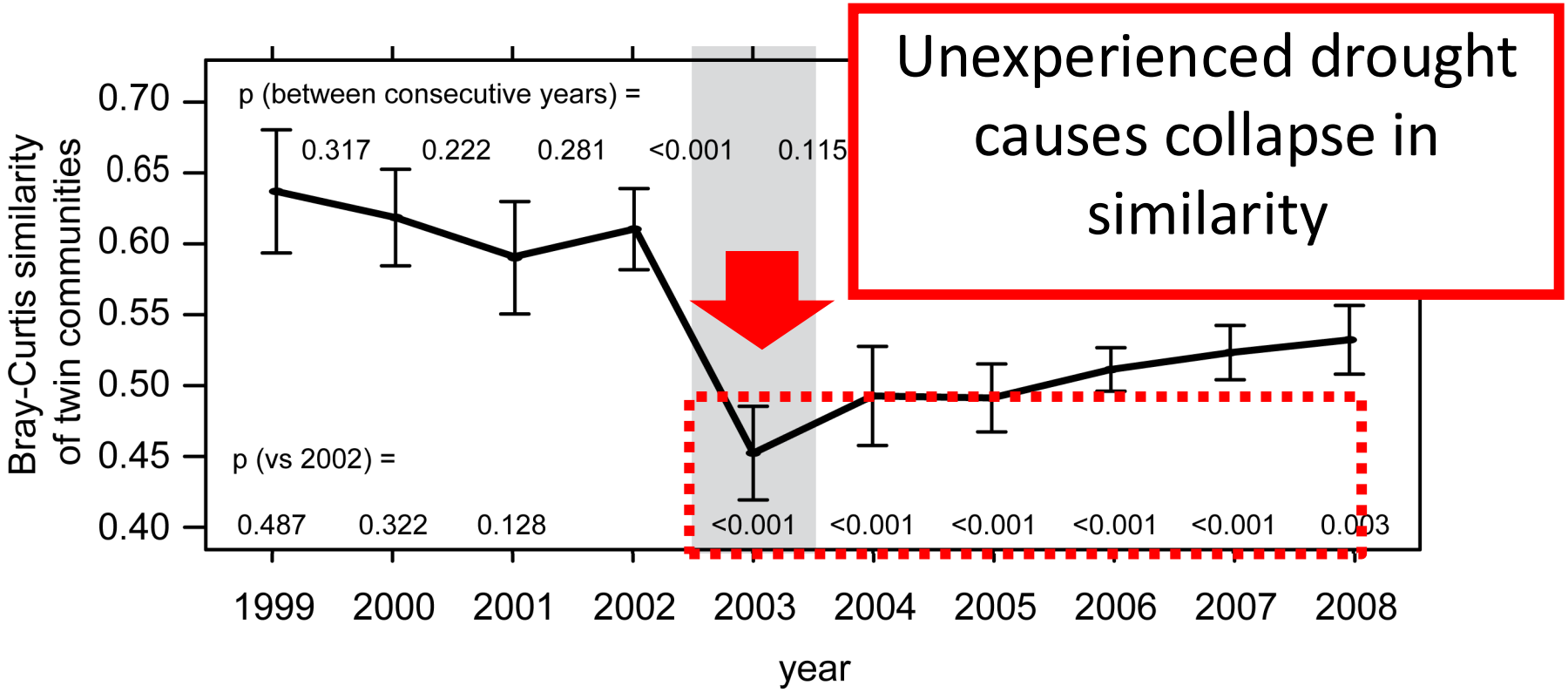
Hosts
S = Susceptible
E = Exposed
I = Infectious
R = Resistent or immune
D = Deceased



West-Nile-Virus

Mbaoma OC, Thomas SM, Beierkuhnlein C 2024. Spatiotemporally explicit epidemic model for West Nile Virus outbreak in Germany: An inversely calibrated approach. *J Epidemiol Glob Health* **14**, 1052–1070.

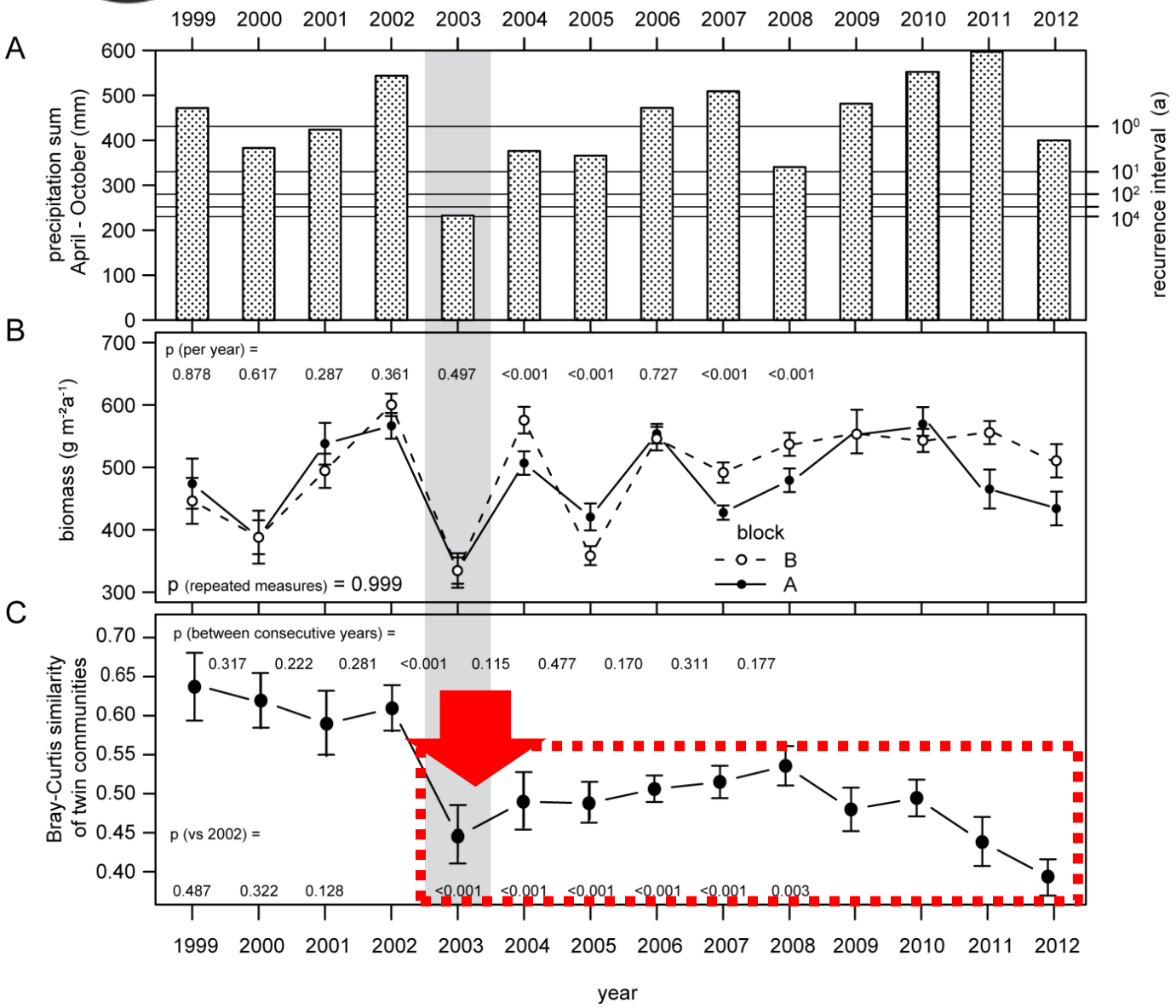
β Diversity and Drought



Similarity between twin grassland communities based on aboveground species-specific biomass was high until 2003, but then …

Kreyling, J., Jentsch, A. and Beierkuhnlein, C. (2011), Stochastic trajectories of succession initiated by extreme climatic events. Ecology Letters, 14: 758-764.

β Diversity and Drought

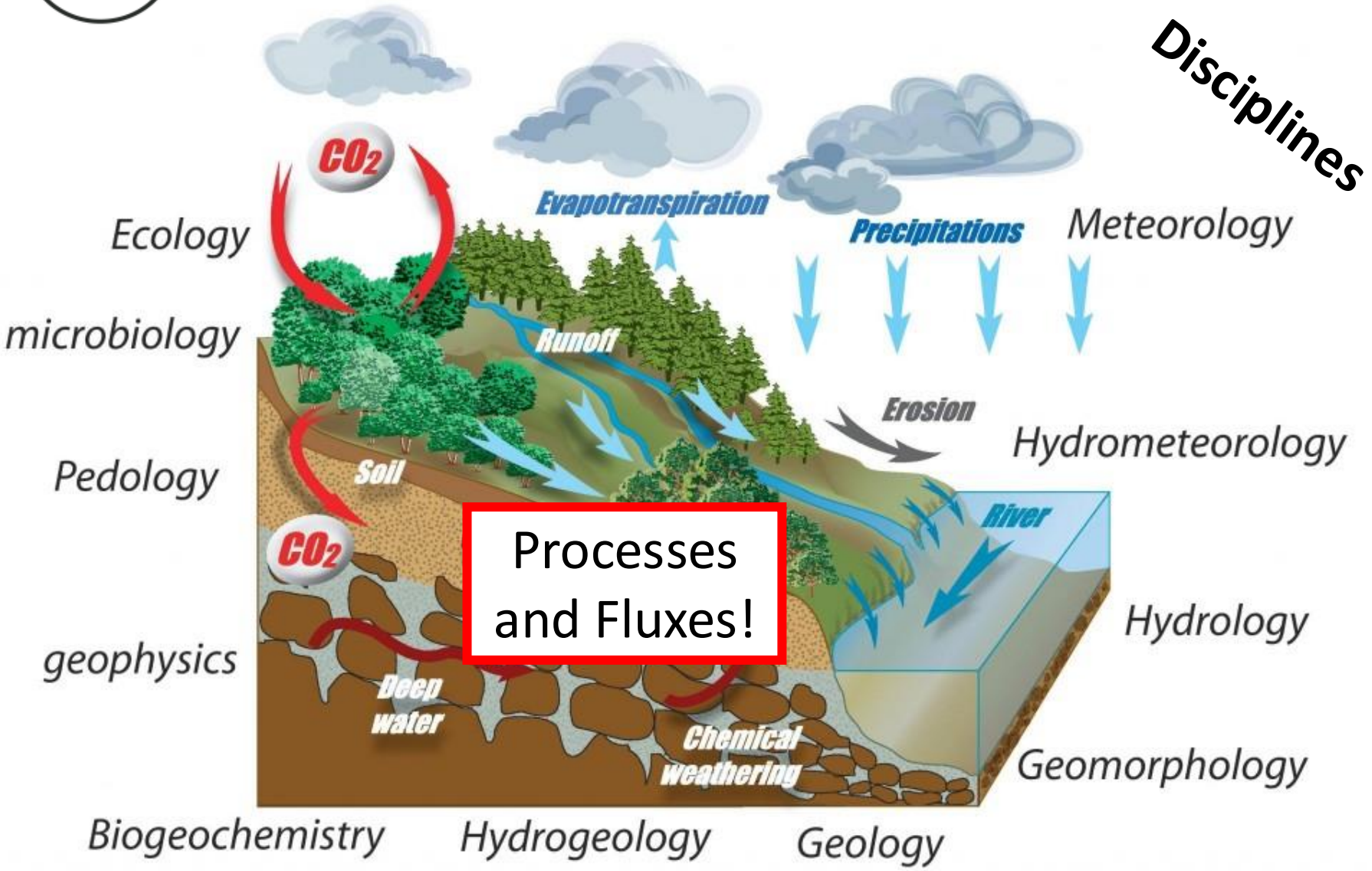


Precipitation

Biomass

Similarity

Biodiversity Climate Nexus



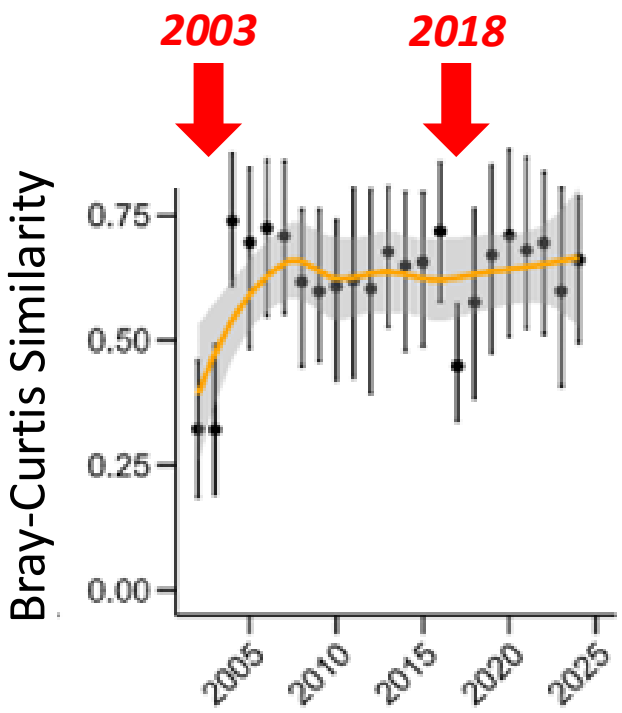
https://www.critex.fr/what-is-critex/la-zone-critique-en/

Extreme Weather

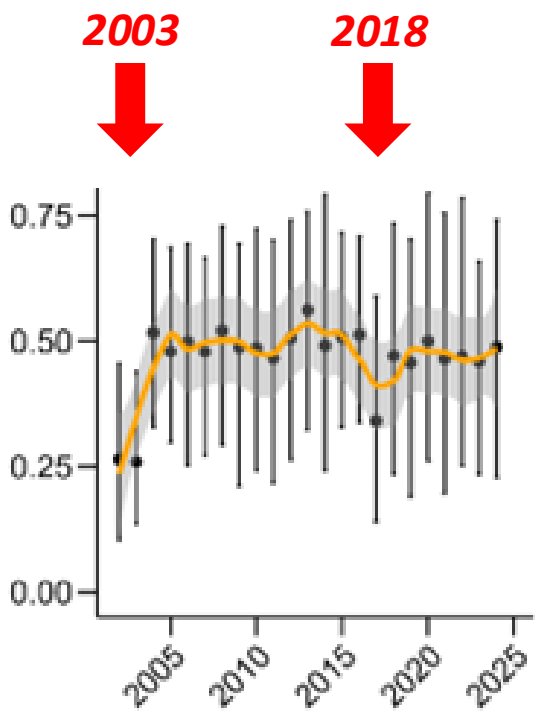
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Extreme climatic conditions enhance heterogeneity

Cover



Biomass

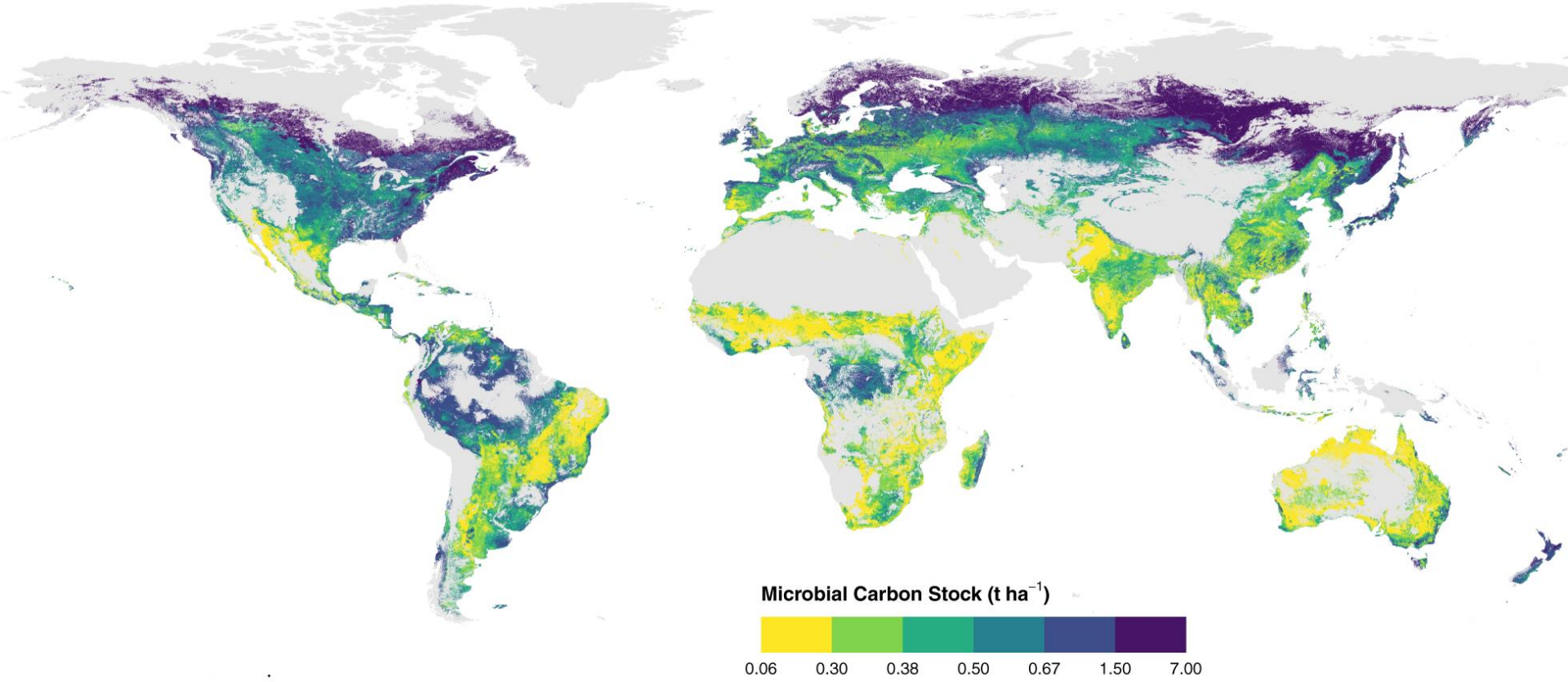


Sumer Drought & Heatwave

September Data

Uncertainty

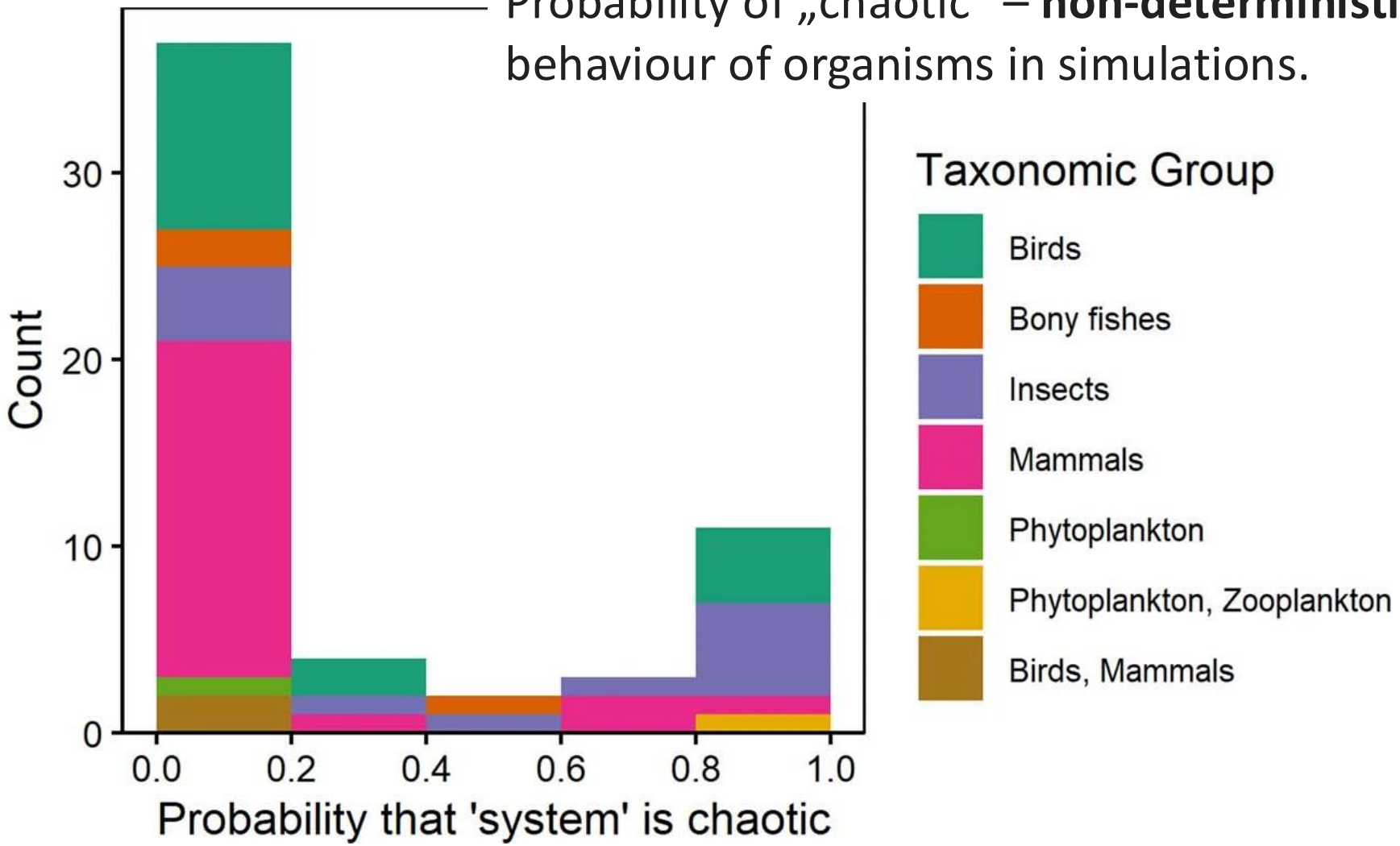
Total Microbial Carbon Stock (t C ha^{-1}) for fungi, bacteria and archaea



Patoine, G. et al. 2022. Drivers and trends of global soil microbial carbon over two decades. Nature Communications 13, 4195.

Uncertainty

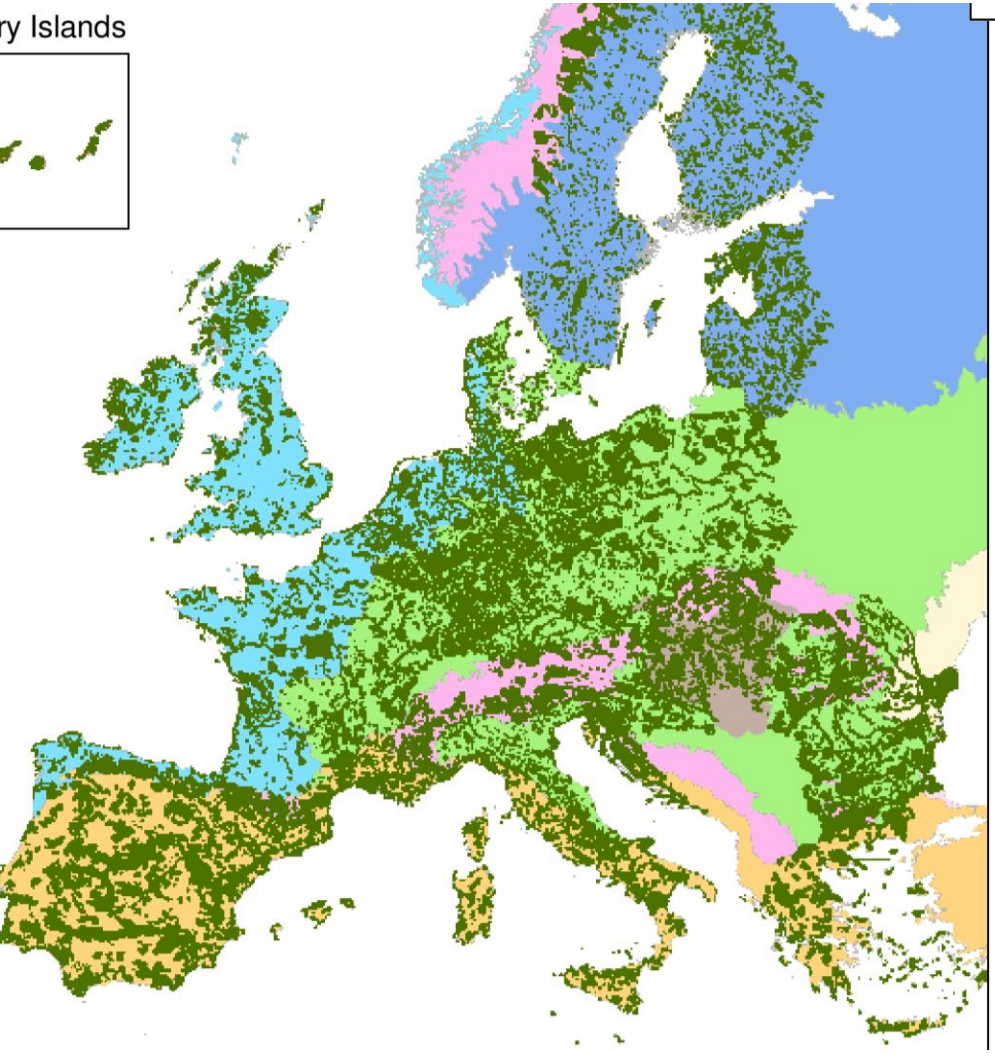
Probability of „chaotic“ – **non-deterministic** behaviour of organisms in simulations.

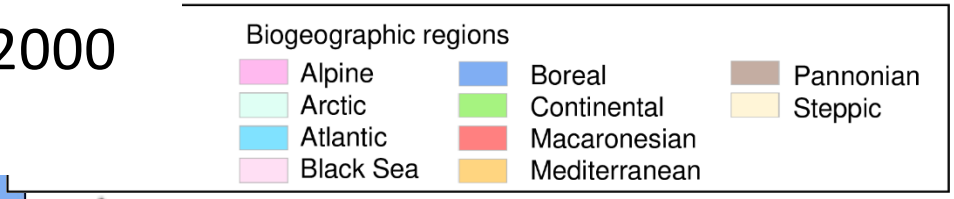


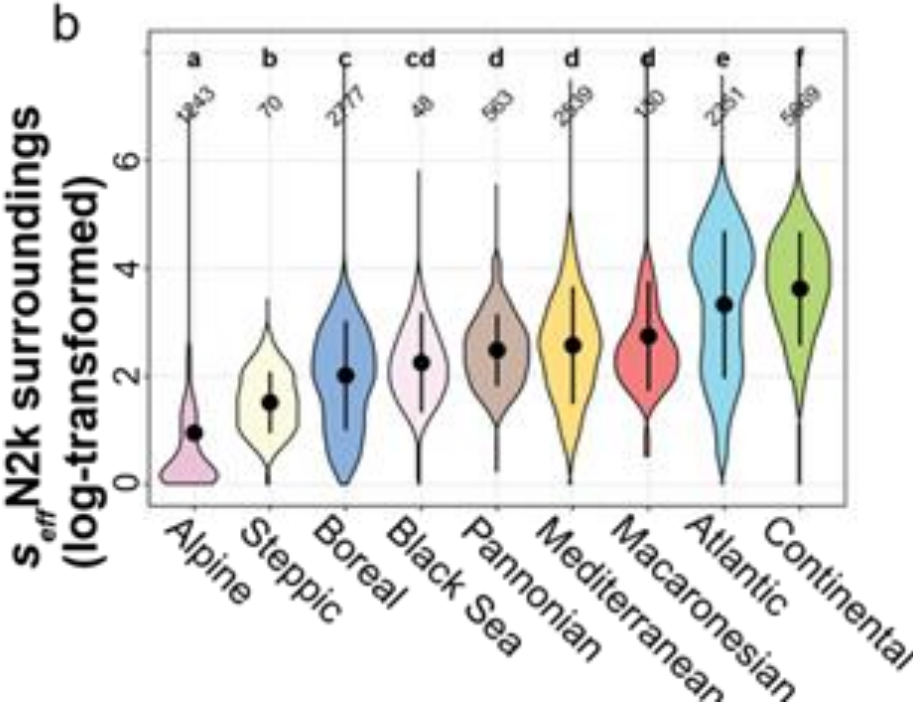
Rogers et al. (2022): Chaos is not rare in natural ecosystems. Nat Ecol Evol 6, 1105–1111

Fragmentation

- Fragmentation in surroundings of N2000 PAs for biogeographical regions







Lawrence A, Beierkuhnlein C (2023) Detecting low fragmented sites surrounding European protected areas – Implications for expansion of the Natura 2000 network. Journal for Nature Conservation 73, 126398.