A climate suitability index for ecological habitats applied to terrestrial arthropods in the Mediterranean Region

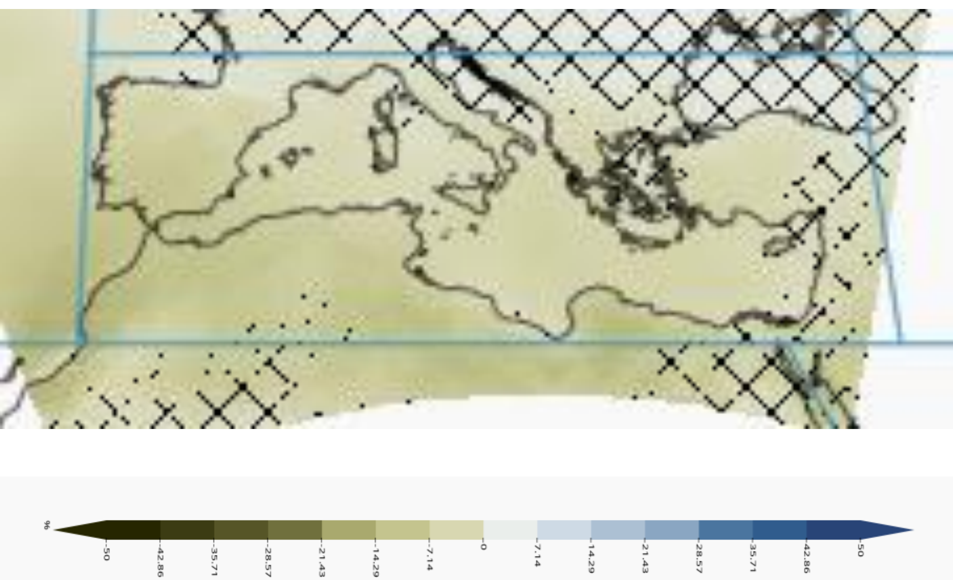
James Ciarlo`, Monique Borg Inguanez, Erika Coppola, Aaron Micallef, David Mifsud

Funded by the European Union
MARIE CURIE ACTIONS
L-Università ta' Malta
The Abdus Salam International Centre for Theoretical Physics
ICTP
esplora
XJENZA MALTA

The Near(?)-Future

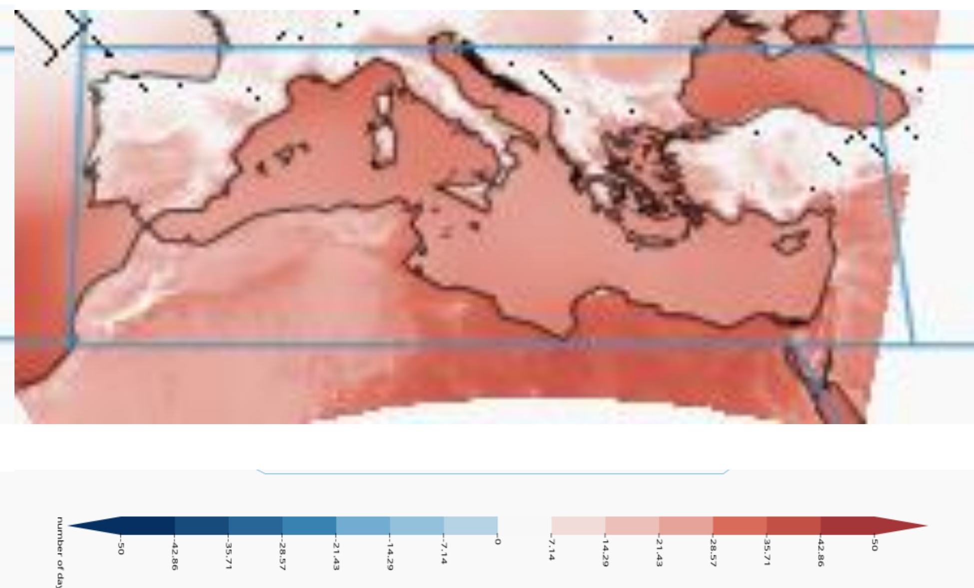
WET DAYS (PRECIPITATION ABOVE 1 MM) - CORDEX-EUR-11 - RELATIVE CHANGE - REL. TO 1981-2010 - WARMING 2°C - ANNUAL

Credit: C3S/ECMWF. Atlas version 2.0



TROPICAL NIGHTS (MINIMUM TEMPERATURE ABOVE 20 °C) - CORDEX-EUR-11 - CHANGE - REL. TO 1981-2010 - WARMING 2°C - ANNUAL

Credit: C3S/ECMWF. Atlas version 2.0



- Robust signal (origianl color)
- No change or no robust signal
- Conflicting signal

A climate suitability index for ecological habitats applied to terrestrial arthropods in the Mediterranean Region

James Ciarlo`, *Monique Borg Inguanez, Erika Coppola, Aaron Micallef, David Mifsud*

Funded by the European Union

MARIE CURIE ACTIONS

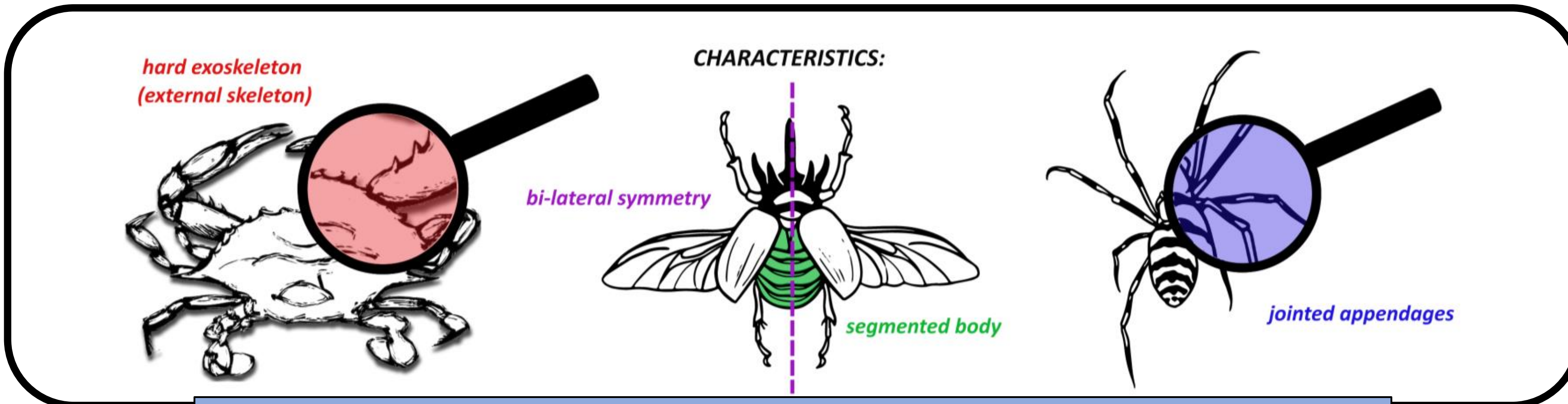
L-Università ta' Malta

The Abdus Salam International Centre for Theoretical Physics

esplora

XJENZA MALTA

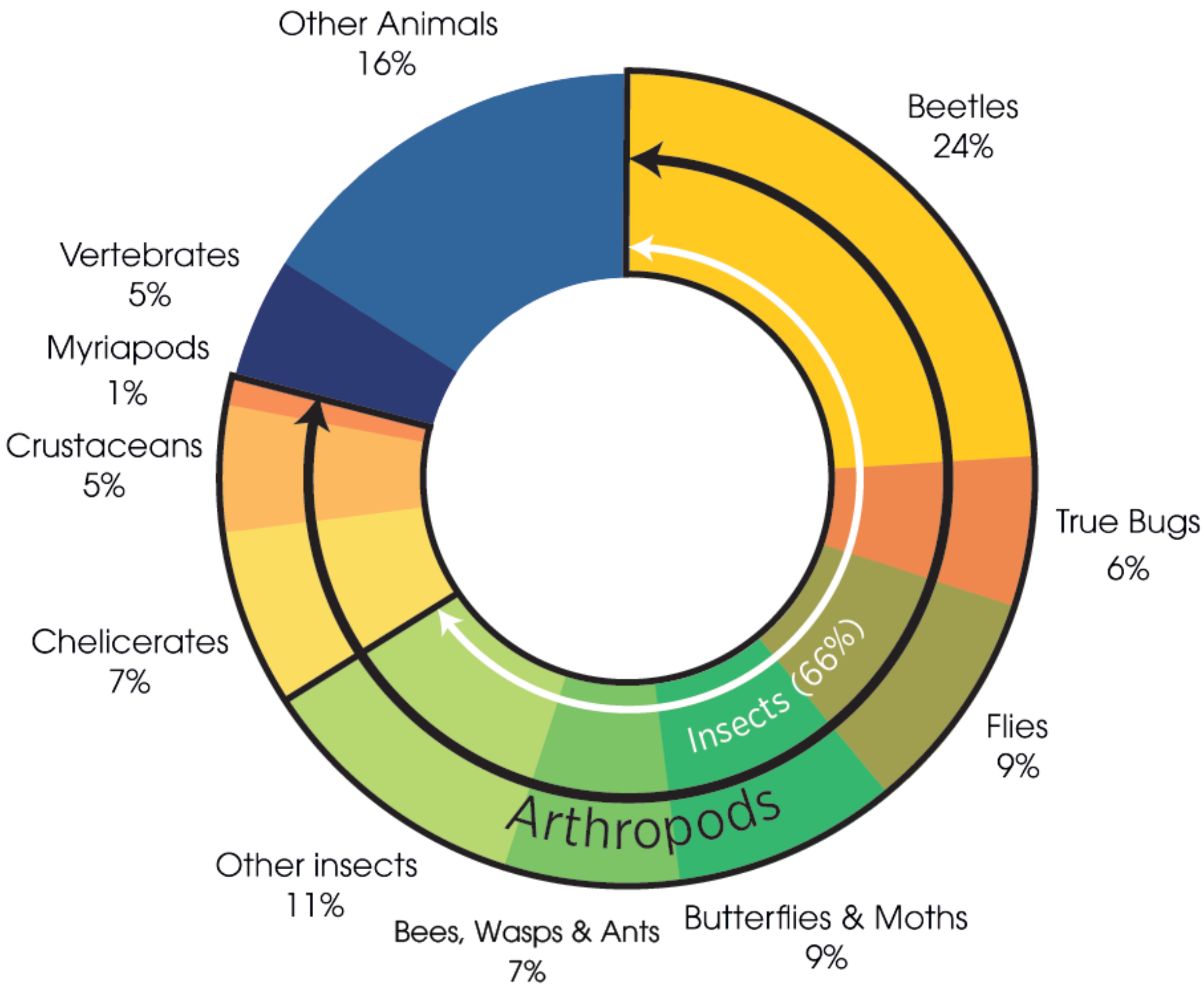
What are arthropods?



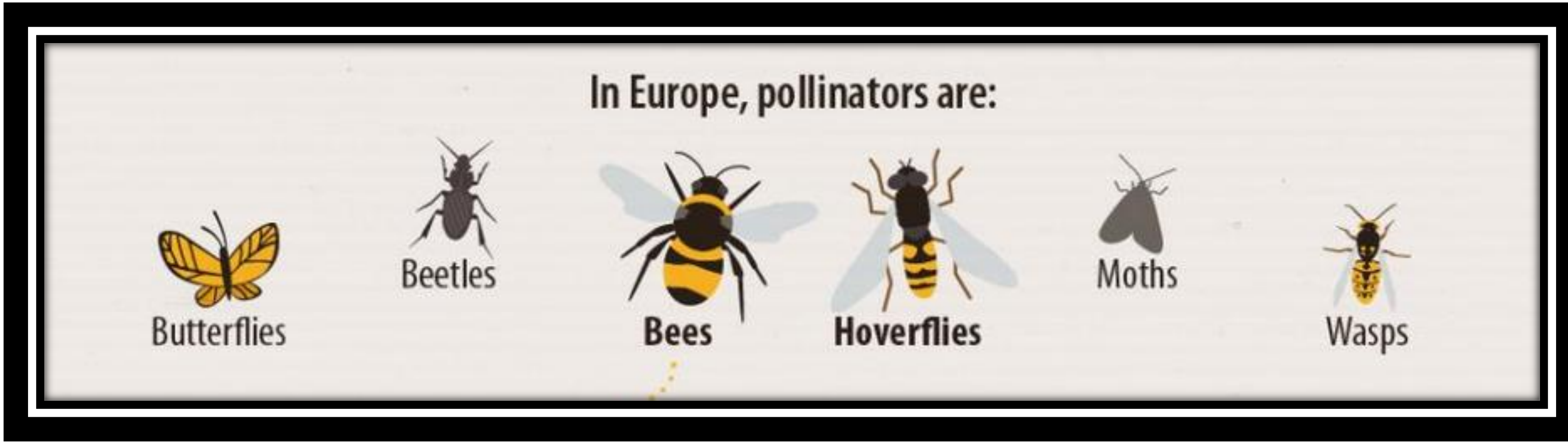
<u>Image credits</u>: This image was designed using arthropod images from Freepik.com and Pinclipart.com

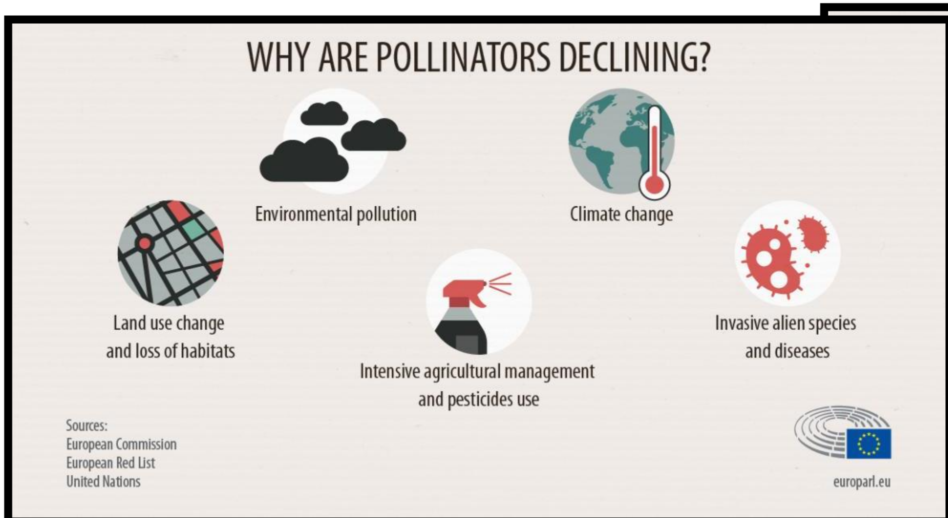


Animal groups



Data source: Reuters (2022). The collapse of insects. Available online: https://www.reuters.com/graphics/GLOBAL-ENVIRONMENT/INSECT-APOCALYPSE/egpbykdxjvq/ Accessed: 17/06/2024





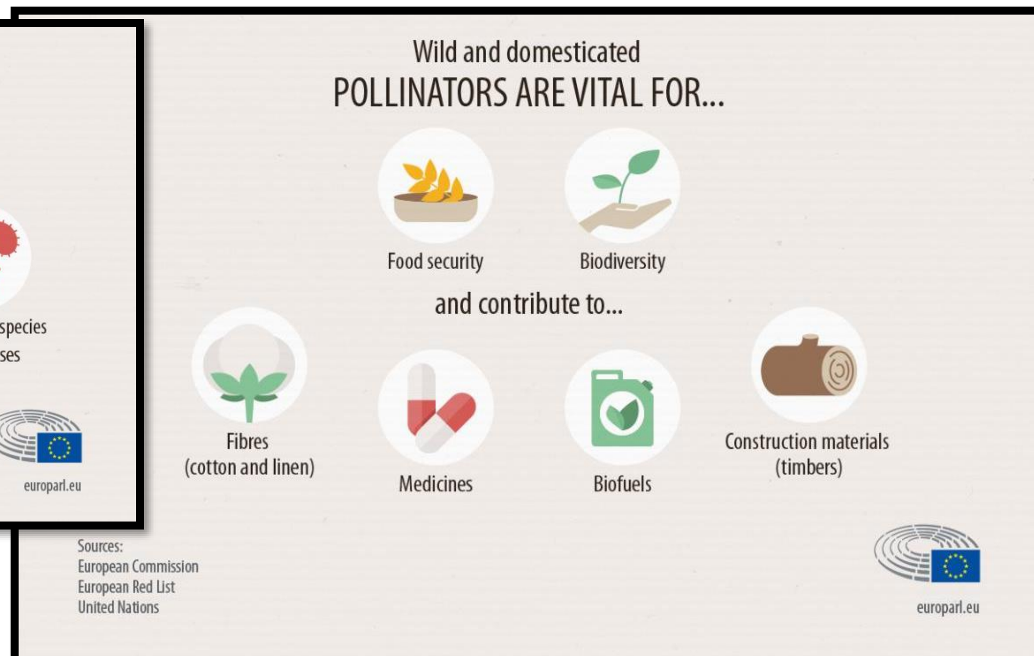


Image Source: European Parliament (2021). What's behind the decline in bees and other pollinators? (infographic). Available online: https://www.europarl.europa.eu/topics/en/article/20191129STO67758/what-s-behind-the-decline-in-bees-and-other-pollinators-infographic

“So important are insects and other land-dwelling arthropods that if all were to disappear, humanity probably could not last more than a few months.”

– Edward O Wilson, 1993

*“As species are exterminated by shifting climate zones, **ecosystems can collapse**, destroying more species.”*

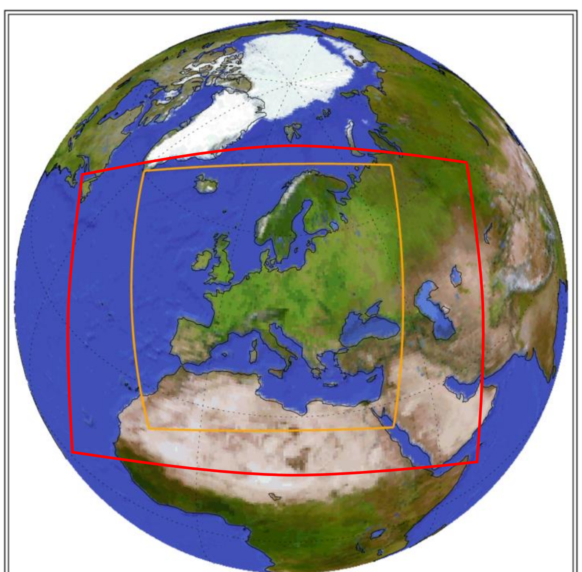
– James Hansen, 2009

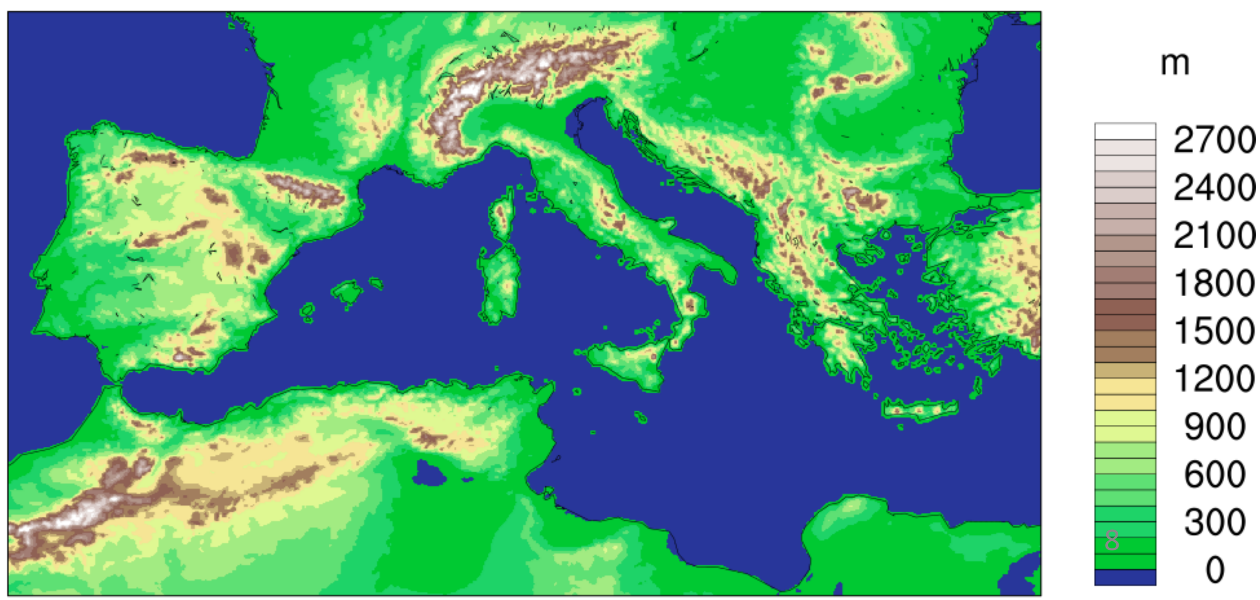
RegCM5 Configuration

The Abdus Salam International Centre for Theoretical Physics

Giorgi, et al., 2023; Coppola et al., 2024

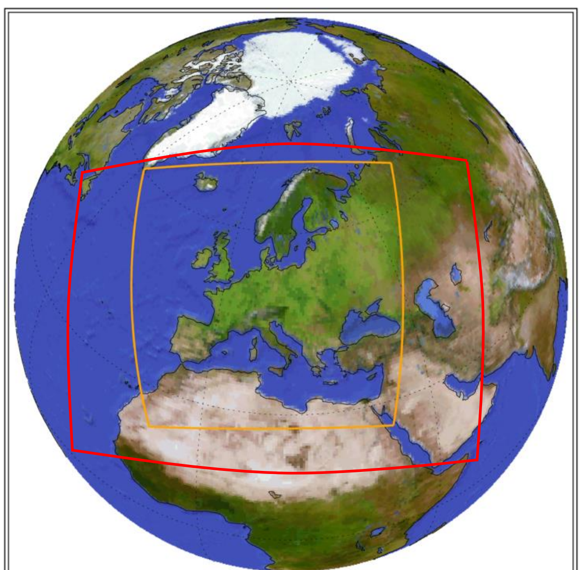
DOMAIN	**Resolution**	**Boundary layer scheme** (ibltyp)	**Cumulus convection scheme** (icup_lnd/ocn)	**Moisture scheme** (ipptls)	**Cloud fraction algorithm** (icldfrac)
Extra-European	0.44° (~50 km)	Holtslag PBL	Tiedtke/Tiedtke	Explicit moisture Nogherotto/Tompkins	Xu-Randall empirical
Europe	0.11° (~12.5 km)	Holtslag PBL	Tiedtke/Tiedtke	Explicit moisture Nogherotto/Tompkins	Xu-Randall empirical
Western/Central Mediterranean	0.03° (~3.4 km)	Holtslag PBL	none	Explicit moisture Nogherotto/Tompkins	SUBEX

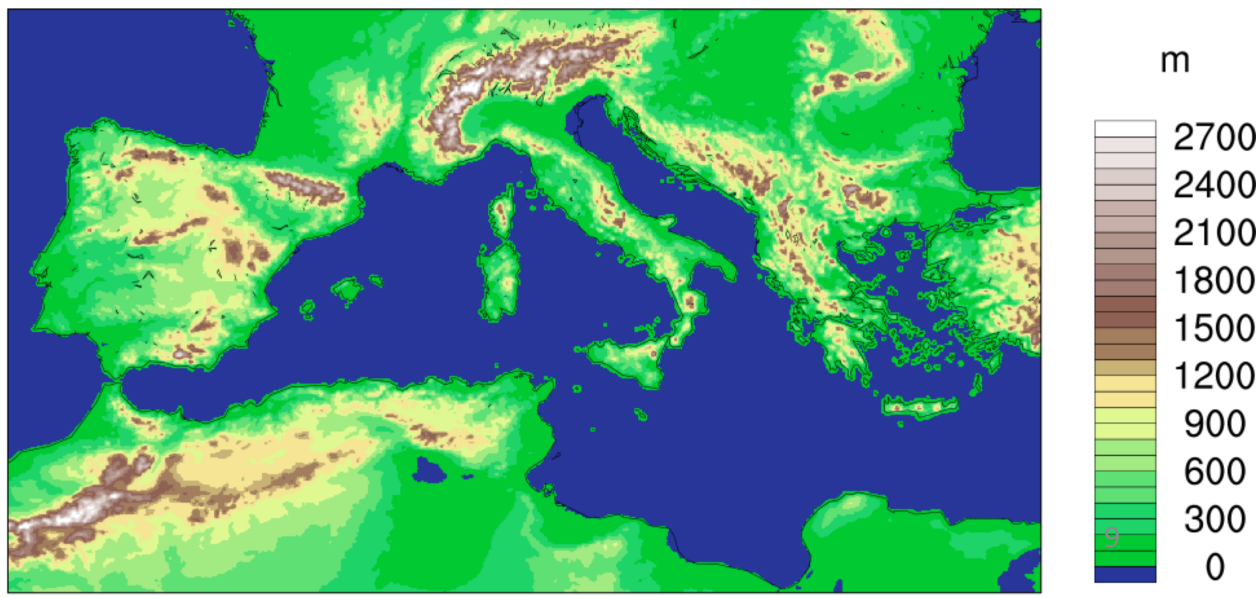




Simulation Drivers & Experiments

Driving Model	LSM	Ensemble	Res.	Experiments
ECWMF-ERA5	BATS/CLM4.5	-	0.25°	evaluation
MPI-ESM1-2-LR	BATS	r1i1p1f1	250km	historical, past2k, midHolocene, lgm
MPI-ESM1-2-HR	CLM4.5	r1i1p1f1	100km	historical, ssp370 (GWLs 1.5, 2, 3)





Simulation performance

Simulation	CPUs	Run-time /10 yrs	RAW output /10yrs
Europe 12.5 km	384	9.6 days	9.9 TB
West-Central Mediterranean 3.4 km	960	31.9 days	46 TB

After processing (incomplete runs)	
6.5M core hours	282 TB

Simulation performance

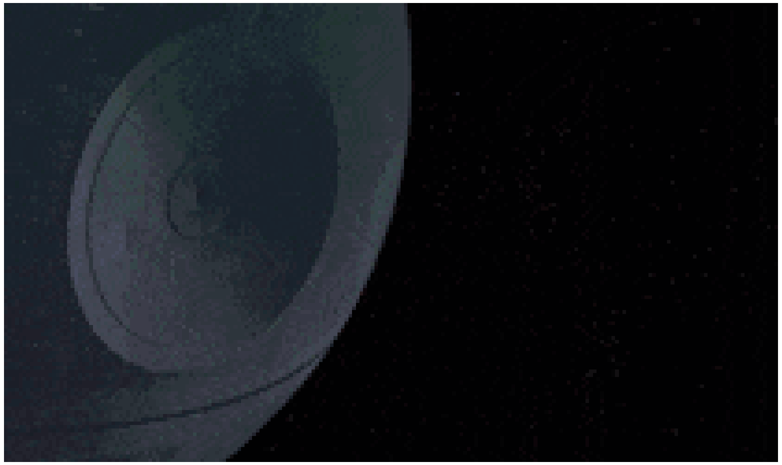
Simulation	CPUs	Run-time /10 yrs	RAW output /10yrs
Europe 12.5 km	384	9.6 days	9.9 TB
West-Central Mediterranean 3.4 km	960	31.9 days	46 TB

After processing (incomplete runs)

6.5M core hours	282 TB

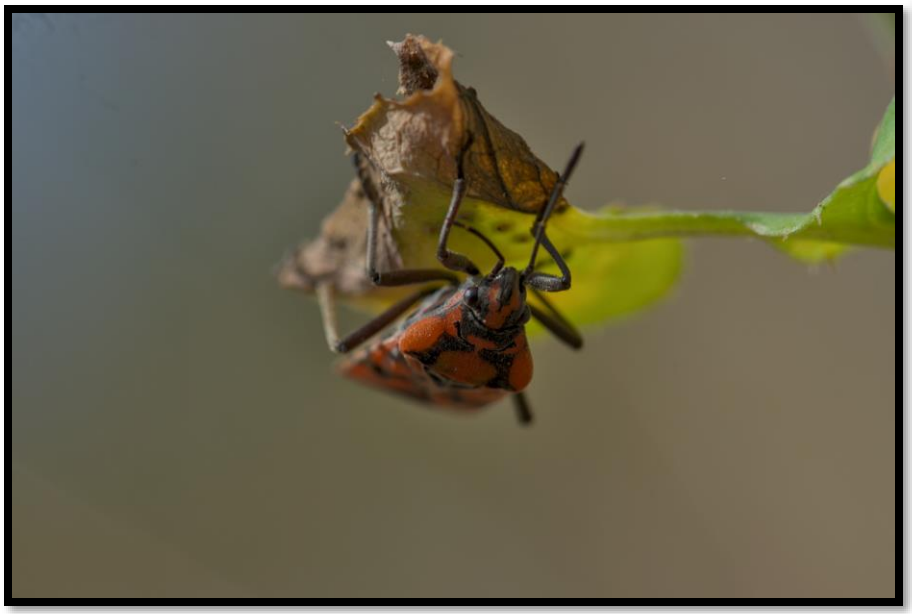
After 20th October 2024

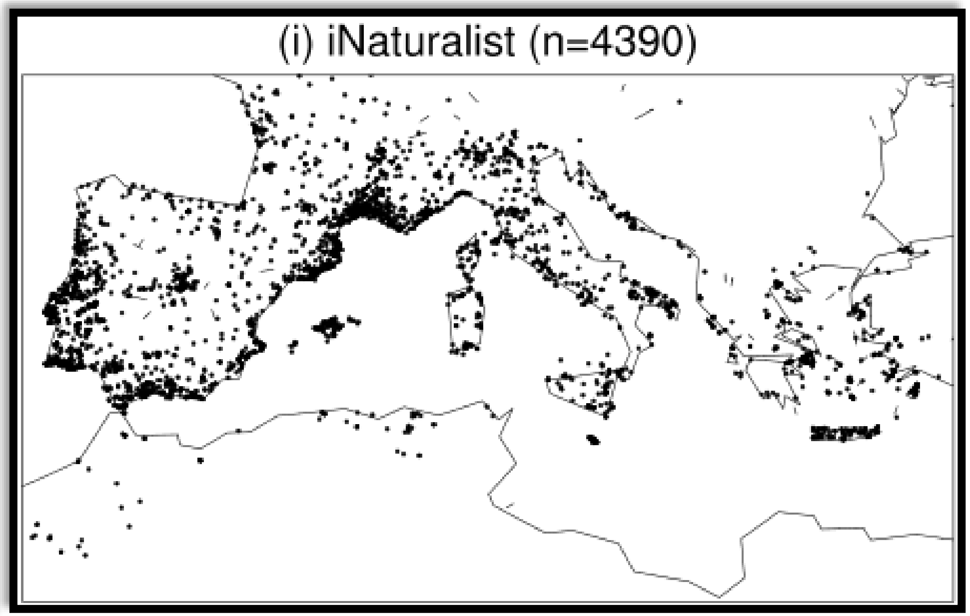
!!	0 TB



Ecological Niche Model

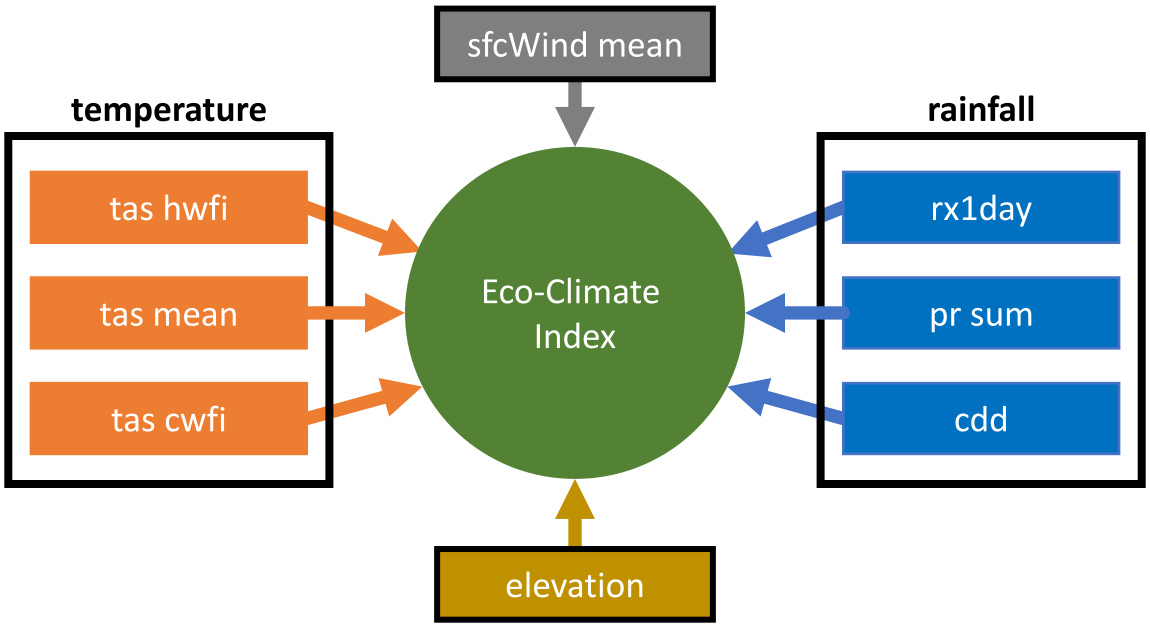
- **A living organism observed at a particular location can be assumed to find the climate of that location favourable**. *Hence, a collection of locations where the organism was observed, can describe the range of climate conditions necessary for its survival.*
- E.g.: **Seed Bug** (*Spilostethus pandurus*) as species, *s*
  - n_s = 4390 Research Grade observations (iNaturalist community, 2023)





Ecological Niche Model

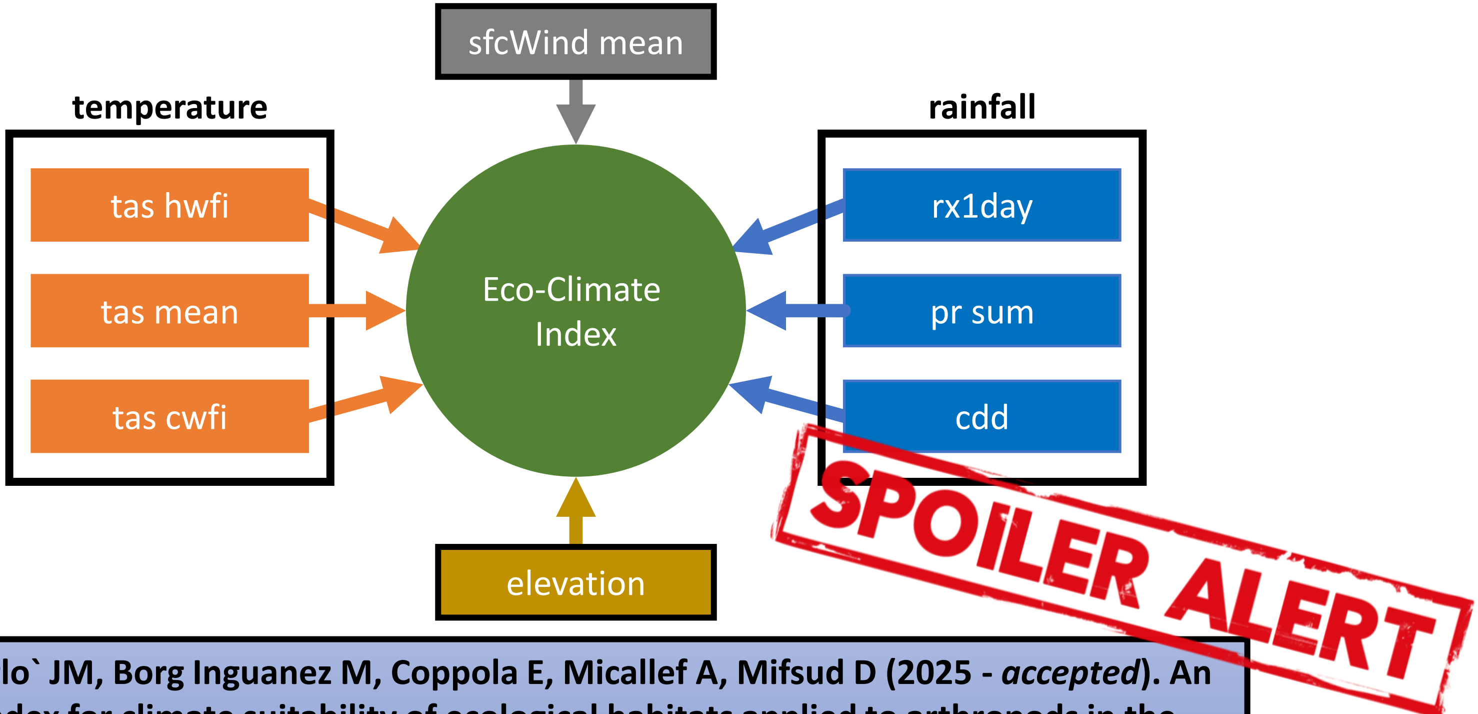
- 8 climate indices ($i = 1 \dots p$) identified that may affect *X. violacea* (s)
- Statistics extracted from index values (x_{sij}) at sampling locations ($j = 1 \dots n_s$):
  - **mean** (μ_{si}), **standard deviation** (σ_{si}),
  - **min** & **max** -> to set a **deviation limit** (L_{si})



Ciarlo` JM, Borg Inguanez M, Coppola E, Micallef A, Mifsud D (2025 - *accepted*). An index for climate suitability of ecological habitats applied to arthropods in the Mediterranean Sea. *Earth System Dynamics*, 16, 1391–1407, https://doi.org/10.5194/esd-16-1391-2025

Ecological Niche Model

- 8 climate indices ($i = 1 \dots p$) identified that may affect *X. violacea* (s)
- Statistics extracted from index values (x_{sij}) at sampling locations ($j = 1 \dots n_s$):
  - **mean** (μ_{si}), **standard deviation** (σ_{si}),
  - **min** & **max** -> to set a **deviation limit** (L_{si})



Ciarlo` JM, Borg Inguanez M, Coppola E, Micallef A, Mifsud D (2025 - *accepted*). An index for climate suitability of ecological habitats applied to arthropods in the Mediterranean Sea. *Earth System Dynamics*, 16, 1391–1407, https://doi.org/10.5194/esd-16-1391-2025

- The **ideality of climate conditions** can be defined as

$$C_{sij} = \begin{cases} 1, & \text{if } x_{sij} - \mu_{si} = 0 \\ 1 - \left| {d_{sij}}/{L_{si}} \right|, & \text{if } x_{sij} - \mu_{si} = d_{sij}\sigma_{si} \\ 0, & \text{if } x_{sij} - \mu_{si} = L_{si}\sigma_{si} \end{cases}$$

- Using a **standardized distance**, $d_{sij} = \frac{x_{sij} - \mu_{si}}{\sigma_{si}}$

$$\boldsymbol{C_{sij} = 1 - \left| \frac{x_{sij} - \mu_{si}}{\sigma_{si}} \right| \frac{1}{L_{si}}}$$

- Defining **the limit as**

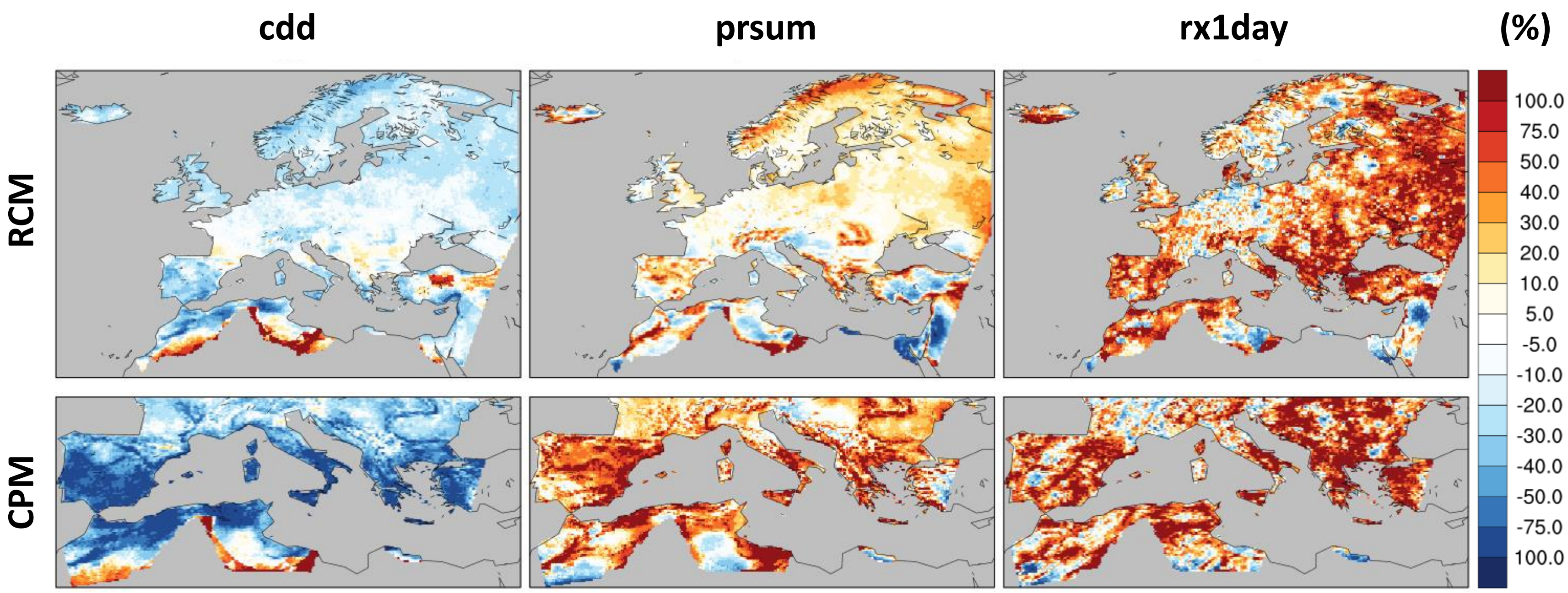
$$L = \max(d_{si,max}, d_{si,min}) \text{ with } \begin{matrix} d_{si,max} = \left| \frac{x_{si,max} - \mu_{si}}{\sigma_{si}} \right| \\ d_{si,min} = \left| \frac{x_{si,min} - \mu_{si}}{\sigma_{si}} \right| \end{matrix}$$

combined into an **<u>Eco-Climate Index</u>**

$$\boldsymbol{E_{sj} = \frac{C_{s1j} \times \cdots \times C_{spj}}{max(C_{s1j} \times \cdots \times C_{spj})}}$$

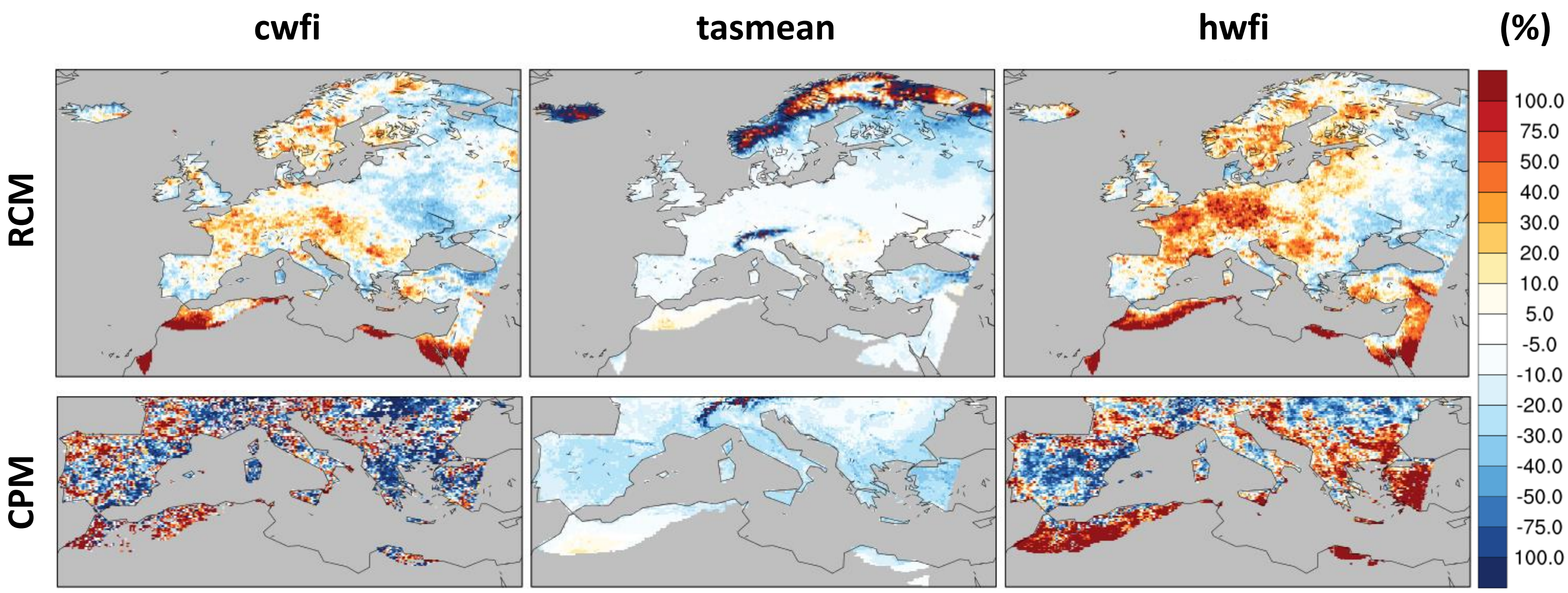
Biases for Climate Indices

	Res.	Data source
OBS	0.25°	E-OBS
RCM	12.5 km	ERAINT CMIP5-EUR-11 (6 members)
CPM	3.4 km	ERA5 RegCM5-0-BATS



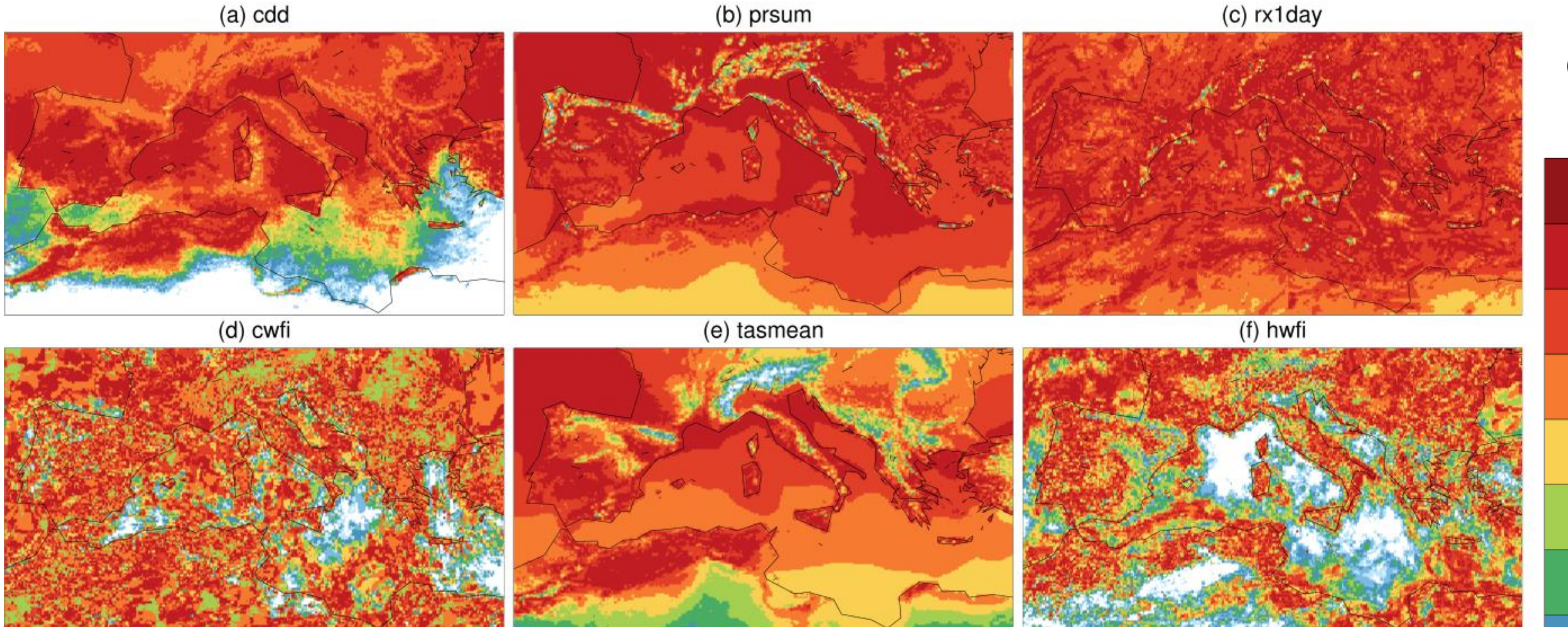
Biases for Climate Indices

	Res.	Data source
OBS	0.25°	E-OBS
RCM	12.5 km	ERAINT CMIP5-EUR-11 (6 members)
CPM	3.4 km	ERA5 RegCM5-0-BATS

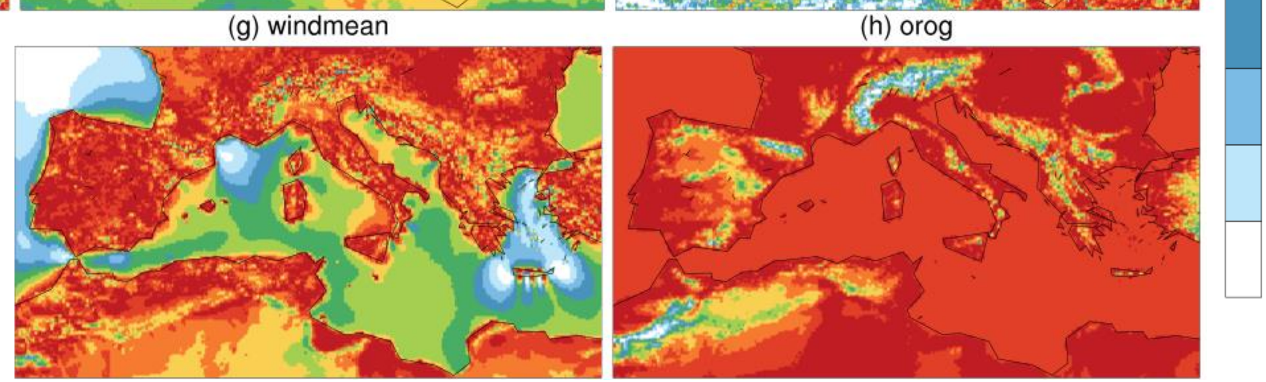


Ideality of Climate Conditions: C_s

Seed Bug (*Spilostethus pandurus*)



cdd	consecutive dry days
prsum	annual rainfall sum
rx1day	maximum 1 day rainfall
cwfi	cold wave frequency
tasmean	mean temperature
hwfi	heat wave frequency
windmean	mean wind speed
orog	elevation



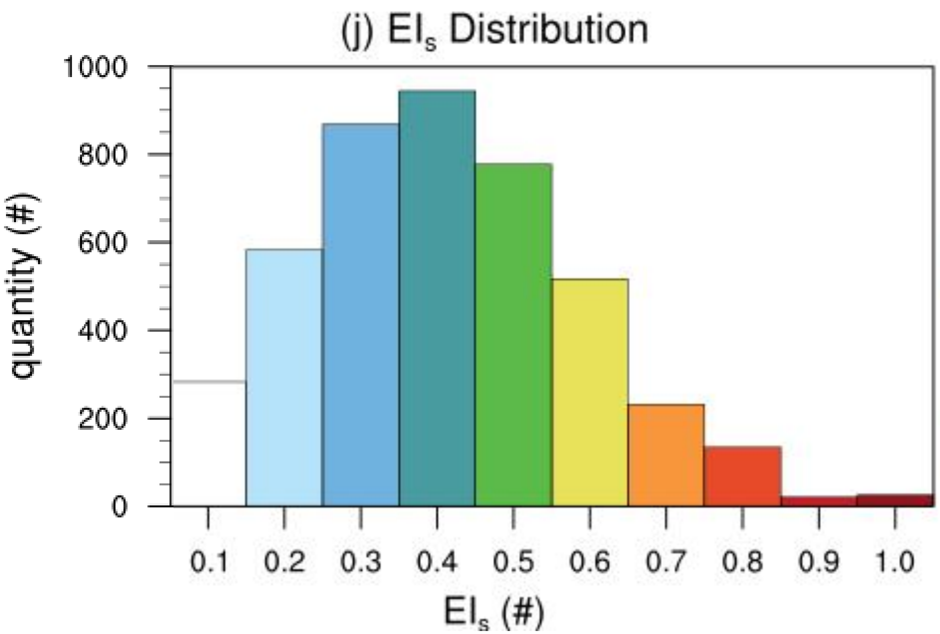
https://doi.org/10.5194/egusphere-2024-1954
Preprint. Discussion started: 18 July 2024

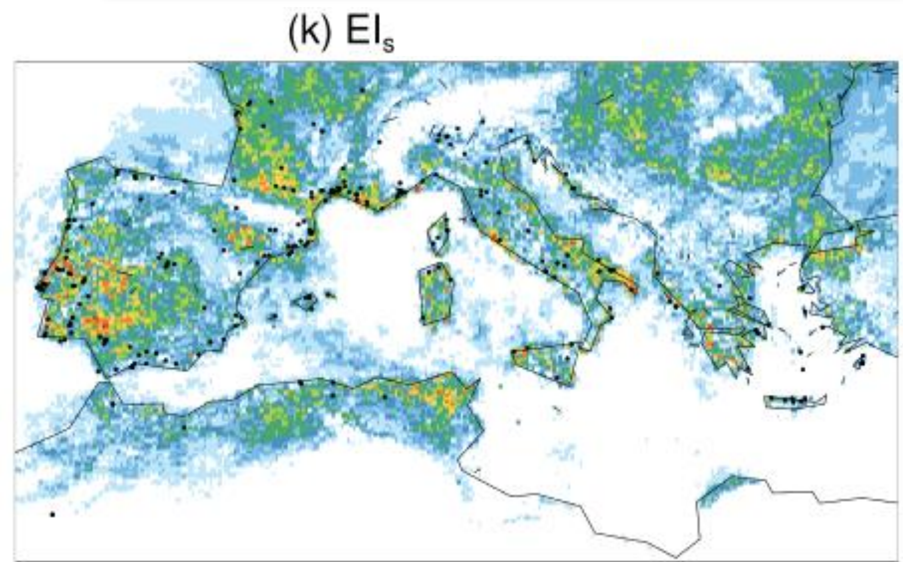
EGUsphere Preprint repository

A climate suitability index for ecological habitats applied to terrestrial arthropods in the Mediterranean Region

James M. Ciarlo'[1,2], Monique Borg Inguanez[3], Erika Coppola[2], Aaron Micallef[4,5], David Mifsud[1]

[1]Institute of Earth Systems, University of Malta, Msida, Malta
[2]Abdus Salam International Centre for Theoretical Physics, Trieste, Italy
[3]Department of Statistics and Operations Research, University of Malta, Msida, Malta
[4]Department of Geosciences, University of Malta, Msida, Malta
[5]Monterey Bay Aquarium Research Institute, Moss Landing, CA, USA



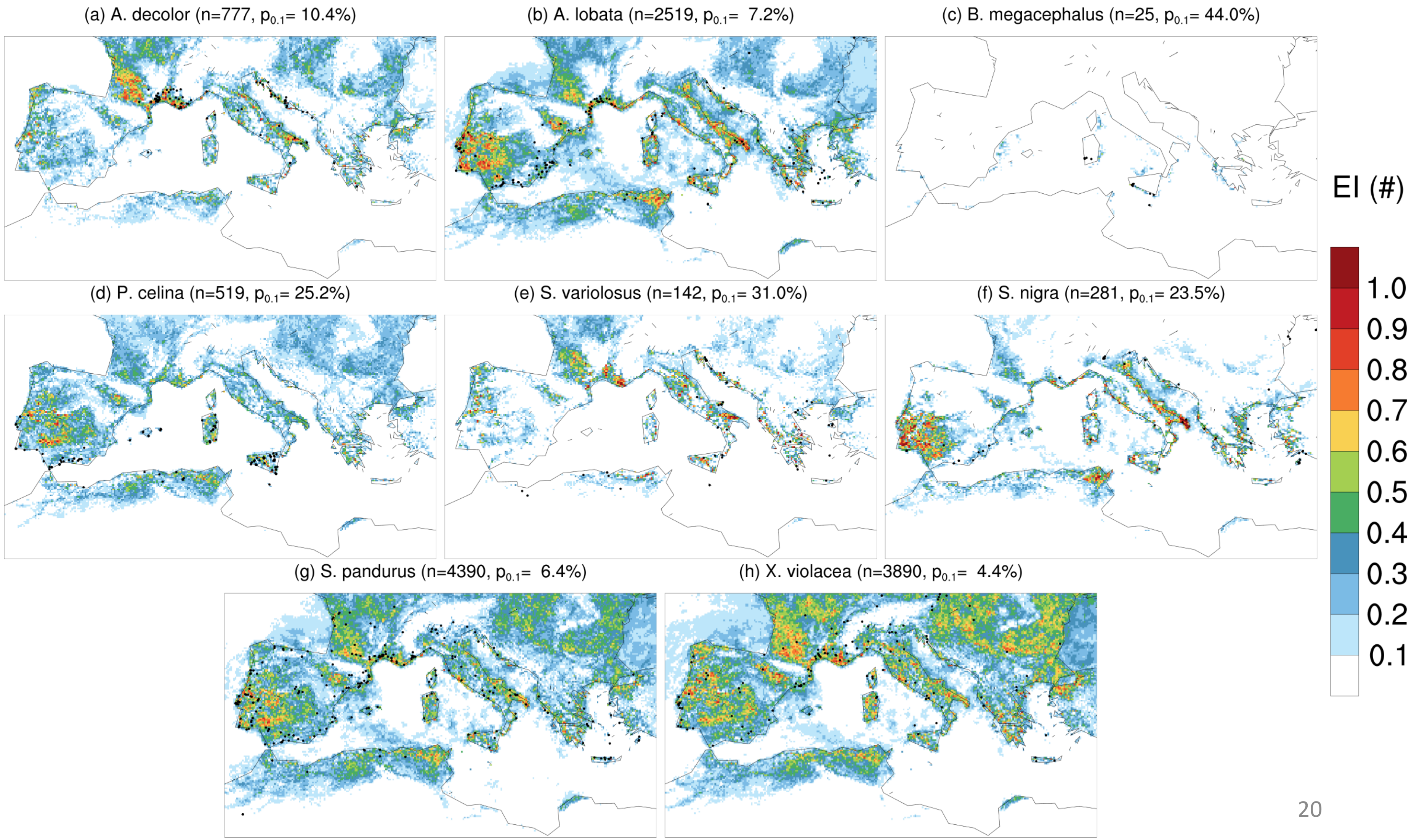


<u>based on Evaluation simulation (1995-2004)</u>

EI$_s$ approaching 1 describes favourable climate

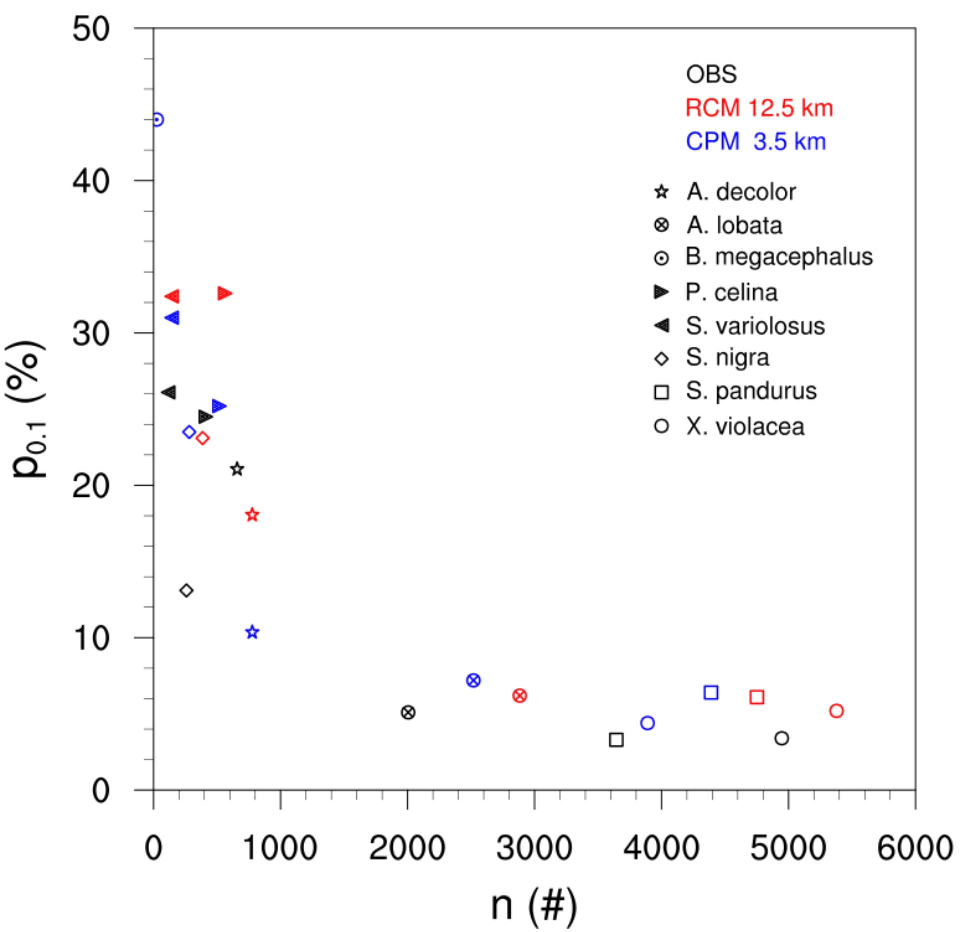
does <u>not</u> imply presence <u>nor</u> account for food source, competitors, predators

Eco-Climate Index: EI_s



Eco-Climate Index

- "effectiveness" of metric, $p_{0.1}$:
  - % of points with $EI_s < 0.1$
- **n_s is more important than horizontal resolution of climate data**



- ***<u>NOTE:</u>*** *This is a proof-of-concept for the method. Do not interpret as actual habitats.*
- *For a species-specific assessment, identify independent climate indices suitable for that organism.*

Regional Paleoclimate Modelling

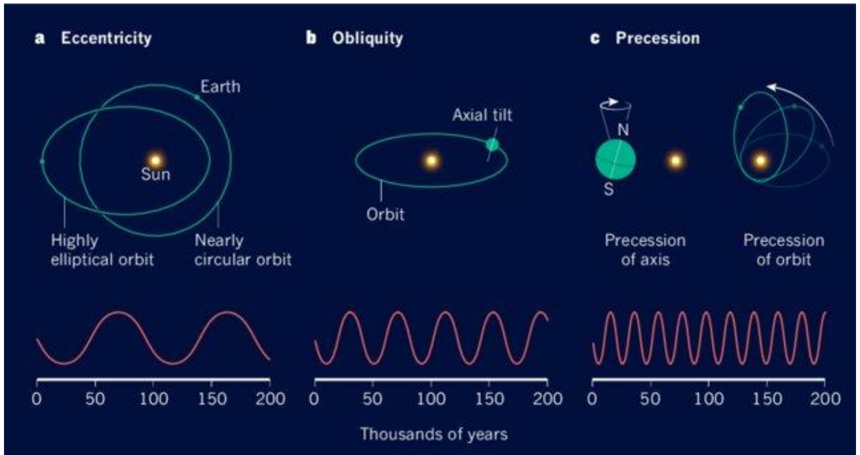
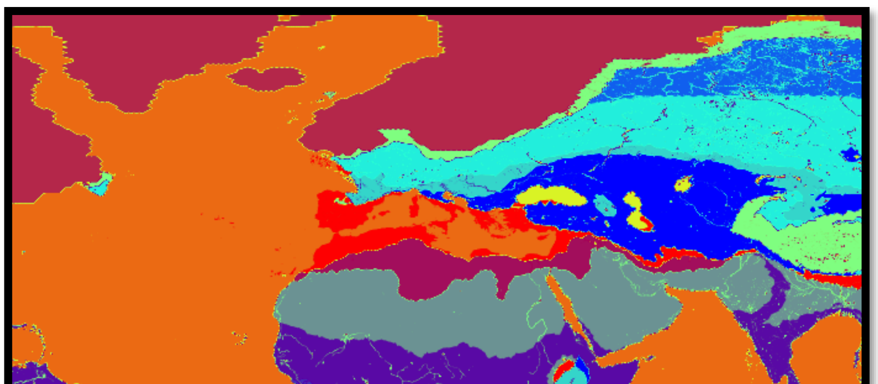


Image Source: Maslin, M. Forty years of linking orbits to ice ages. *Nature* **540**, 208–209 (2016). https://doi.org/10.1038/540208a

Vegetation categories
[adjusted with Köppen–Geiger classification]



- **RegCM5 Paleoclimate**
  - Milankovitch Cycles
    - Orbit shape (*eccentricity*)
    - Axial Tilt (*obliquity*)
    - Axial Wobble (*precession*)
  - Solar cycle

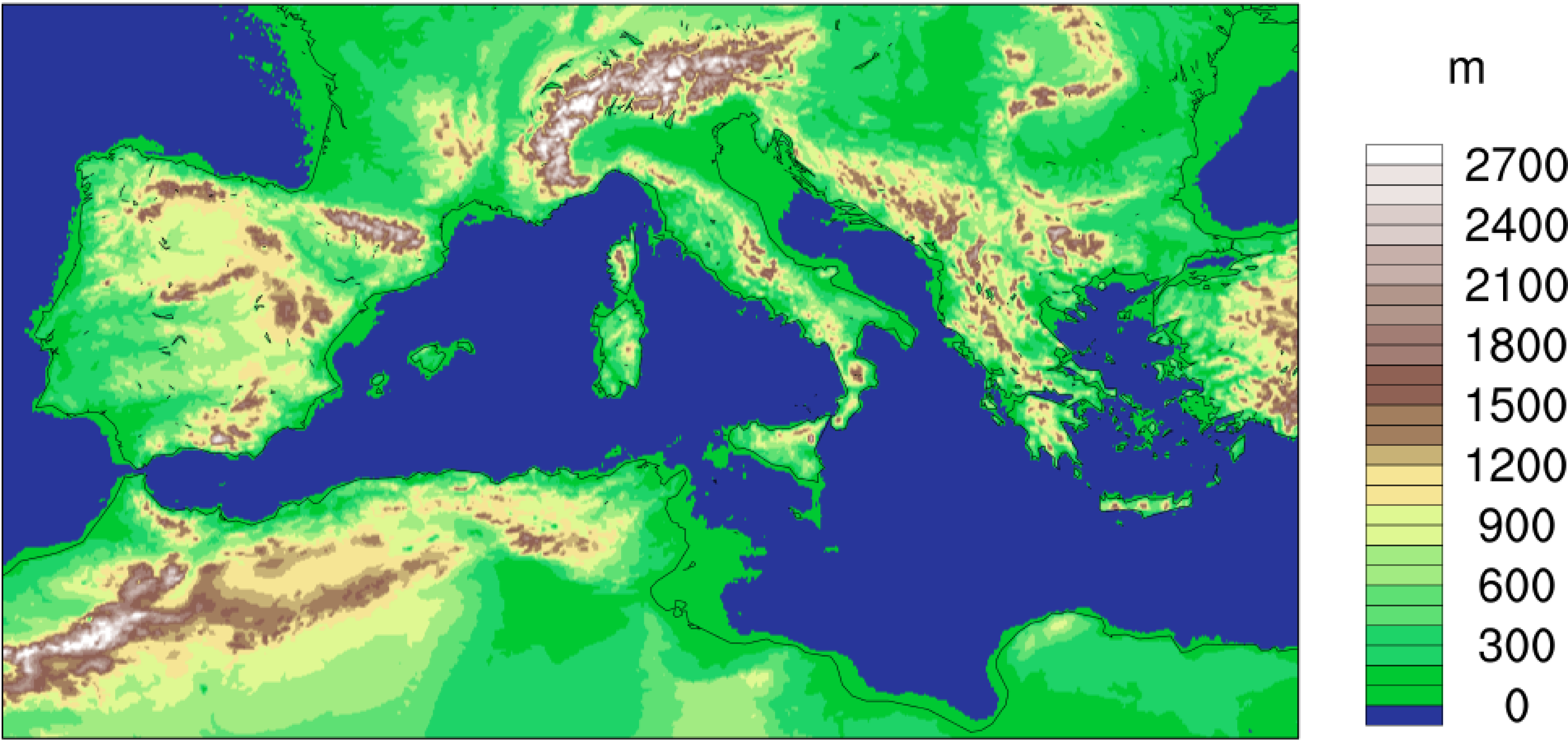
  PhD: Del Gobbo (2021)

  Special thanks to G. Giuliani
- **Gas concentrations**

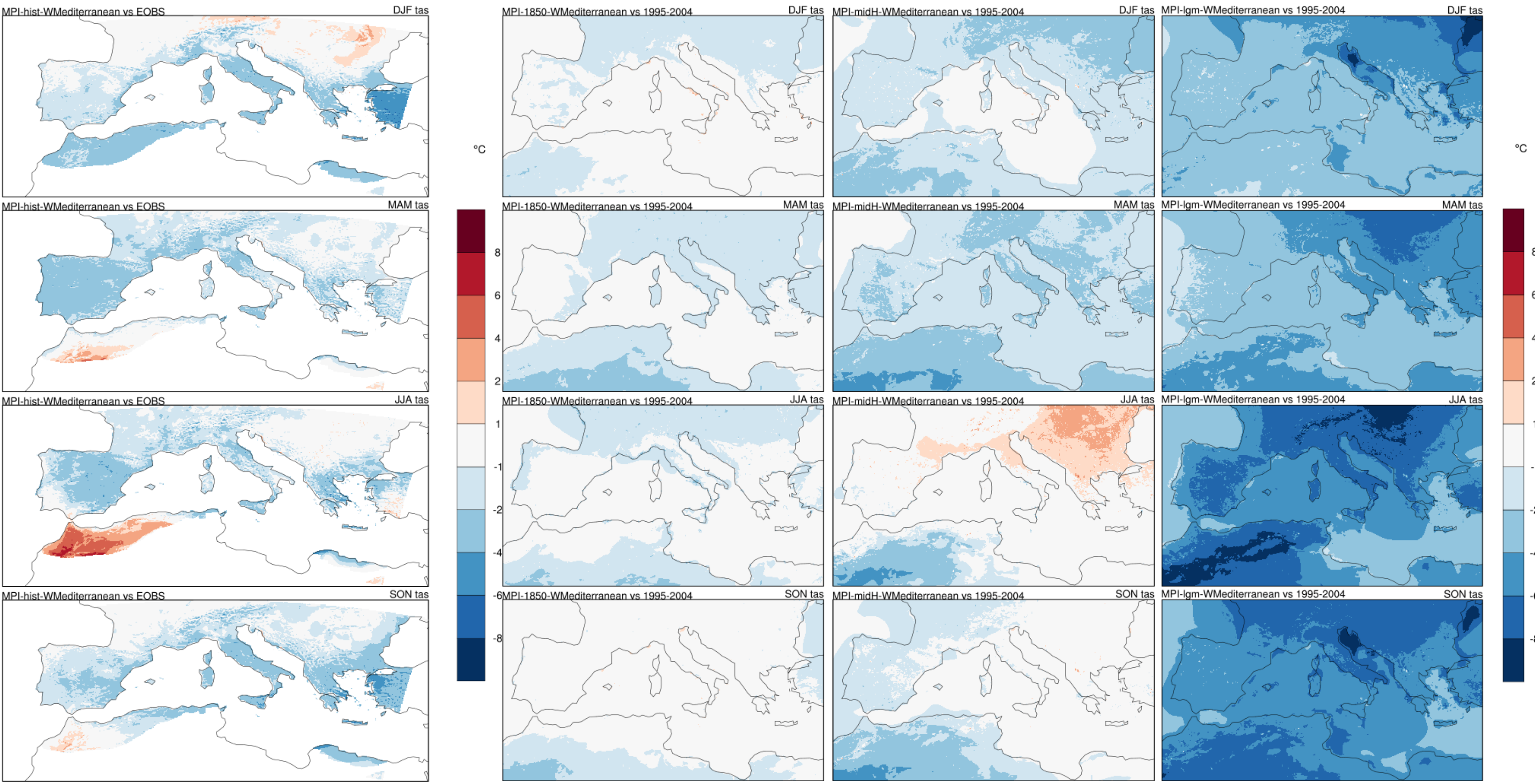
  https://pmip4.lsce.ipsl.fr/doku.php/exp_design:lgm
- **Terrain adjustments**
  - Land-use (BATS)
    - Vegetation categories based on Köppen–Geiger classification.
  - Elevation (ICE7G), soil

The Last Glacial Maximum

21,000 years ago / 19,000 BCE

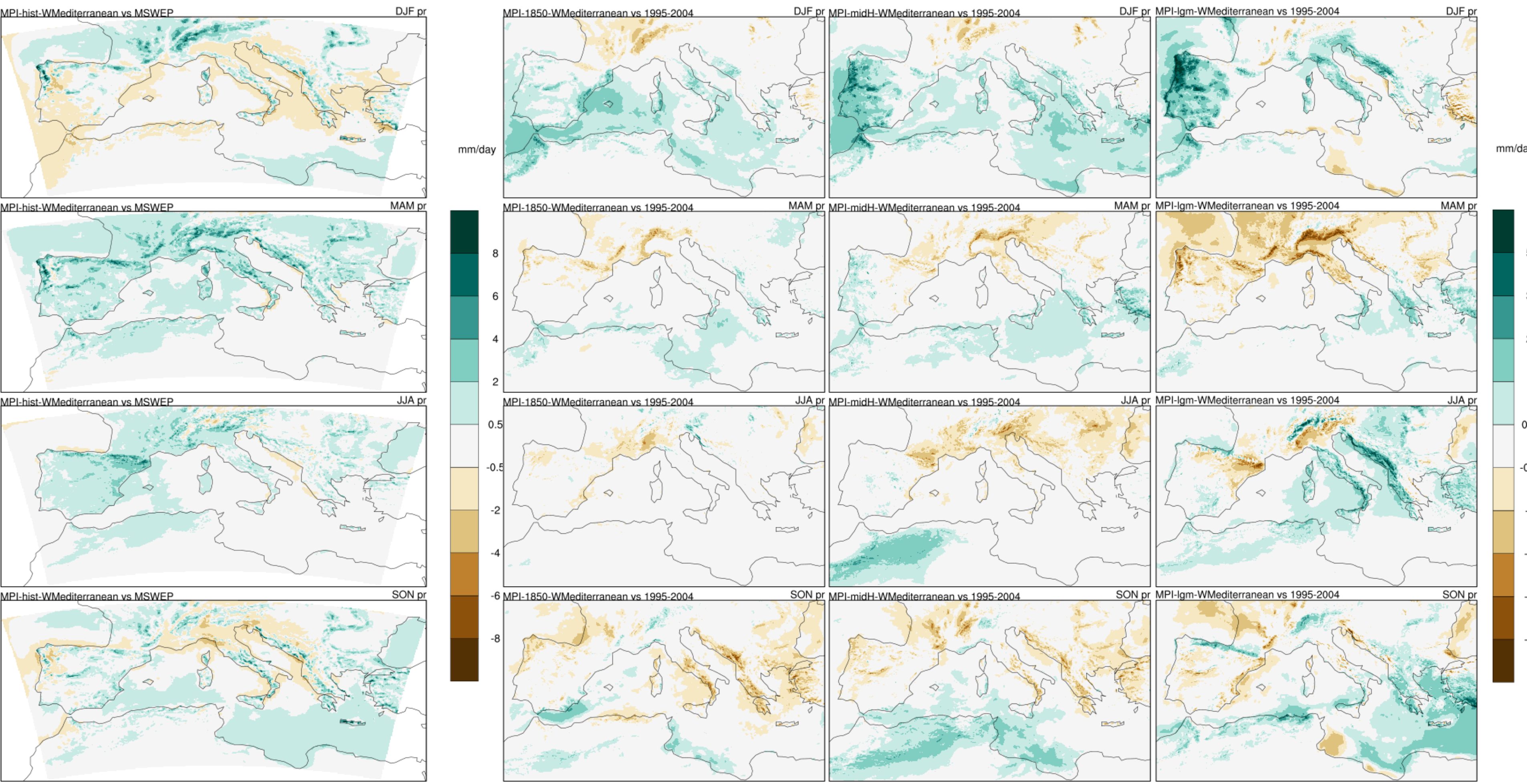


Air temperature conditions



bias** (v. EOBS)*   ***change: 1850s   mid-Holocene   lgm

Precipitation bias and changes



bias** (v. MSWEP)* ***change: 1850s mid-Holocene lgm

Paleoclimate changes in EI_s

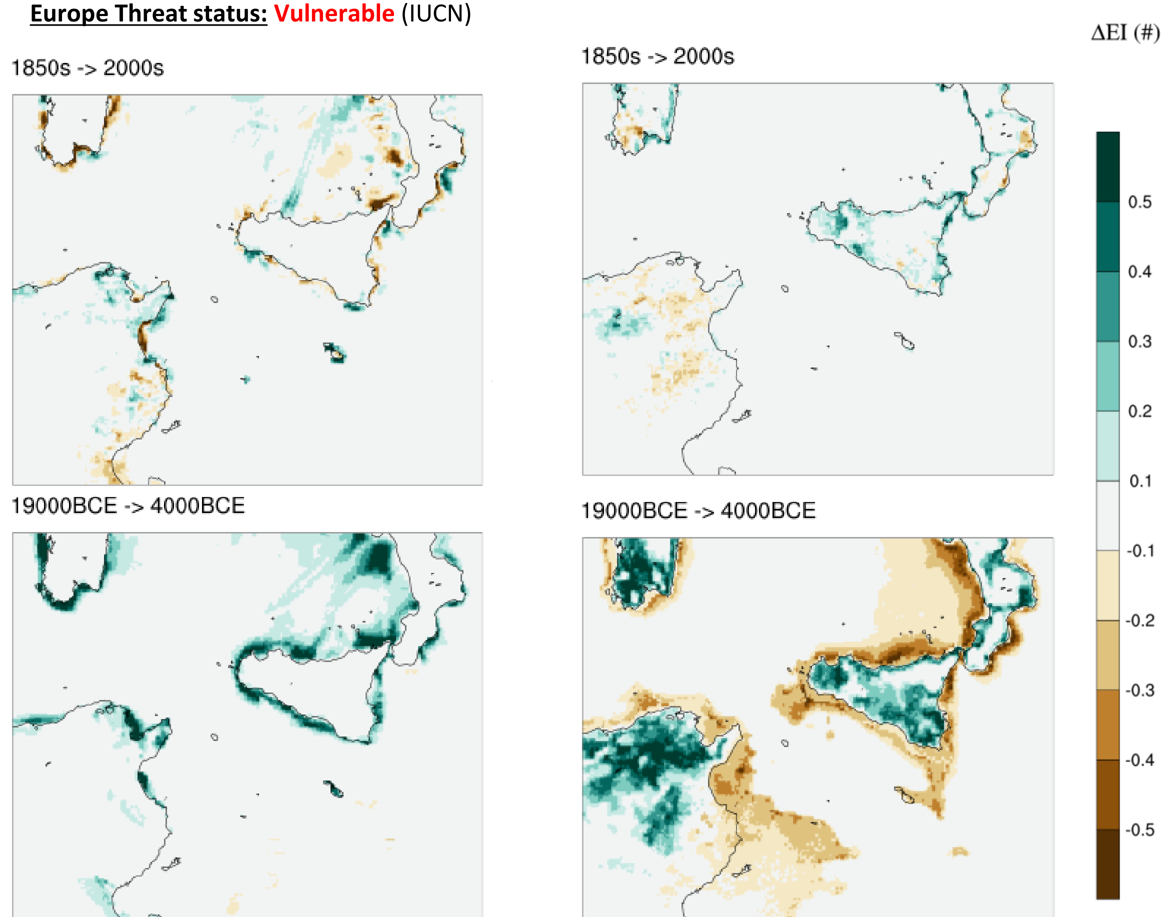
Sand Cricket (*Brachytrupes megacephalus*)
© Giacomo Gola, CC BY-NC
Europe Threat status: Vulnerable (IUCN)

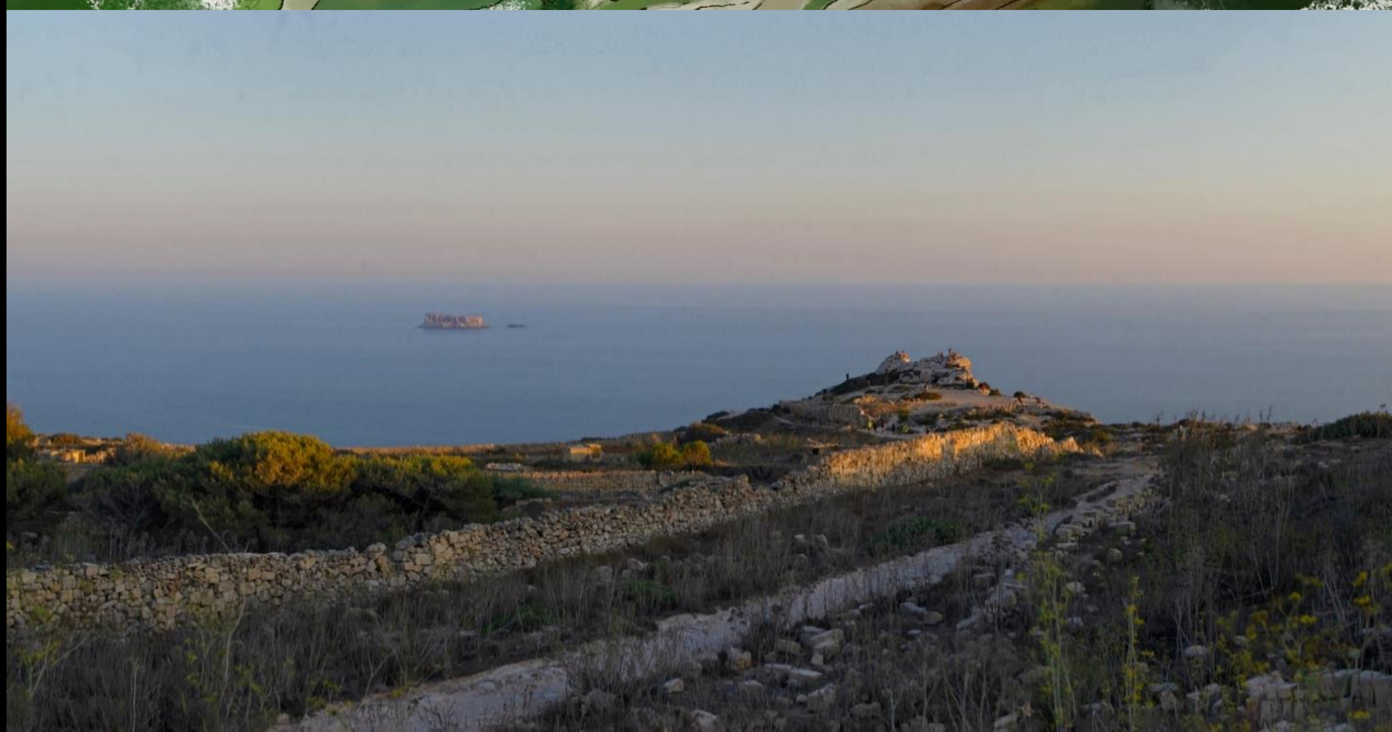
Island Bluetail Damselfly (*Ischnura genei*)
© fred_jacq, (CC-BY-NC)

- Green: habitat gain
- Brown: habitat loss

- **gains do NOT imply a realized niche (*actual habitat*)**
- EI_s does account for non-climatic factors:
  food source, competitors, predators, adaptation, …

- large changes suggest greater climatological pressures lead to:
  - Adaptation, migration, or extinction.





The Ant!

https://www.um.edu.mt/projects/paleosim

james.ciarlo@um.edu.mt

References

- Ciarlo` JM, Borg Inguanez M, Coppola E, Micallef A, Mifsud D (2025 - *accepted*). An index for climate suitability of ecological habitats applied to arthropods in the Mediterranean Sea. Earth System Dynamics
- Coppola E, Giorgi F, Giuliani G, et al. (2024). The Fifth Generation Regional Climate Modeling System, RegCM5: the first CP European wide simulation and validation over the CORDEX-CORE domains. ESS Open Archive. DOI: 10.22541/essoar.170542078.80092084/v1
- Del Gobbo C (2021). Use of the Regional Climate Model RegCM4 to assess circulation, precipitation and temperature patterns sustaining the Tagliamento glacier (southeastern Alps) at 21 ka (Doctoral thesis). Università degli Studi di Trieste, Trieste, Italy. Available from https://arts.units.it/handle/11368/2988360
- Giorgi F, Coppola E, Giuliani G, Ciarlo JM, et al (2023). The Fifth Generation Regional Climate Modeling System, RegCM5: Description and Illustrative Examples at Parameterized Convection and Convection-Permitting Resolutions. *JGR Atmospheres*, 128(6), e2022JD038199. https://doi.org/10.1029/2022JD038199
- iNaturalist community (2023). Complete Research Grade Observations. Exported from https://www.inaturalist.org on [11/08/2023].