XVI OPTIMA Meeting

Climate change in a Mediterranean island biodiversity hotspot and its impact on the Cretan endemic flora

Kougioumoutzis K., Kokkoris I.P., Panitsa M., Strid A., Trigas P. & Dimopoulos, P.

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Agricultural University of Athens, Greece

HELLENIC REPUBLIC
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ΓΕΩΠΟΝΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
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UNIVERSITY OF PATRAS

Introduction

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Anthropocene → human-induced temperature & sea-level rise → alter planetary processes

(proposed new geological epoch)

alter planetary processes → global ecosystem health → shifts in biotic composition and linkage disruption → Novel adaptive matrix → Path to extinction → Unprecedented extinction rates (6th MEE?)

Unprecedented extinction rates → More prominent → Endemic taxa; Mountain ecosystems; Islands

Extinction hotspots

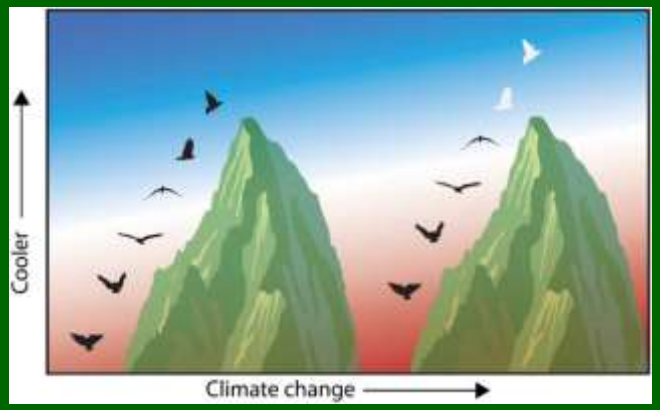
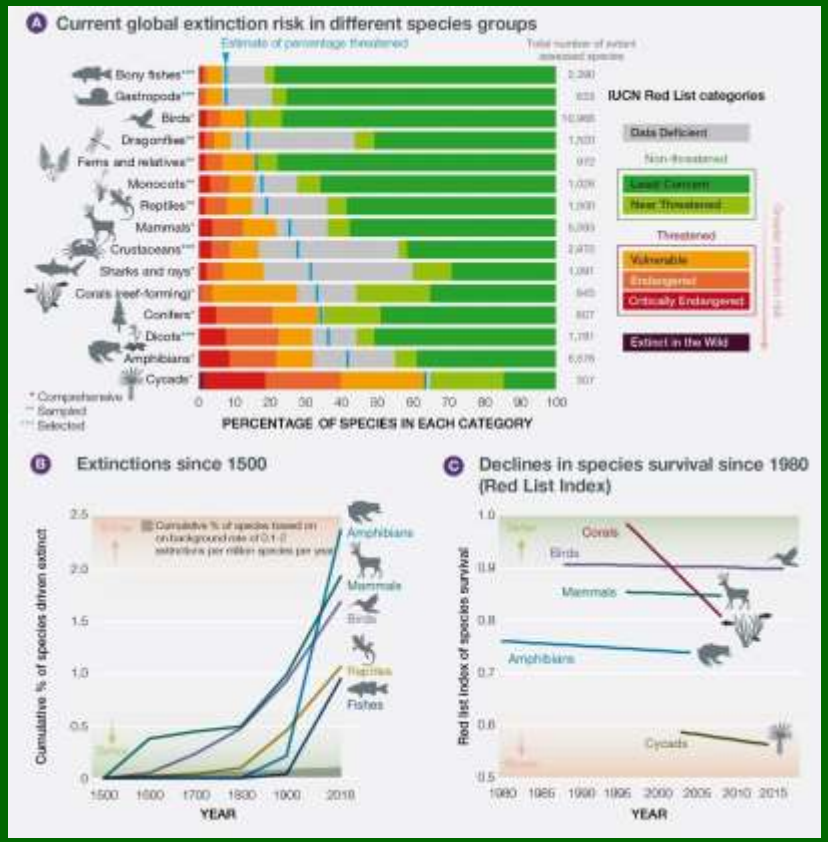


Figure from Urban (2018). Escalator to extinction. *PNAS*, *115*(47), 11871-11873.

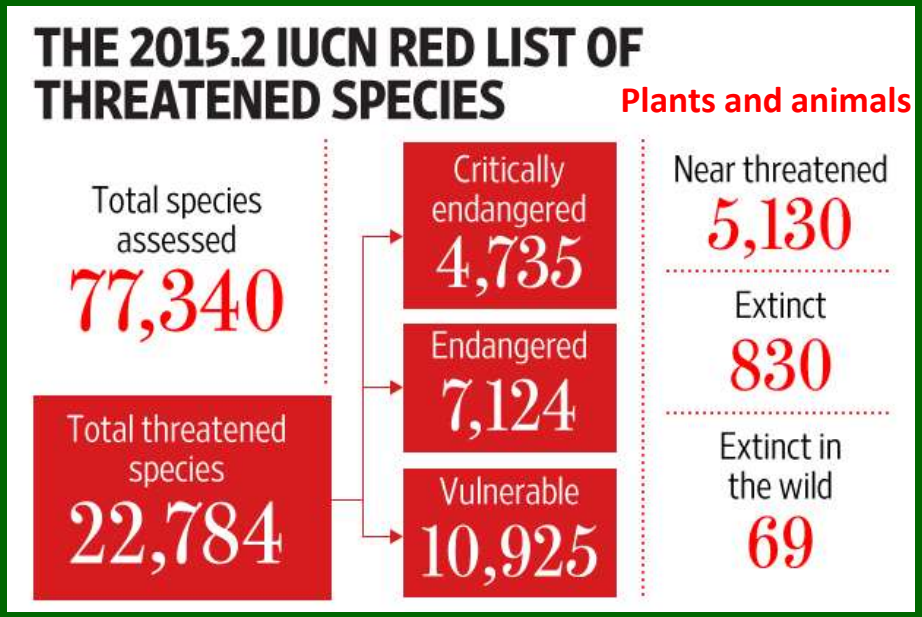
Introduction

- Global projections?



Diaz et al. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

~ 1,000,000 taxa facing extinction (Diaz et al., 2019)



IUCN (2015). Update of the Red List of Threatened Species.

> 50% of the threatened (CR, EN & VU) taxa are plants

118 of the 830 extinct taxa και **35** of the 69 extinct in the wild

199 plant taxa are considered CR(PE) [184 CR(PE) &15 CR(PEW)]

Introduction

- Why focus on the Mediterranean Basin?

Second largest terrestrial biodiversity hotspot in the world

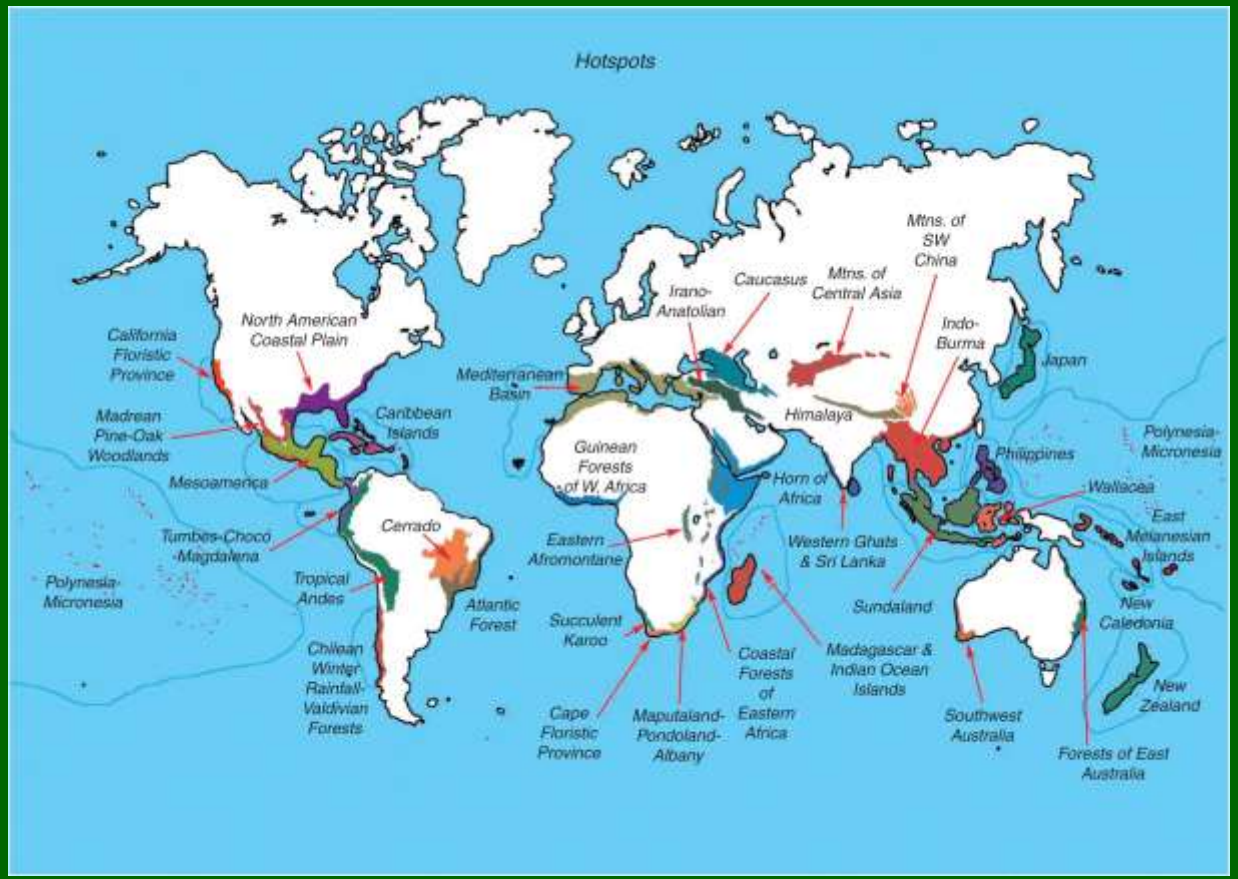


Figure from: Harrison & Noss (2017). Endemism hotspots are linked to stable climatic refugia. *AoB*, *119*(2), 207-214.

Introduction

- Why focus on the Mediterranean Basin?

  Second largest terrestrial biodiversity hotspot in the world – hotspot of vulnerable species

  10,000 islands and islets, numerous mountains

  Biogeographically complex, with high levels of endemism and diversification

  12,500 endemics, most of them having an extremely narrow geographical range

  High insular plant endemism (ca. 9-18%) – up to 40% in the high altitude zone of their mountain ranges

  Several islands constitute biodiversity hotspots

Harrison & Noss (2017). Endemism hotspots are linked to stable climatic refugia. *AoB*, *119*(2), 207-214.
Médail (2017). The specific vulnerability of plant biodiversity and vegetation on Mediterranean islands in the face of global change. *REC*, *17*(6), 1775-1790.
Médail & Myers (2004) Mediterranean basin. Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions, 144-147.
Pacifici et al. (2015). Assessing species vulnerability to climate change. *NCC*, *5*(3), 215.
Rundel et al. (2016) Mediterranean biomes: Evolution of their vegetation, floras, and climate. *AREES*, **47**, 383-407

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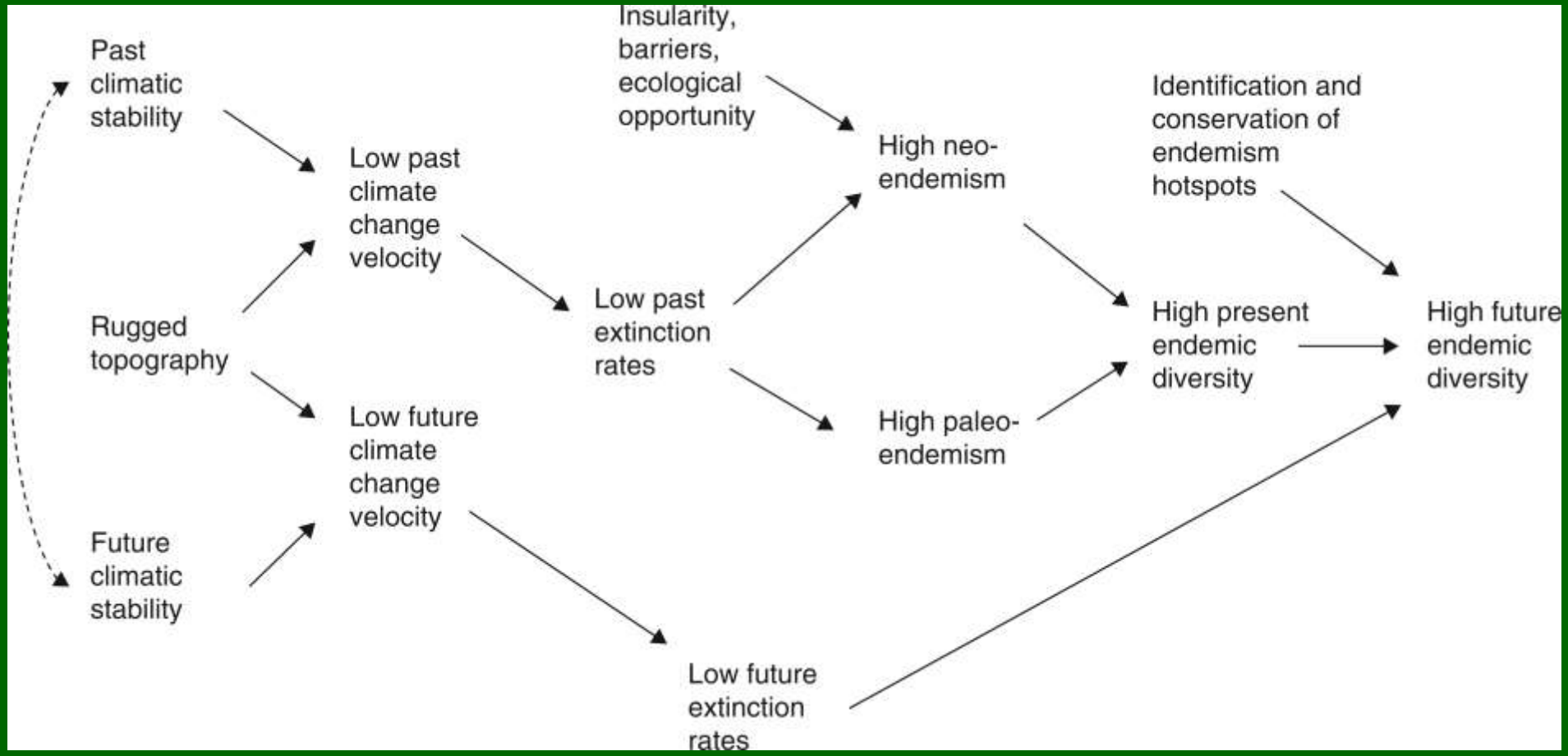

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Médail & Diadema (2009). Glacial refugia influence plant diversity patterns in the Mediterranean Basin. *JoB*, *36*(7), 1333-1345.
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Introduction

1 Beira litoral
2 Estramadura
3 Algarve
4 Cadiz/Algeciras region
5 Serrania de Ronda
6 Sierra Cazorla/Segura
7 Sierra Nevada/Gata
8 Balearic Islands
9 Valencia region
10 Ebro Valley
11 Sistema central
12 S. Pyrenees
13 S.E. Pyrenees
14 S. Cévennes
15 Mont Ventoux
16 E. Provence
17 Maritime Alps
18 Corsica
19 Sardinia
20 Alpi Apuani
21 Campania
22 S. Apennines
23 Sicilia
24 S. Calabria
25 Gargano
26 N. Istria
27 Velebit Mountains
28 S. Bosnia/Biokovo
29 Montenegro
30 Olympe/Katalympos
31 C. Greece (Pindos)
32 Peloponnese
33 Crete
34 Chalkidiki peninsula
35 Izmit region
36 Boz/Aydin dag
37 S.W. Anatolia
38 C. Taurus
39 E. Taurus
40 Amanus
41 Lebanon range
42 Israel/Palestine
43 Cyprus
44 Cyrenaic (Lybia)
45 J. Zaghouan/Cap Bon
46 Petite Kabylie/de Collo
47 Grande Kabylie
48 Tlemcen Mountains
49 Rif Mountains
50 Middle Atlas
51 High Atlas
52 Souss/W. Anti Atlas

Figure from: Médail & Diadema (2009). Glacial refugia influence plant diversity patterns in the Mediterranean Basin. *JoB*, *36*(7), 1333-1345.

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High insular plant endemism (ca. 9-18%) – up to 40% in the high altitude zone of their mountain ranges

Several islands constitute biodiversity hotspots and climate refugia

Among the regions expected to experience the largest changes in climate

These impacts will be more prominent on islands and mountain summits

But very few extinctions have been documented (22 taxa)

Domina et al. (2015). Taxonomy and conservation in Higher Plants and Bryophytes in the Mediterranean Area. *Biodiversity Journal*, *6*(1), 197-204.

Introduction

- Why focus on Crete?

Fifth largest Mediterranean island →
- Long-lasting human presence
- Intense grazing
- Massively cultivated

Hottest endemic hotspot of the Mediterranean Basin (17.6% endemism & 395 endemic taxa)

Long-term geographical isolation, high environmental and topographical heterogeneity

Roughly 30% of Cretan SIE have been assessed and only five are considered CR

Introduction

- Aims

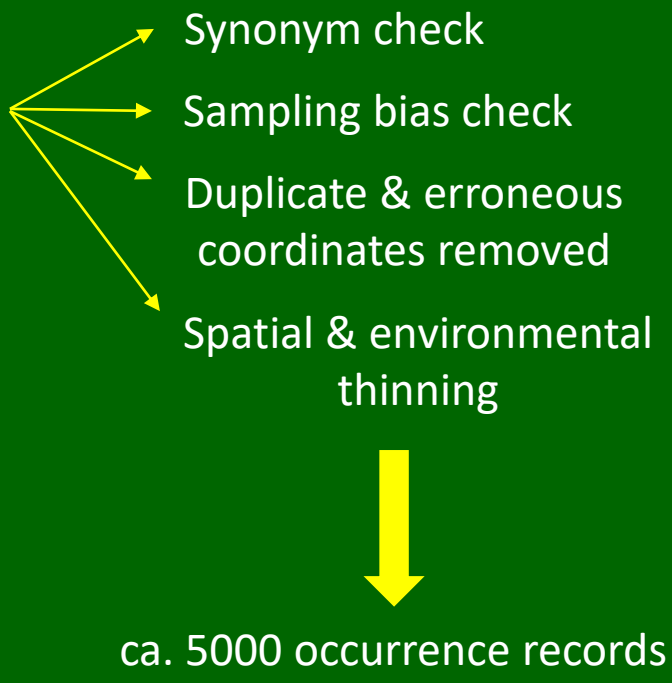
- Will climate change affect the Cretan SIE?
- What is the extinction risk status of every Cretan SIE?
- Do species with narrower niches have higher extinction probability?
- Was Crete climatically stable?
- Which areas currently act as endemic hotspots in Crete?
- Are they going to shift in the future?
- Which areas will experience the largest change in SIE community assembly?
- Do NATURA 2000 sites adequately protect the most vulnerable of the Cretan SIE?
- Which species should be of conservation priority based on their evolutionary distinctiveness?

Materials and Methods

Materials and Methods

- Species occurrence data

ca. 8800 occurrence records



Materials and Methods

- Environmental data

current and future climate data

- Three GCMs (BCC, CCSM4 & HadGEM2-ES)
- Two RCPs (2.6 and 8.5)
- Two databases (WorldClim & CHELSA)
- 30 arc-secs resolution

"traditional" climate variables

'envirem' R package

additional climate variables

Title & Bemmels (2018). ENVIREM: an expanded set of bioclimatic and topographic variables increases flexibility and improves performance of ecological niche modeling. *Ecography*, *41*(2), 291-307.

Materials and Methods

- Environmental data

topographical and soil data

Soil pH at varying depths

Elevation, slope, aspect, topographical position index, terrain ruggedness index, heat load index

https://land.copernicus.eu/
Evans JS (2019). *spatialEco*. R package version 1.2-0, https://github.com/jeffreyevans/spatialEco.
Hengl et al. (2017) SoilGrids250m: Global gridded soil information based on machine learning. *PLoS one*, **12**, e0169748

Materials and Methods

- Environmental data

Climate, topographical and soil data

Only seven variables were not highly correlated (Spearman rho < 0.7 & VIF < 5)

Dormann et al. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, *36*(1), 27-46.
Naimi et al. (2014) Where is positional uncertainty a problem for species distribution modeling? *Ecography*, **37**, 191–203.
Rogerson (2001). Statistical Methods for Geography. London: Sage.

Materials and Methods

- Phylogenetic data

"supertree" approach → GBMB megaphylogeny
"supertree" approach → sPlot framework

Appended any missing Cretan SIE next to a randomly selected congener

Pruned the phylogeny to the Cretan SIE

Bruelheide et al. (2019). sPlot–A new tool for global vegetation analyses. *Journal of Vegetation Science*, *30*(2), 161-186.
Magallón et al. (2015). A metacalibrated time-tree documents the early rise of flowering plant phylogenetic diversity. *New Phytologist* **207**: 437–453.
Maitner et al. (2018). The bien r package: A tool to access the Botanical Information and Ecology Network (BIEN) database. *MEE*, *9*(2), 373-379.

Materials and Methods

- Phylogenetic data

"supertree" approach

- GBMB megaphylogeny
- sPlot framework
- Evolutionary Distinctiveness (ED)
- Evolutionary Distinct Globally Endangered (EDGE)

$$\mathbf{EDGE} = ln(1 + ED) + GE \times ln(2)$$

LC = 0
NT = 1
VU = 2
EN = 3
CR = 4

Isaac et al. (2007). Mammals on the EDGE: conservation priorities based on threat and phylogeny. *PloS one*, *2*(3), e296.

Materials and Methods

- Species distribution modeling

Three different modeling algorithms

Pseudo-absence generation (PAs)
- Equal prevalence
- 19.8 km min distance — median autocorrelation
- 1000 PAs per species

For species with < 10 records → Ensemble of Small Models (ESM) framework

Predictive performance evaluated via TSS metric
- Repeated split-sampling (10 times)
- 80-20 split (calibration-evaluation)
- Null model significance testing

Allouche et al. (2006) Assessing the accuracy of species distribution models: Prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology*, **43**, 1223–1232.
Raes & ter Steege. (2007) A null-model for significance testing of presence-only species distribution models. *Ecography*, **30**, 727–736.

Materials and Methods

- Species distribution modeling

Model projection

- Models with TSS < 0.8 were discarded
- Binary transformation based on TSS score as threshold
- Conservative approach (Clamping mask values > 0)
- Urban and suburban areas mask
- Limited dispersal capacity

Araújo et al. (2019). Standards for distribution models in biodiversity assessments. Science Advances, 5(1), eaat4858.
Elith et al. (2010) The art of modeling range-shifting species. *MEE*, **1**, 330–342.
Tuanmu & Jetz (2014). A global 1-km consensus land-cover product for biodiversity and ecosystem modeling. *GEB*, *23*(9), 1031-1045.

Materials and Methods

- Hotspots analysis

  Stacked the final binary maps of all SIE

  Potential hotspots ⟶ 20% of cells with suitable environmental conditions

  Significant differences between current and future environmental conditions

  Identified sites with great compositional turnover in a Generalized Dissimilarity Modeling (GDM) framework

Fitzpatrick et al. (2013) Environmental and historical imprints on beta diversity: insights from variation in rates of species turnover along gradients. *Proceedings. Biological sciences*, 280, 20131201.
Manion et al. (2018) gdm: Generalized Dissimilarity Modeling. R package version 1.3.7.

Materials and Methods

- Bioregionalization

GDM results → Fuzzy & hierarchical clustering (Silhouette method) → Biogeographical compartments

For every GCM/RCP

Similarity via V-measure

Nowosad & Stepinski (2018). Information-theoretical approach to measuring landscape complexity. *BioRxiv*, 383281.
Rosenberg & Hirschberg (2007). V-measure: A conditional entropy-based external cluster evaluation measure. In *Proceedings of the 2007 joint conference on empirical methods in natural language processing and computational natural language learning (EMNLP-CoNLL)* (pp. 410-420).

Results - Discussion

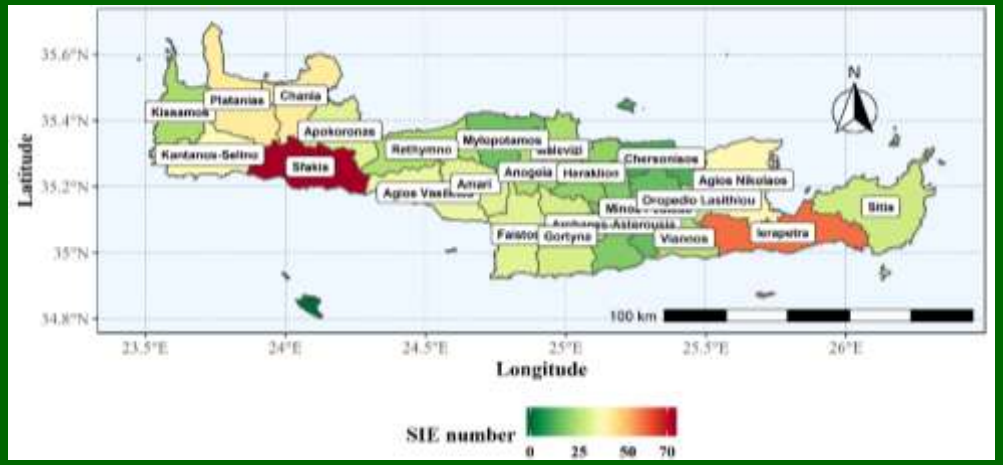
Results - Discussion

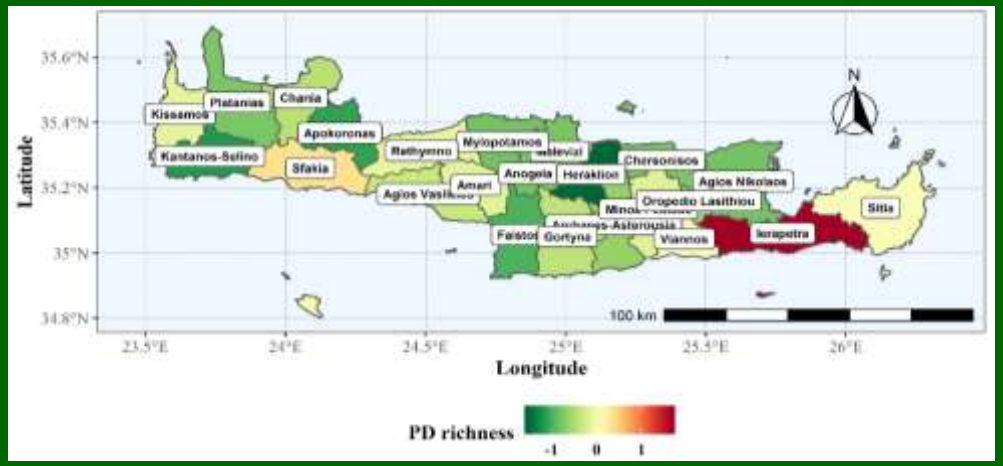
- Which areas are more diverse?

Mountainous areas in W & E Crete

Ierapetra is the only region to host a phylogenetically overdispersed SIE flora

[A result of ecogeographical isolation due to ecological release leading to habitat specialization?]





Results - Discussion

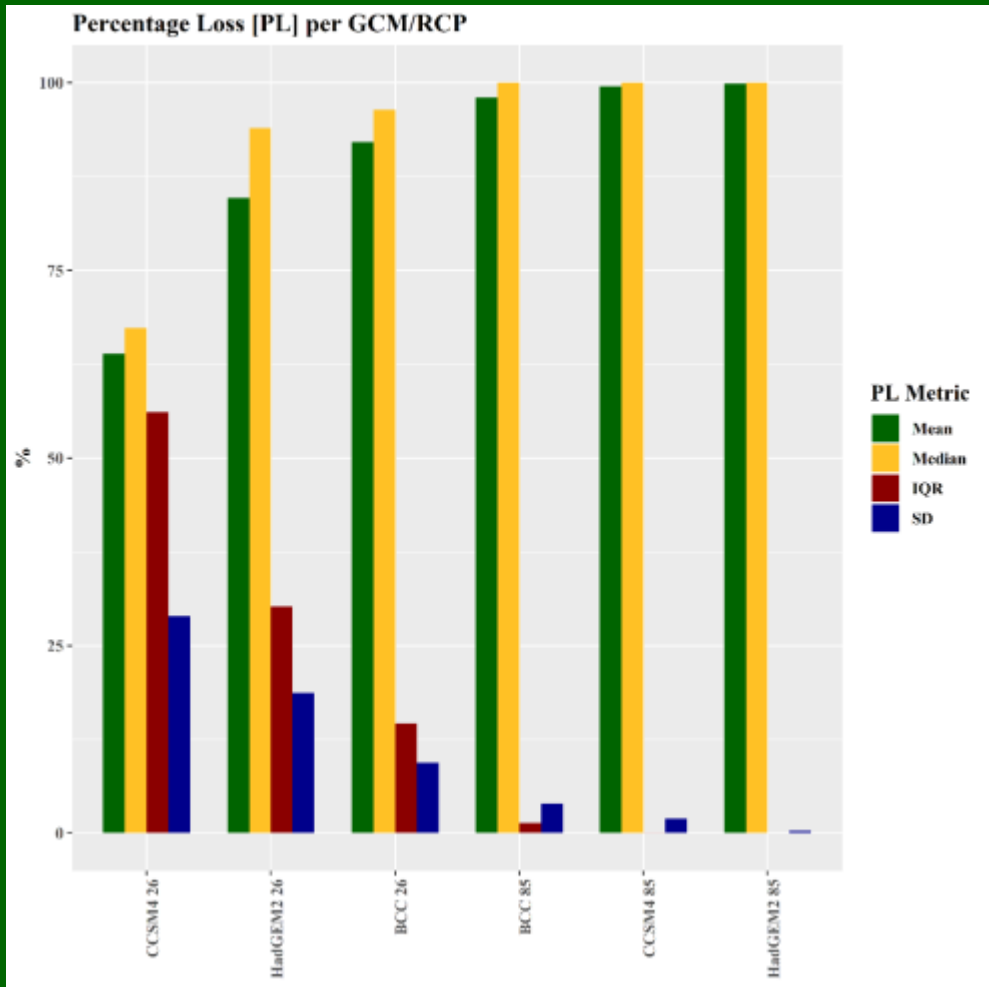
- Species distribution modeling

Models had sufficient predictive power (TSS ≥ 0.8 – median TSS: 0.945)

Median Percentage Loss per GCM/RCP: 67.31 – 100.00

Precipitation-related variables had the highest contribution for most species (54.4%)

All models were found to outperform the null expectation at $P < 0.001$



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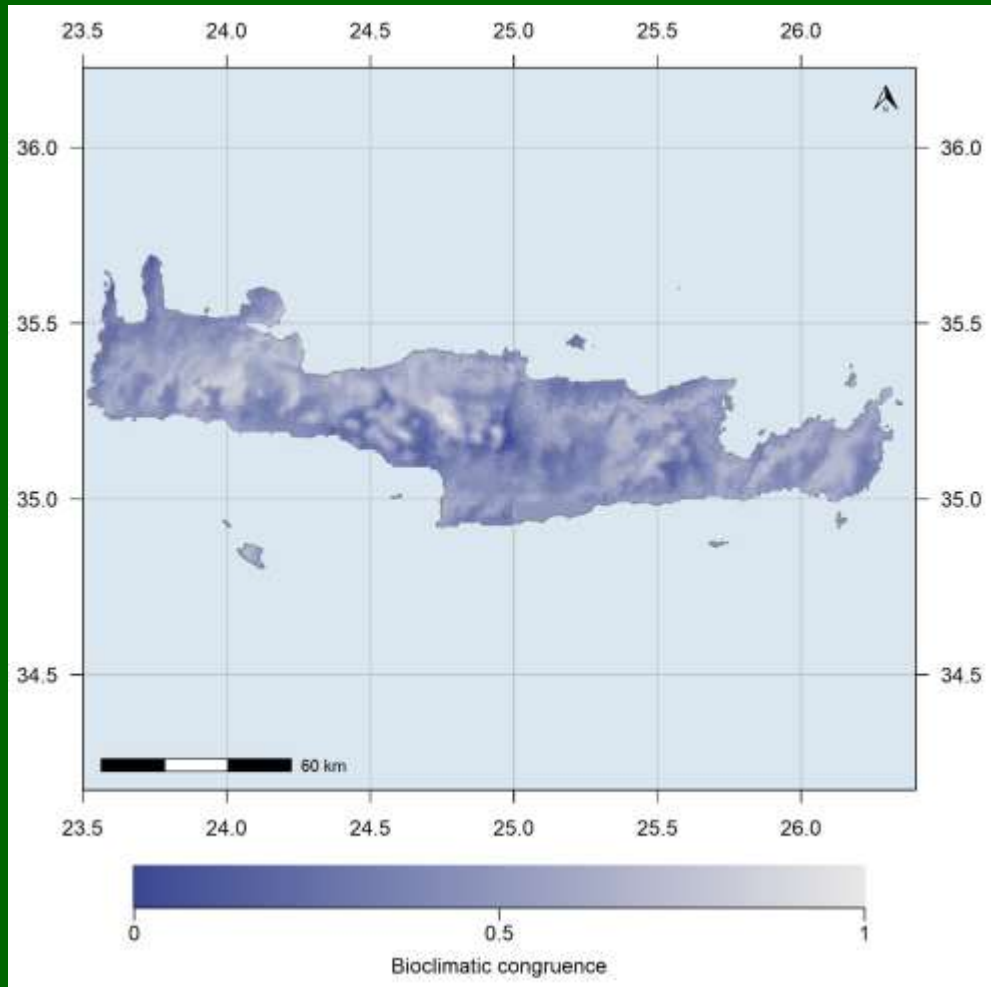

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Dianthus juniperinus subsp. *aciphyllus*

Photo by Papiomytoglou, V.
https://www.greekflora.gr/el/flowers/6169/Dianthus-juniperinus-subsp-aciphyllus

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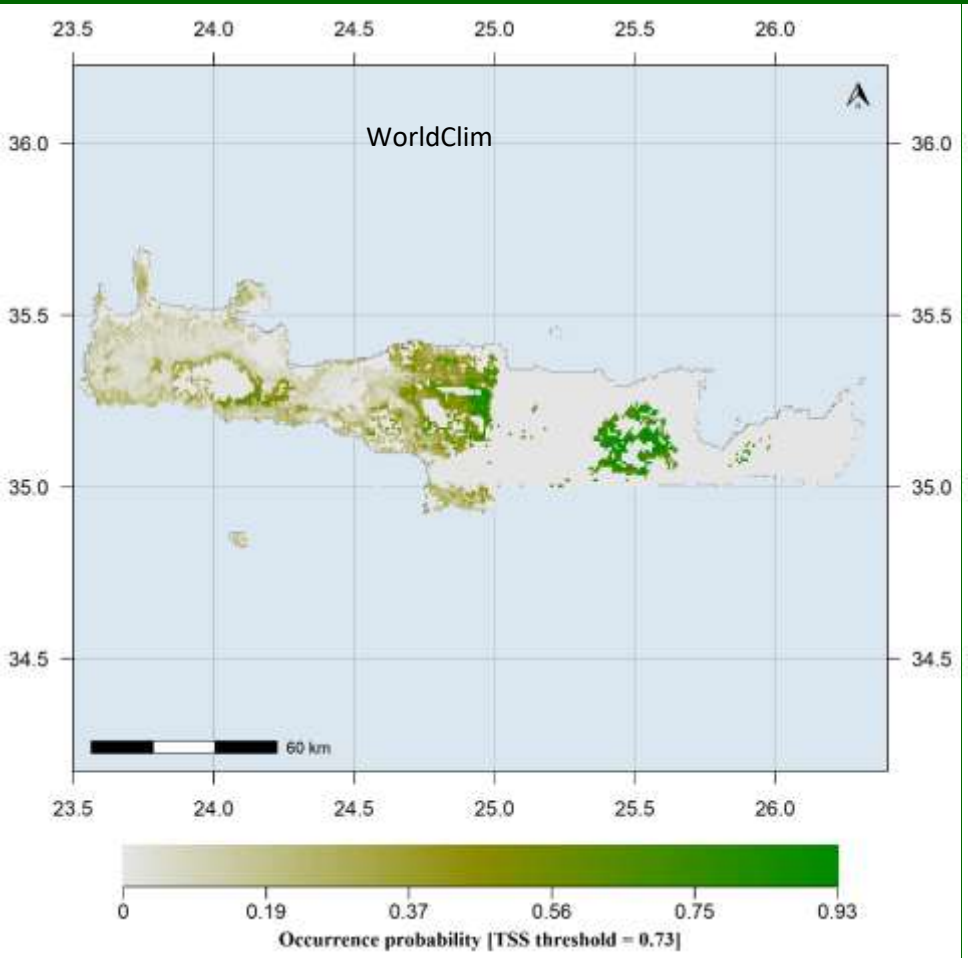

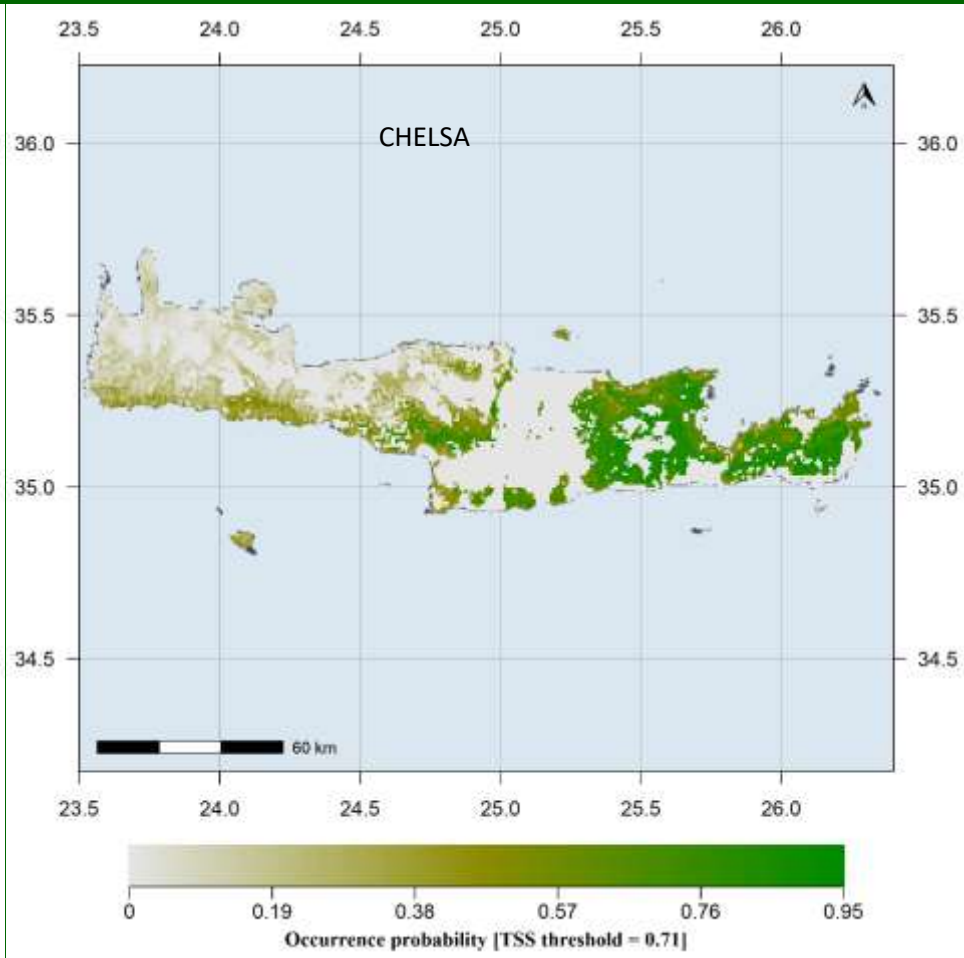

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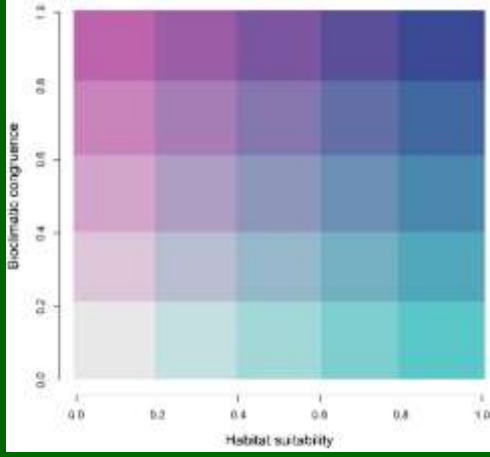

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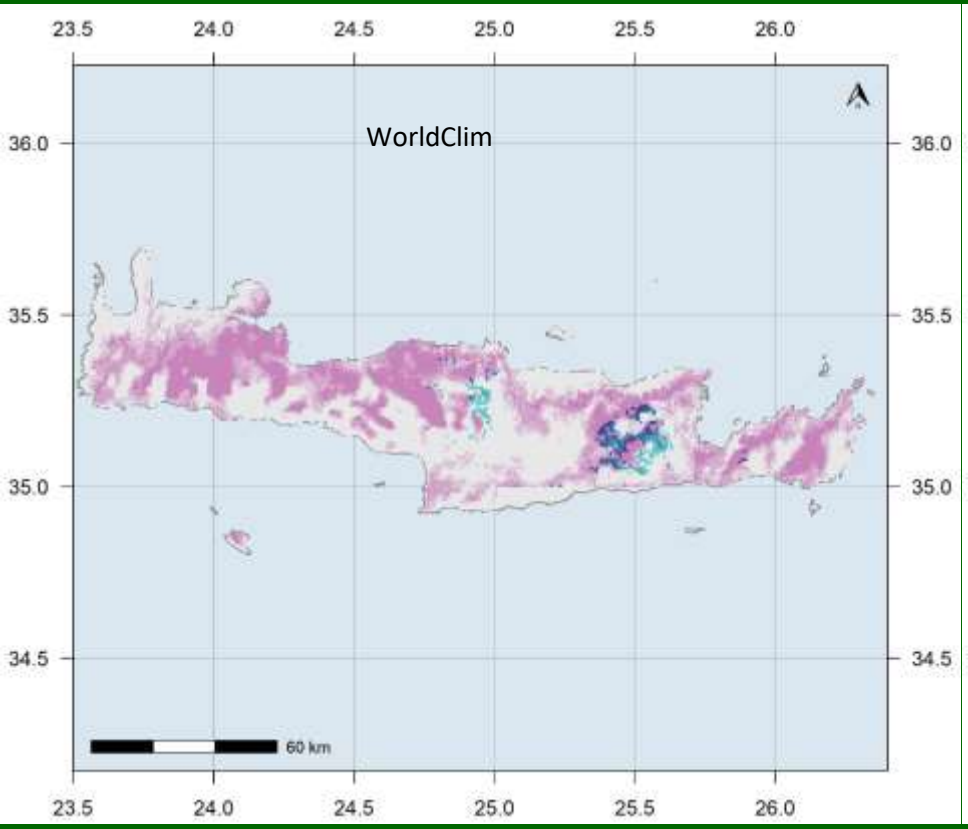

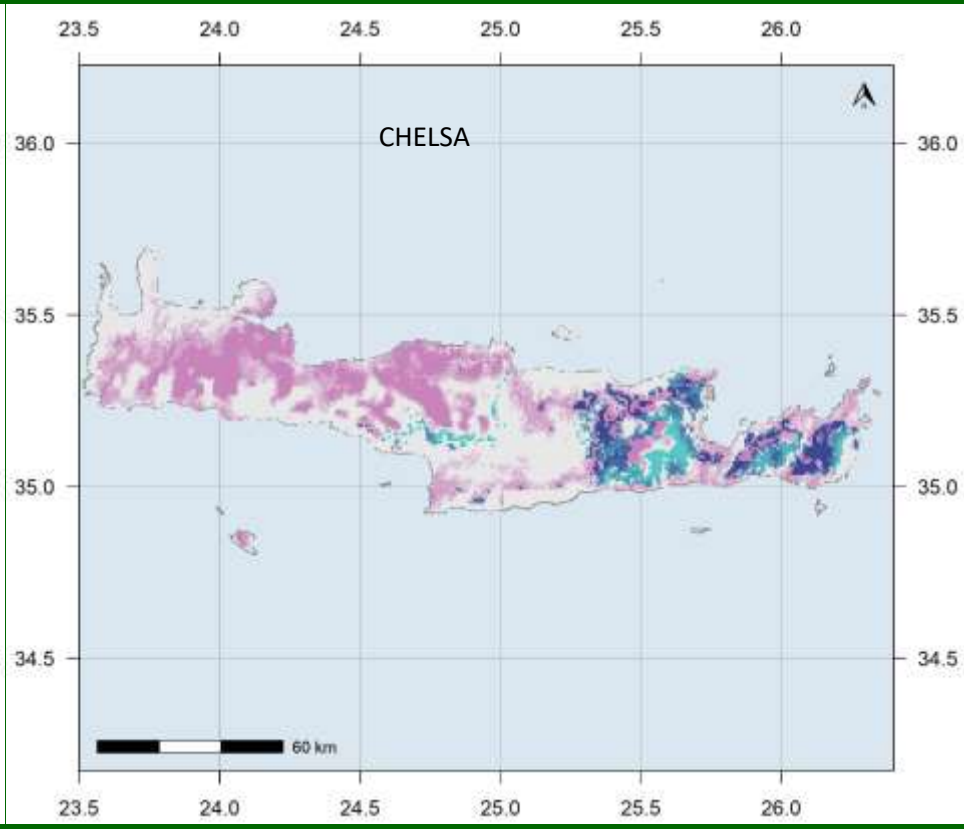

Morales-Barbero & Vega-Álvarez (2019). Input matters matter: Bioclimatic consistency to map more reliable species distribution models. *MEE*, *10*(2), 212-224.

Results - Discussion

- Current and future IUCN status

Imminent extinction: 13.1%

Severe diversity decline under any GCM/RCP [60-148 taxa]

At least 13 taxa are projected to become extinct under any GCM/RCP

Acantholimon androsaceum
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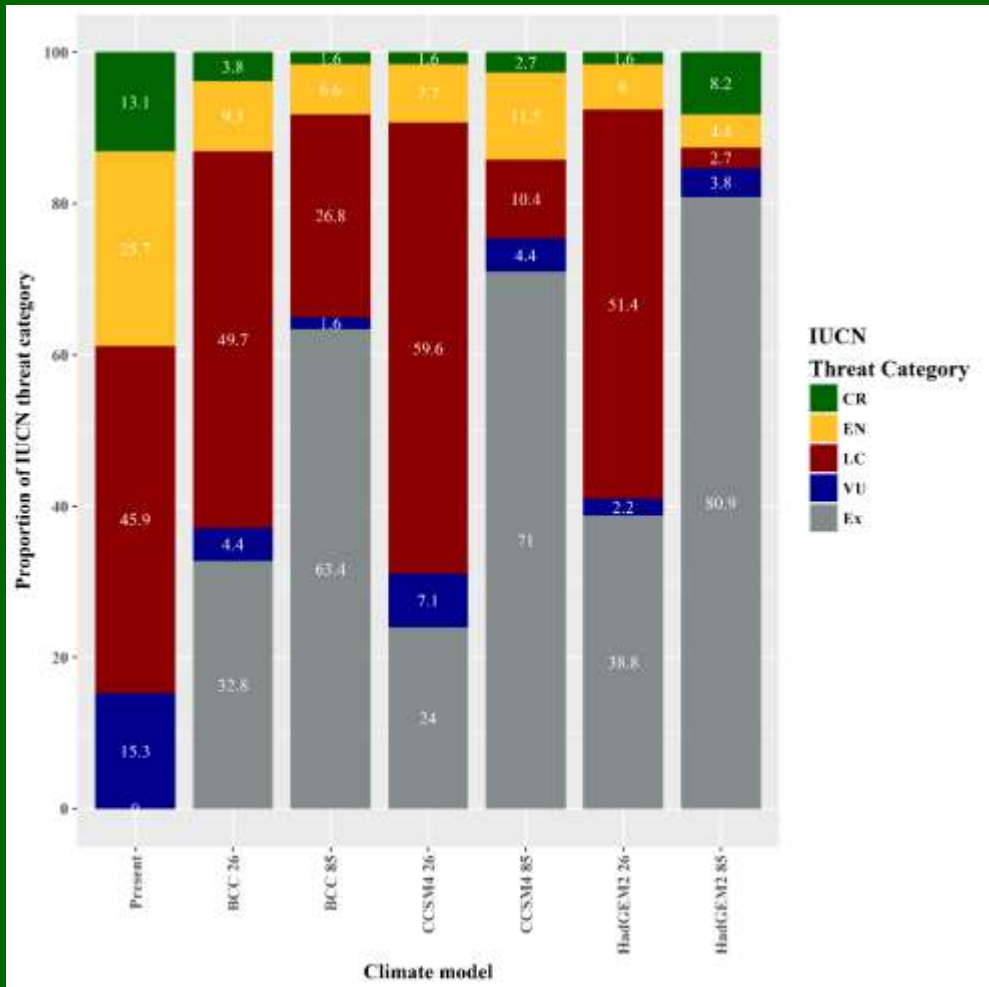

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https://www.west-crete.com/flowers/photos/acantholimon_androsaceum-6large.jpg

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https://www.flickr.com/photos/nturland/2294623647 by Turland, N.

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by Turland, N.

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https://www.west-crete.com/dailypics/crete-2018/7-1-18.php

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https://www.greekflora.gr/el/flowers/3152/Gagea-omalensis by Kofinas, I.

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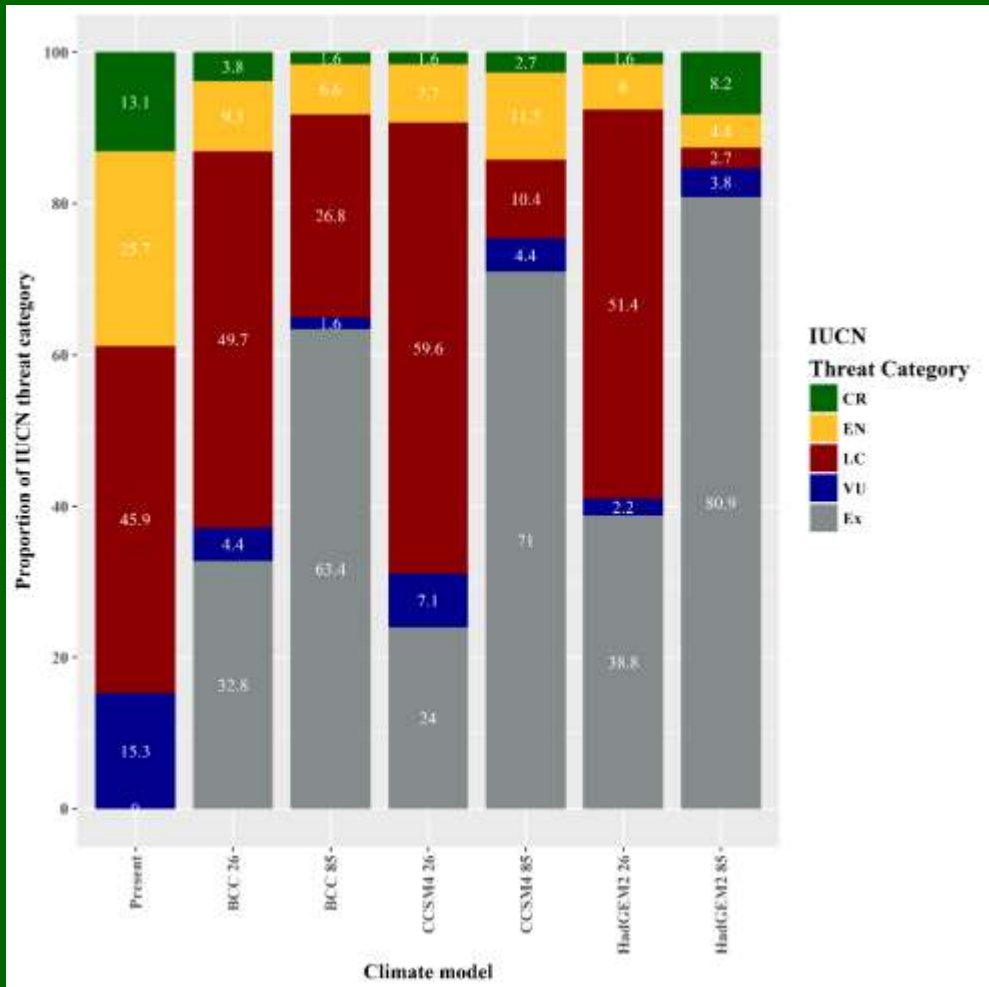
At least 13 taxa are projected to become extinct under any GCM/RCP

The conservation of 44 taxa should be prioritized [EDGE analysis]



Asplenium creticum

Photo by Kofinas, I.
https://www.greekflora.gr/el/flowers/0885/Asplenium-creticum

Cyclamen confusum

https://www.west-crete.com/dailypics/photos1/3054large.jpg

Horstrissea dolinicola

https://top50.iucn-mpsg.org/species/41#&gid=1&pid=4

Euphorbia rechingeri

Photo by Turland, N.
https://www.flickr.com/photos/nturland/2638186870/in/photostream/

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

Gagea omalensis

Photo by Kofinas, I.
https://www.greekflora.gr/el/flowers/3152/Gagea-omalensis

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

Cynoglossum sphacioticum

Photo by Turland, N.
https://www.flickr.com/photos/nturland/2503466822

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

Ranunculus radinotrichus

Photo by Turland, N.
https://www.flickr.com/photos/nturland/2246207520

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

Bolanthus creutzburgii subsp. *zaffranii*

Photo by Turland, N.
https://www.flickr.com/photos/nturland/33377653721

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

Centaurea idaea

Photo by Kofinas, I.
https://www.greekflora.gr/el/flowers/1556/Centaurea-idaea

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

Photo by Trnkoczy, A.
https://calphotos.berkeley.edu/cgi/img_query?enlarge=0000+0000+0516+0230

Results - Discussion

- Niche breadth

Median niche breadth = 0.42

25% of the Cretan SIE have a narrow niche breadth

Significant differences between the IUCN categories (Kruskal-Wallis ANOVA: H = 56.6, d.f. = 3, p-value < 0.05)

Species with narrow niches have higher extinction probability for every GCM/RCP

Hemicryptophytes have the lowest extinction probability (Chamaephytes have the highest)

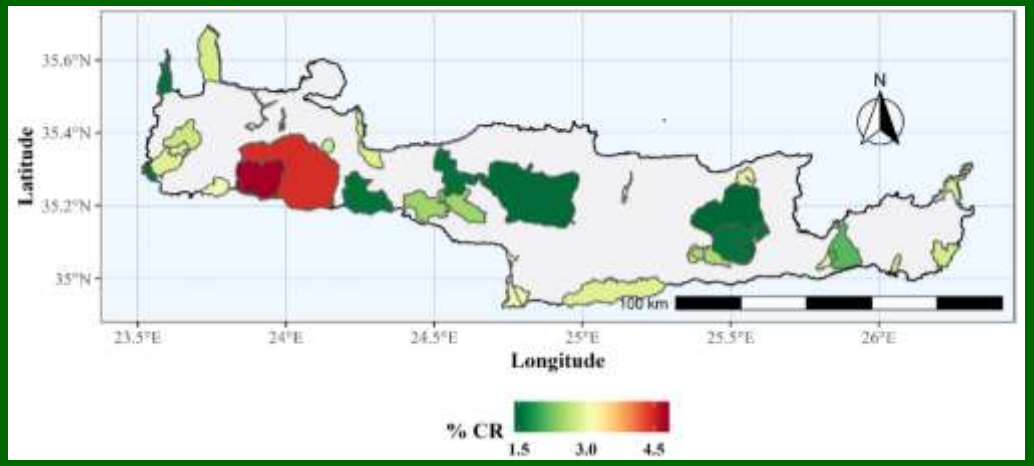
Petromarula pinnata

Photo by Trnkoczy, A.
https://calphotos.berkeley.edu/cgi/img_query?enlarge=0000+0000+0516+0230

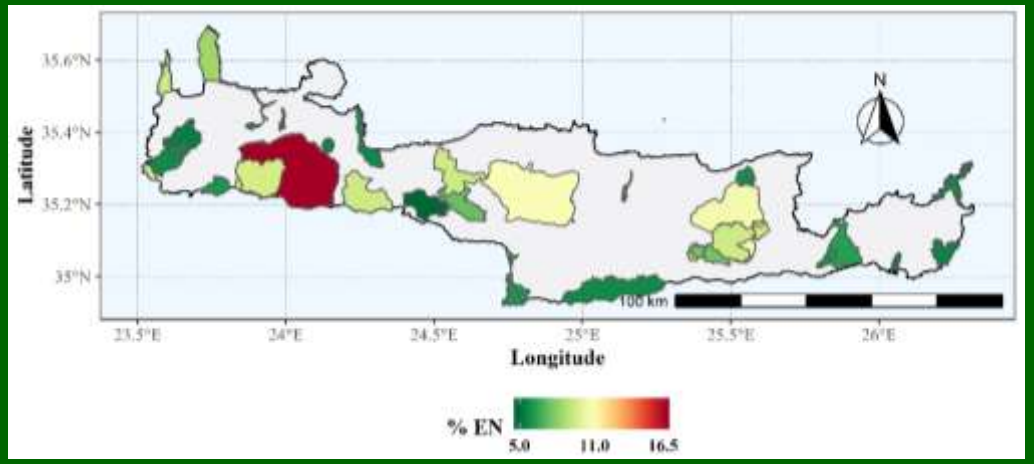
Results - Discussion

- Effectiveness of the NATURA 2000 sites?

Very low proportion of CR SIE taxa

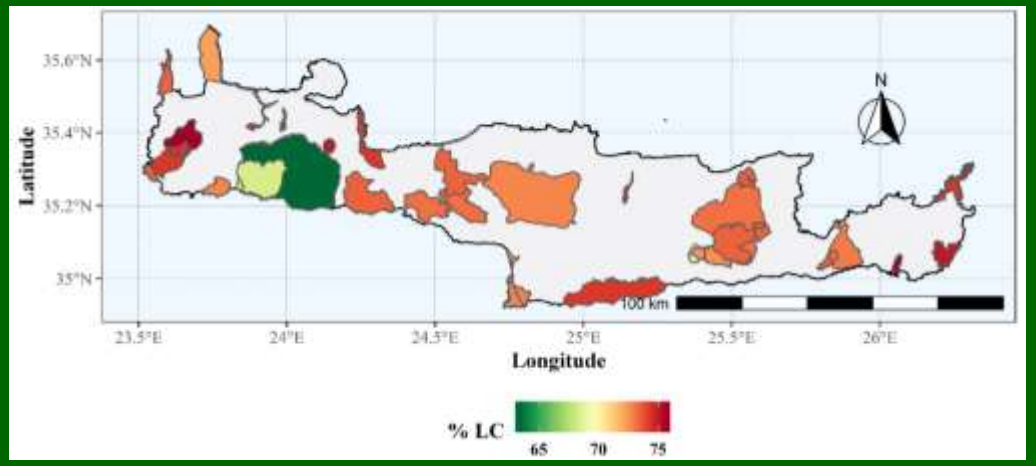


Highest values in Lefka Ori

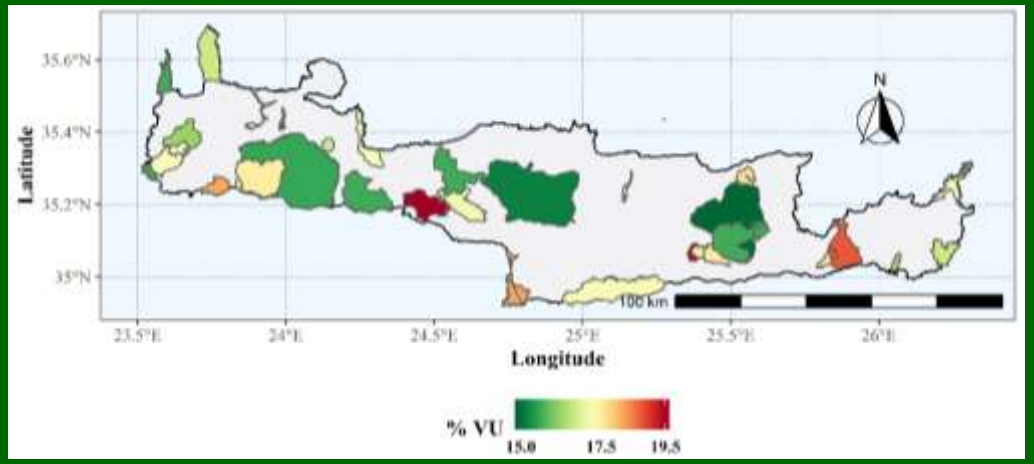


Results - Discussion

- Effectiveness of the NATURA 2000 sites?

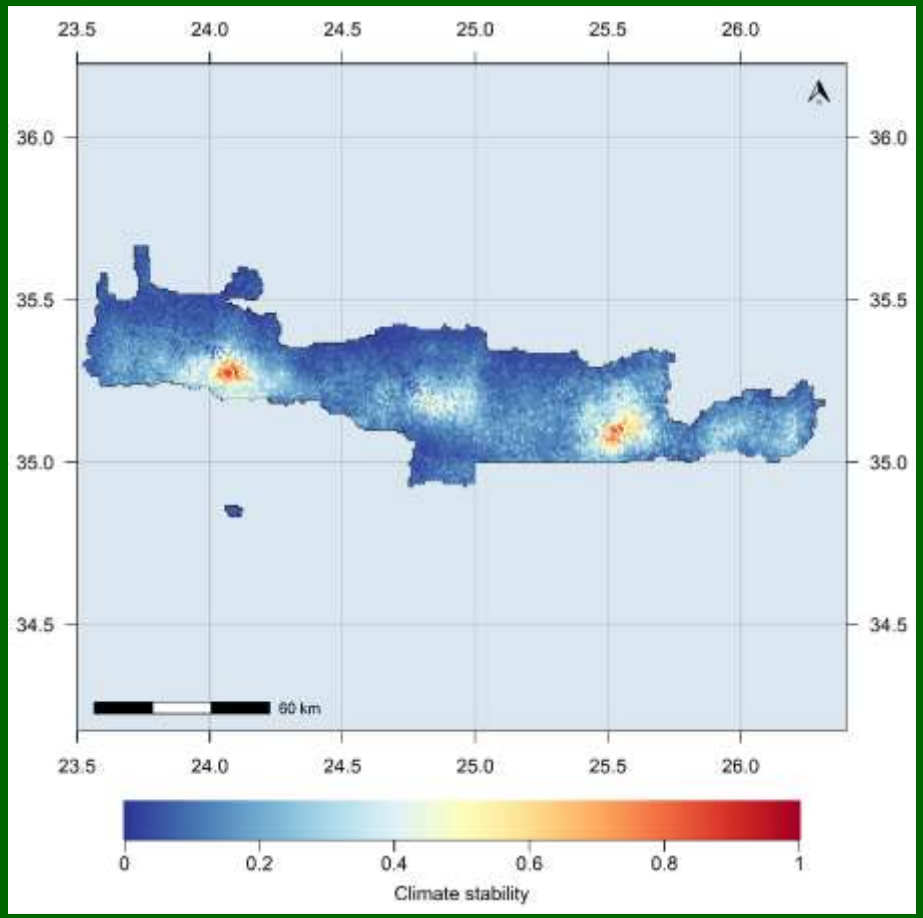


Mostly LC & VU taxa included



Results - Discussion

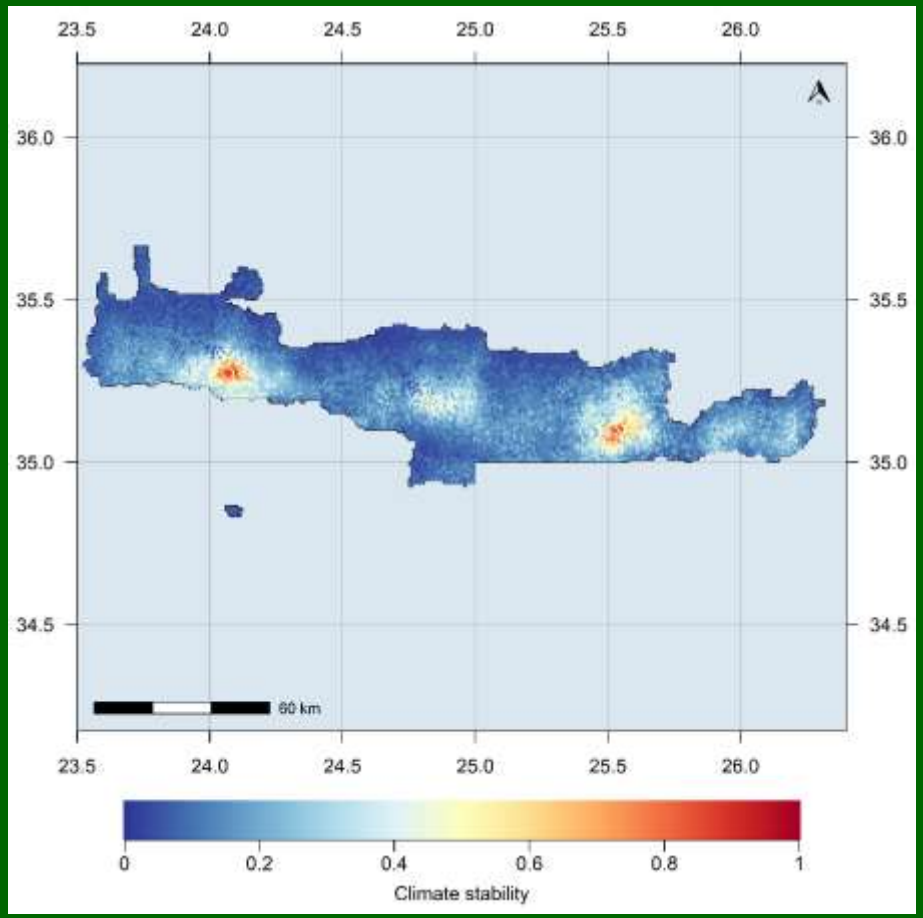
- What about the hotspots?



Was Crete (or part of it) climatically stable?

Results - Discussion

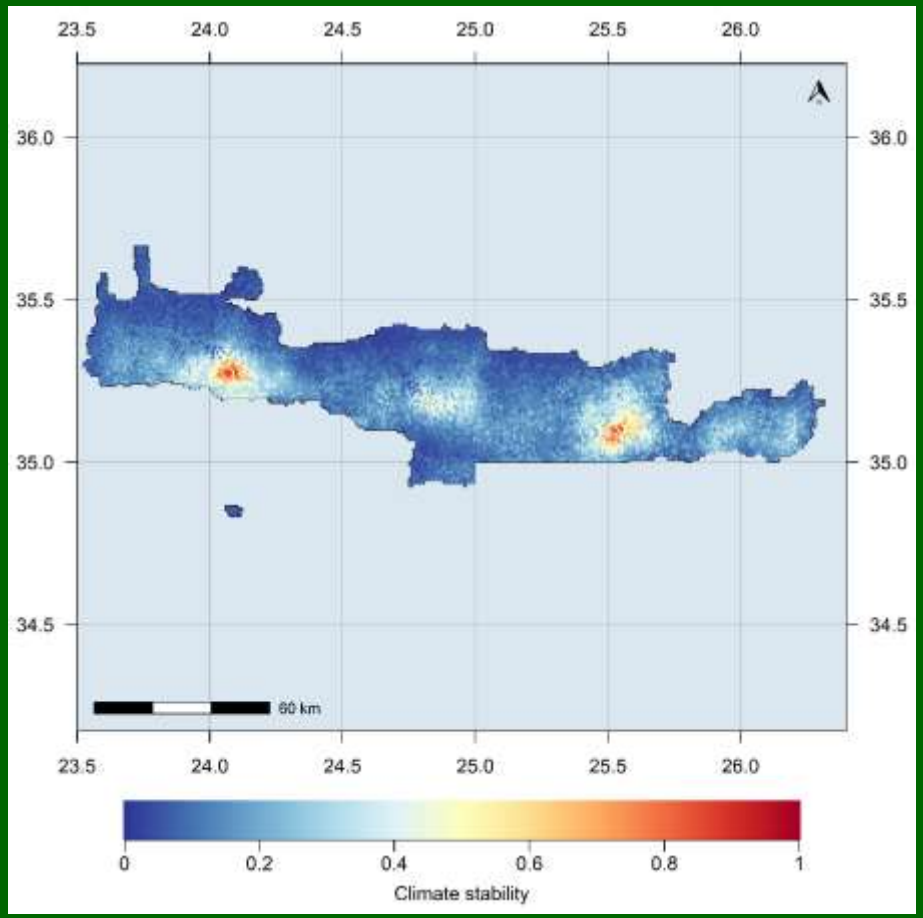
- What about the hotspots?

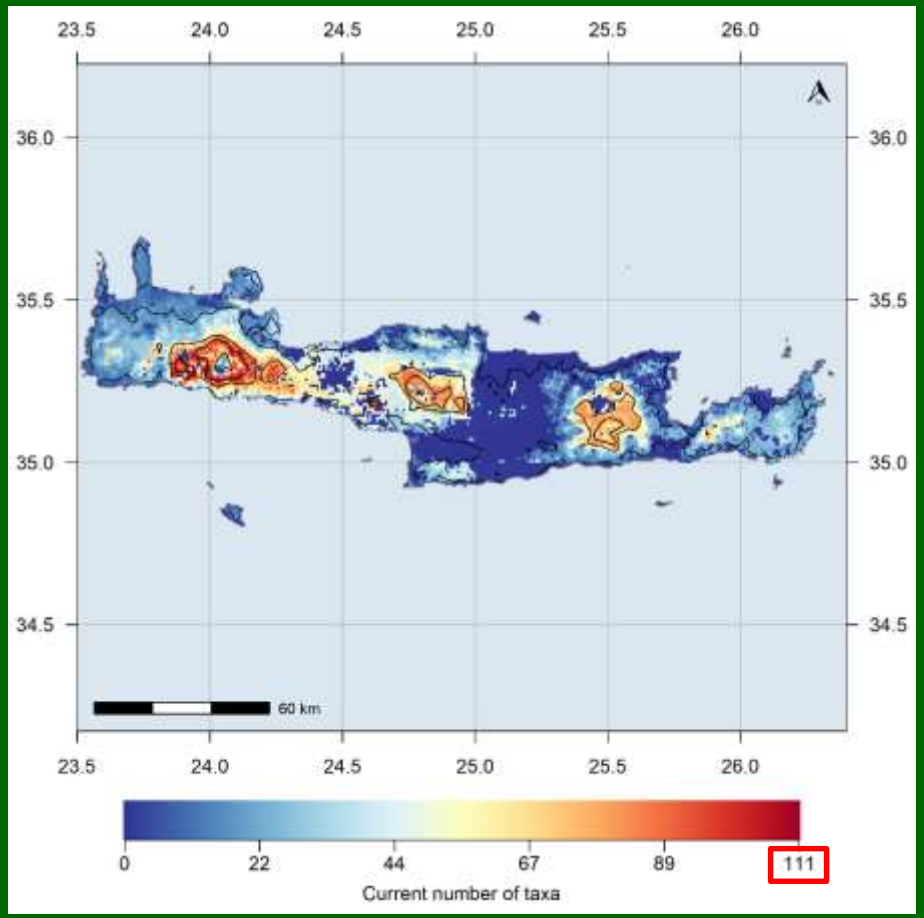


Are these areas SIE hotspots?

Results - Discussion

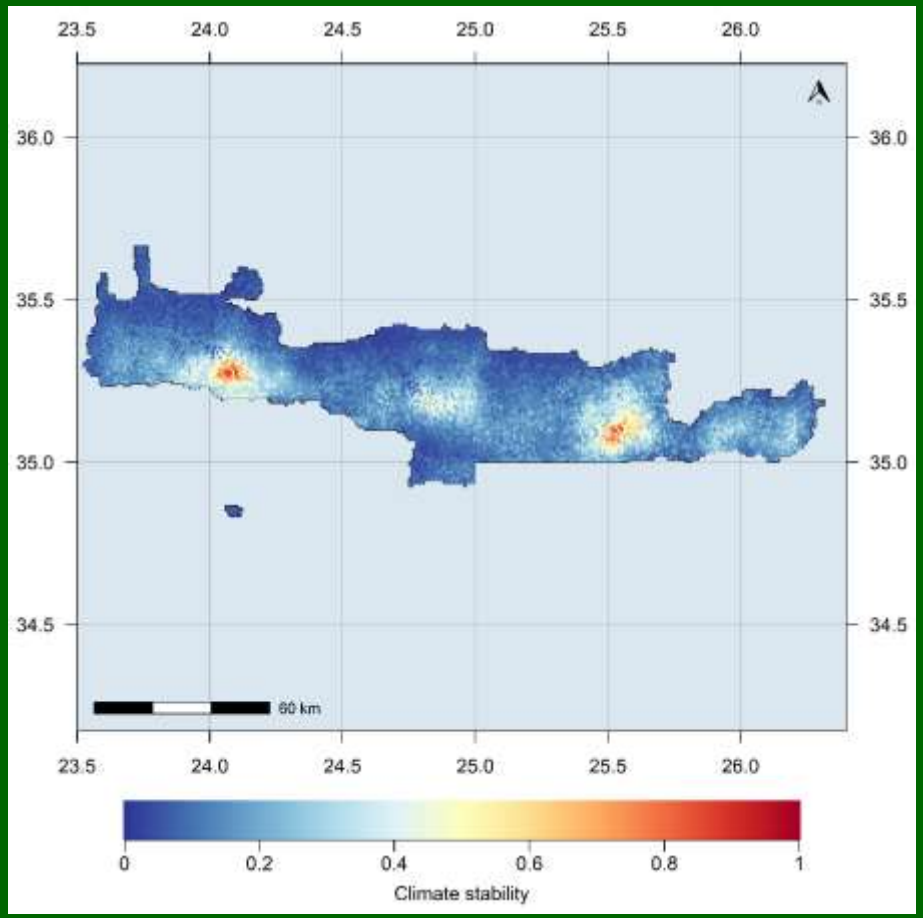
- What about the hotspots?





Results - Discussion

- What about the hotspots?

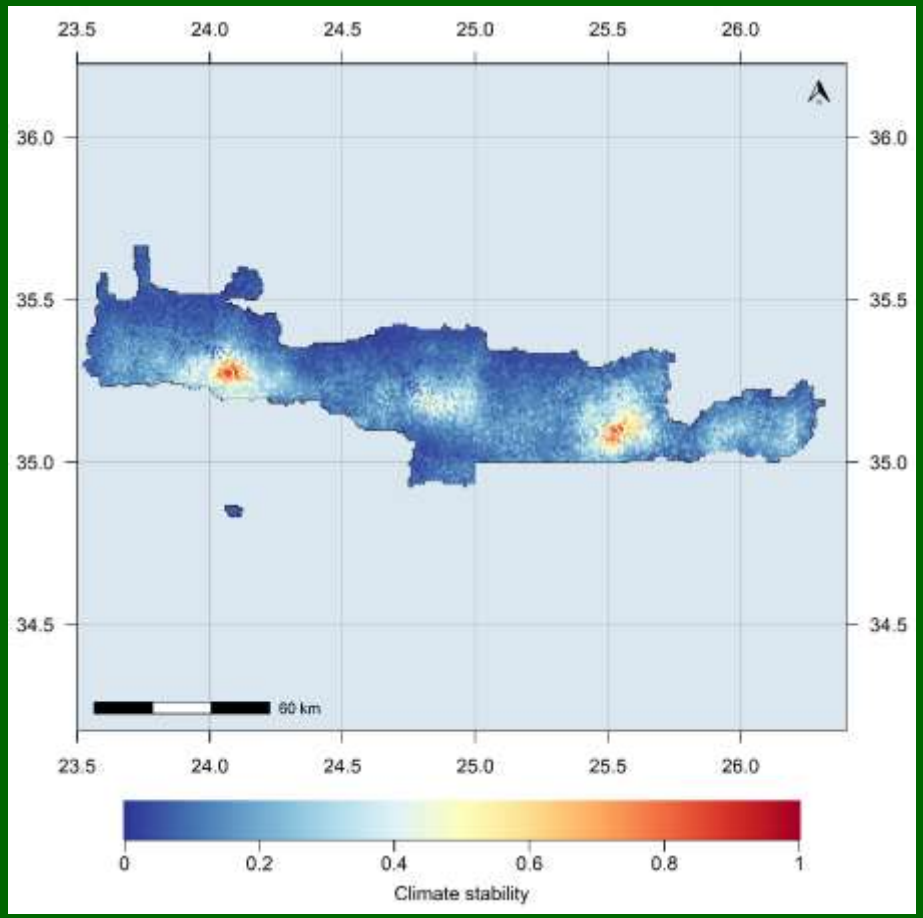


Are these areas SIE hotspots?

Top-20

Results - Discussion

- What about the hotspots?



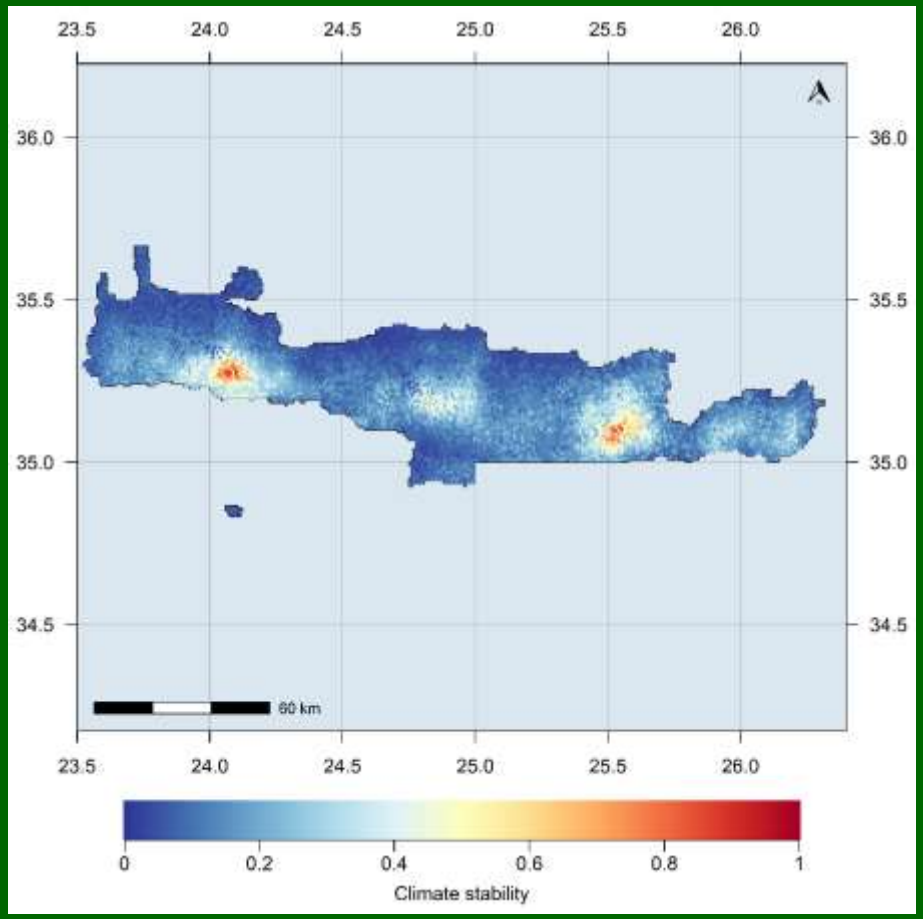
Are these areas SIE hotspots?

Top-20

Top-30

Results - Discussion

- What about the hotspots?

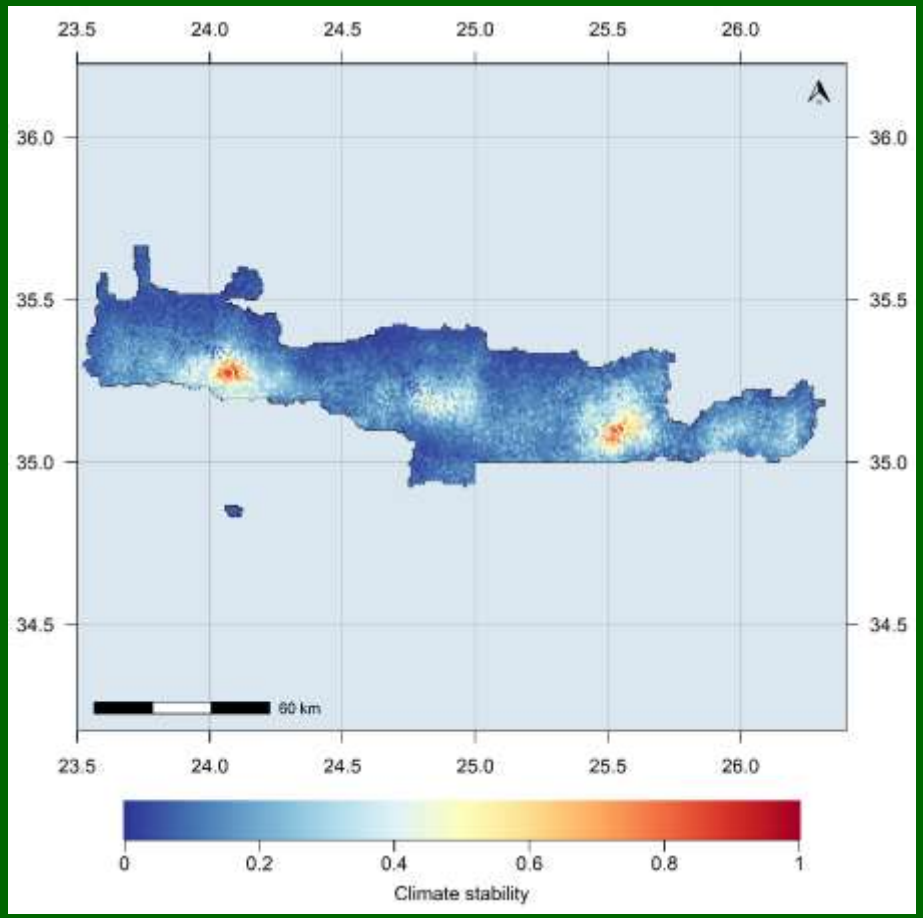


Are these areas SIE hotspots?

Top-20 & CS > 0.75

Results - Discussion

- What about the hotspots?



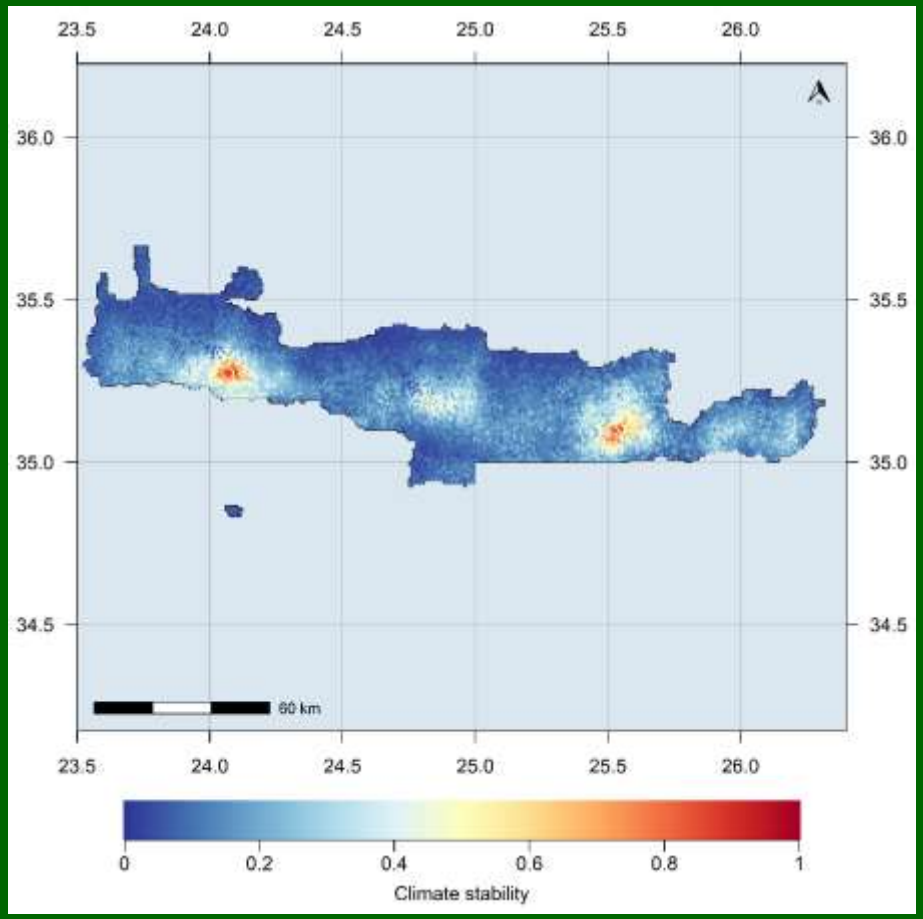
Are these areas SIE hotspots?

Top-20 & CS > 0.75

Top-30 & CS > 0. 50

Results - Discussion

- What about the hotspots?



Will they continue to be?

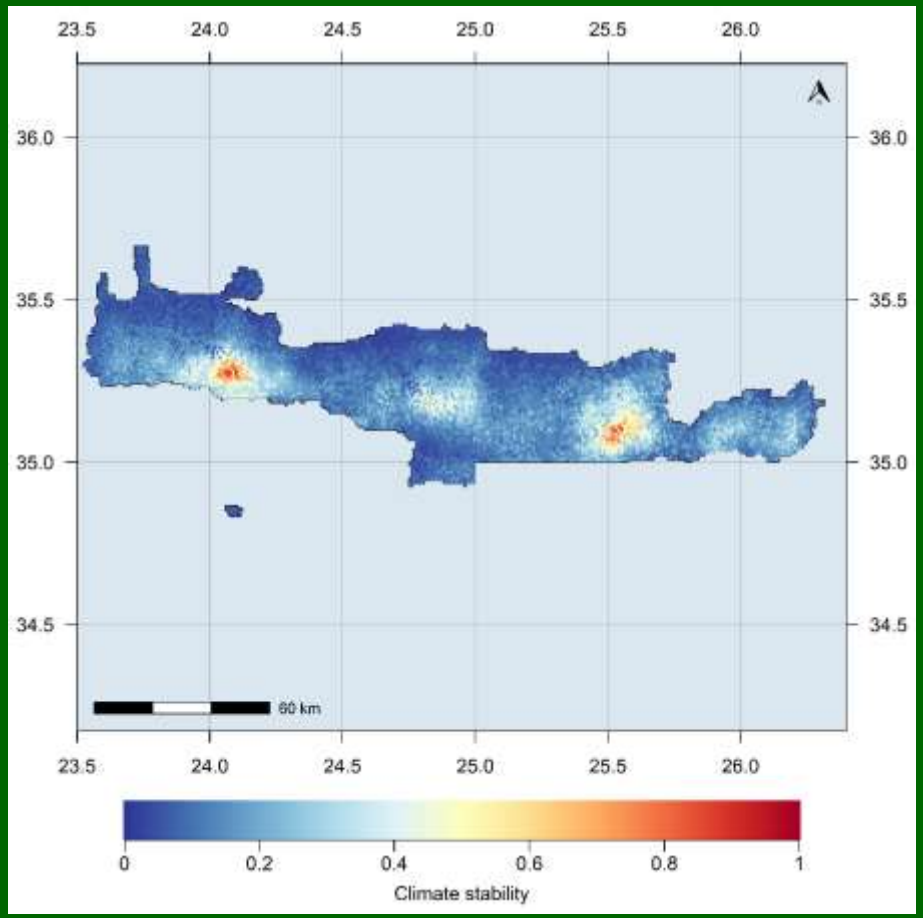
The eastern, central and high altitude parts of Crete are more likely to lose the vast majority of the SIE occurring there

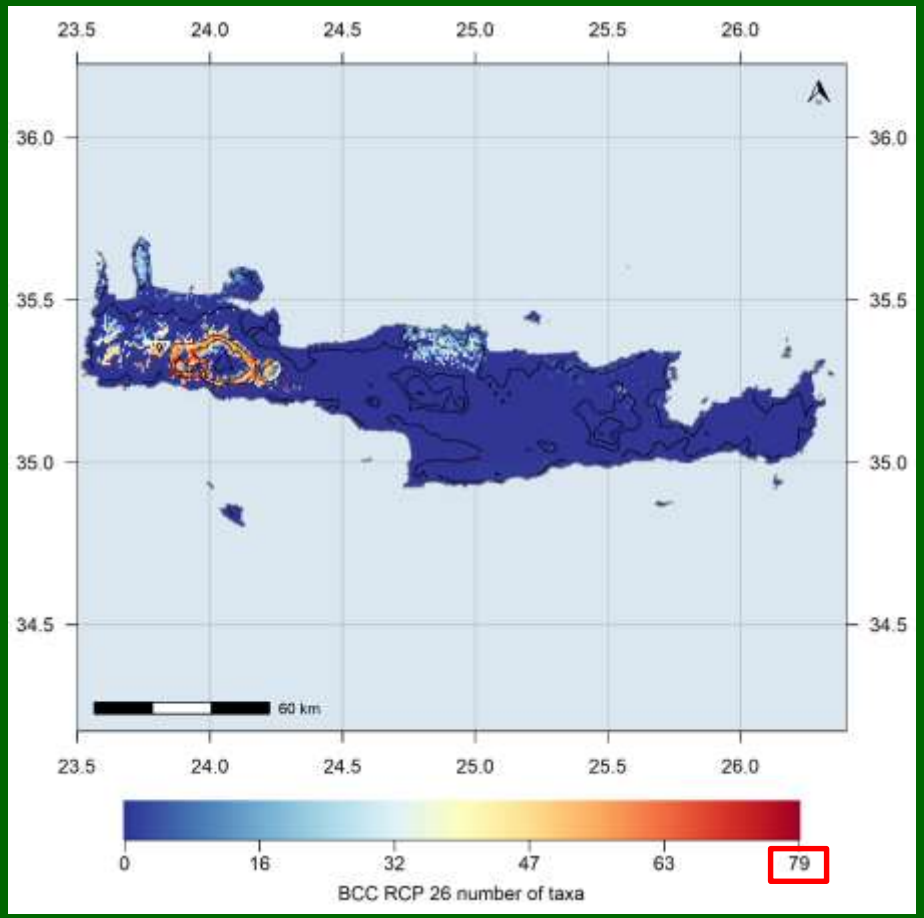
Escalator to extinction phenomenon

Urban, M. C. (2018). Escalator to extinction. *PNAS*, *115*(47), 11871-11873.

Results - Discussion

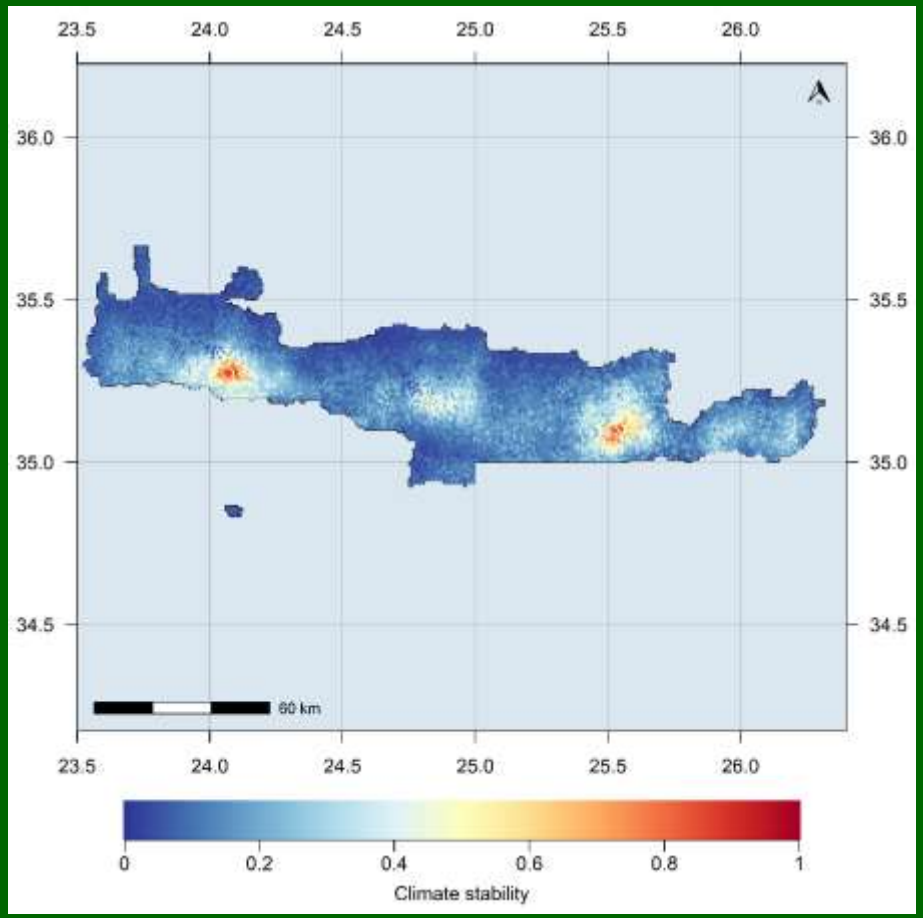
- What about the hotspots?

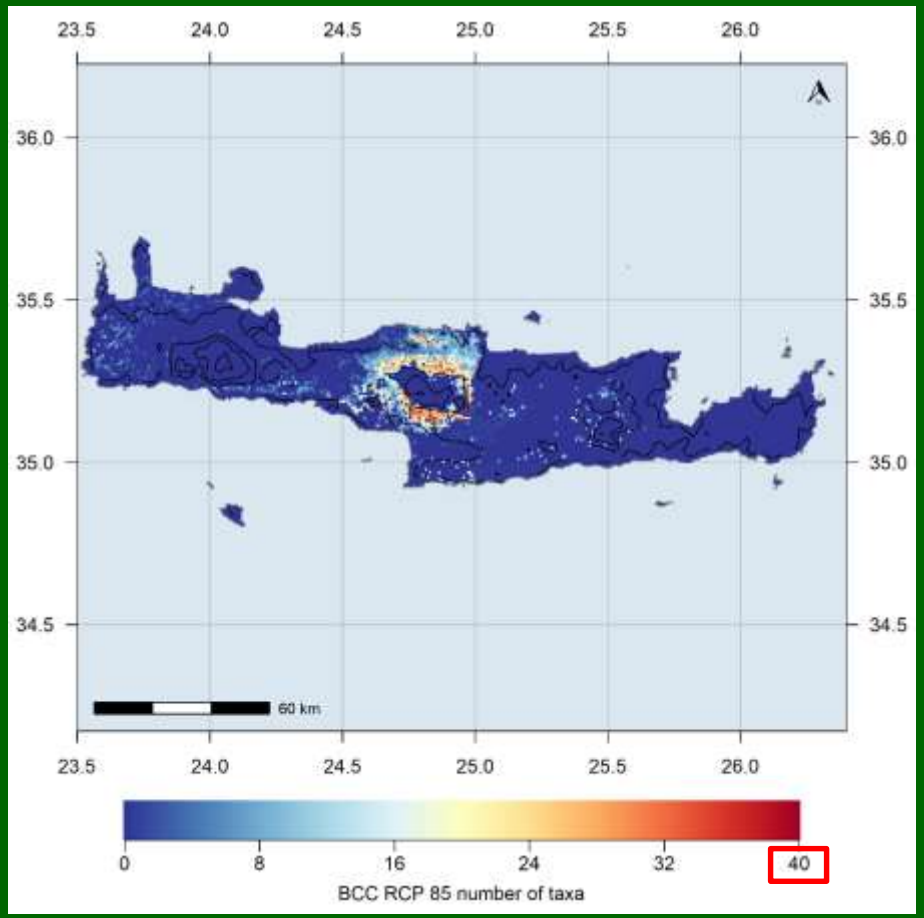




Results - Discussion

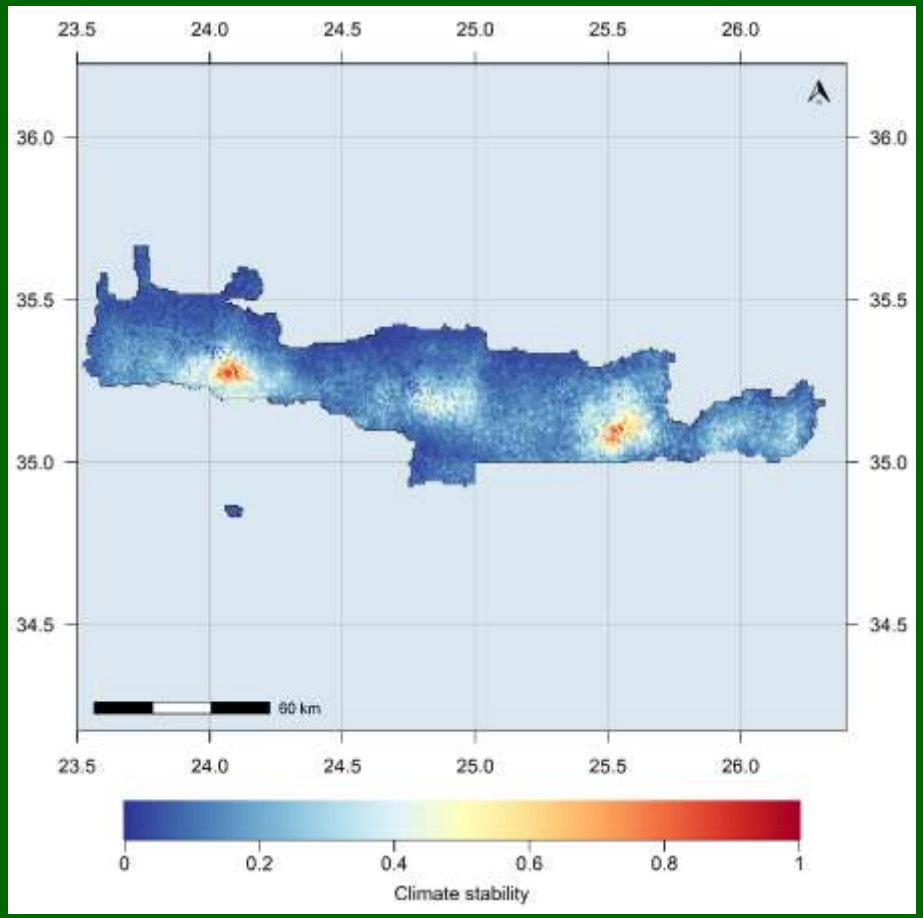
- What about the hotspots?

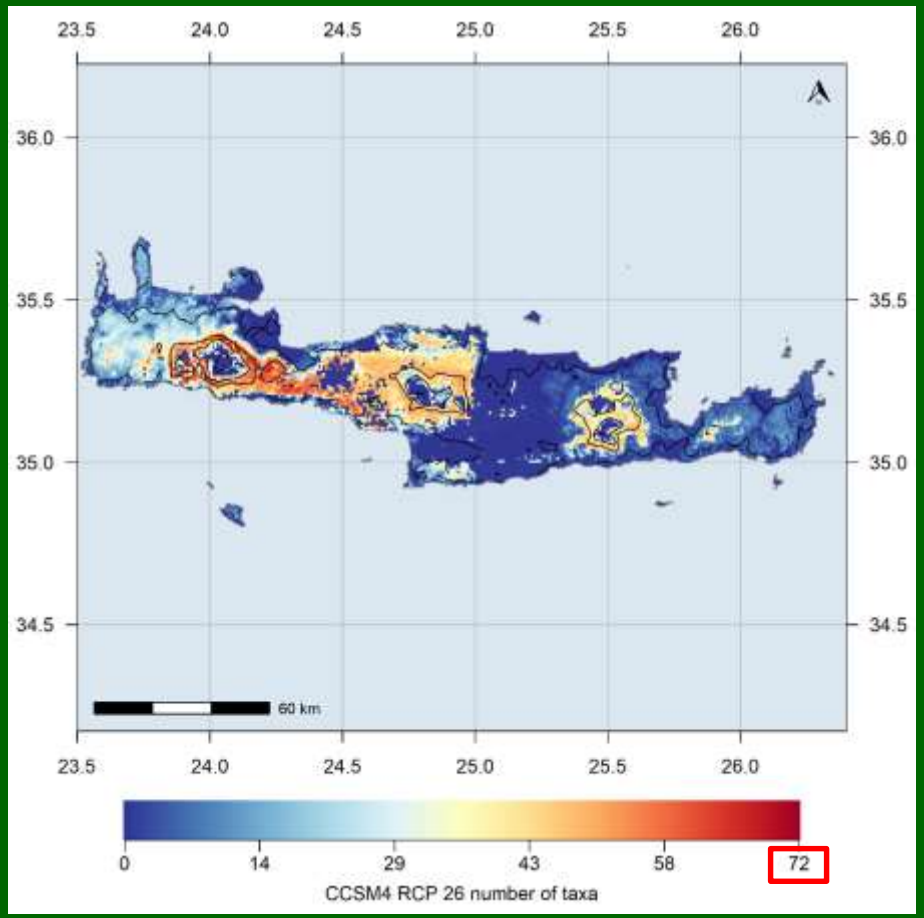




Results - Discussion

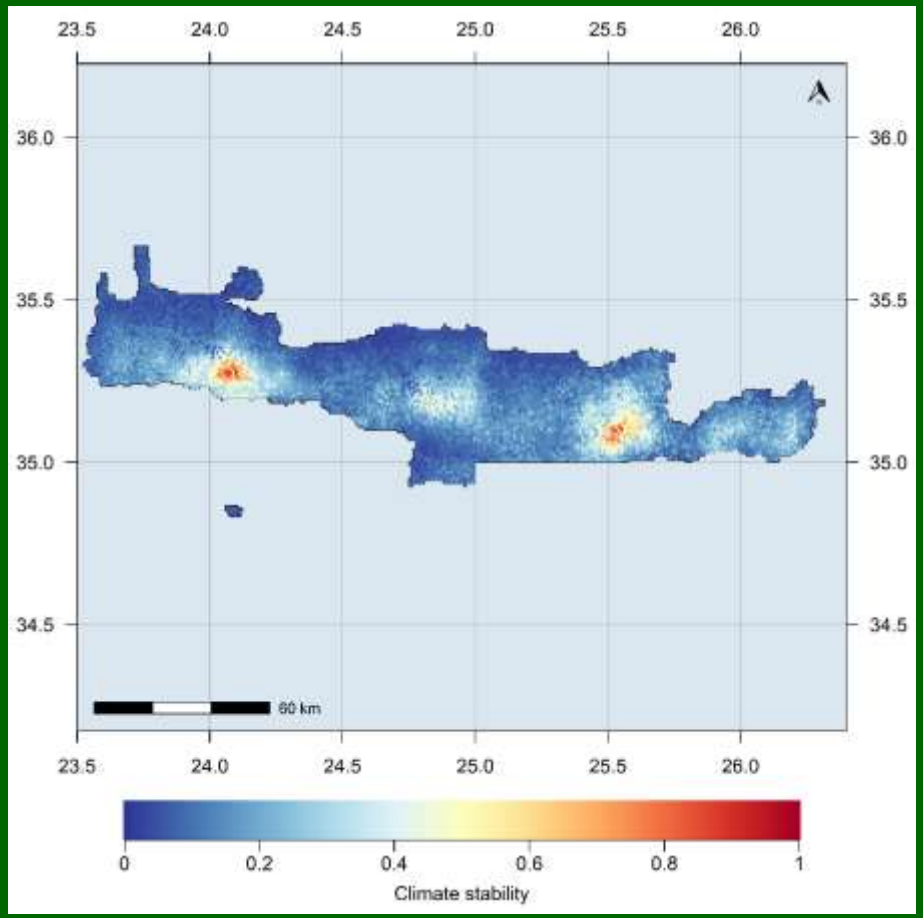
- What about the hotspots?

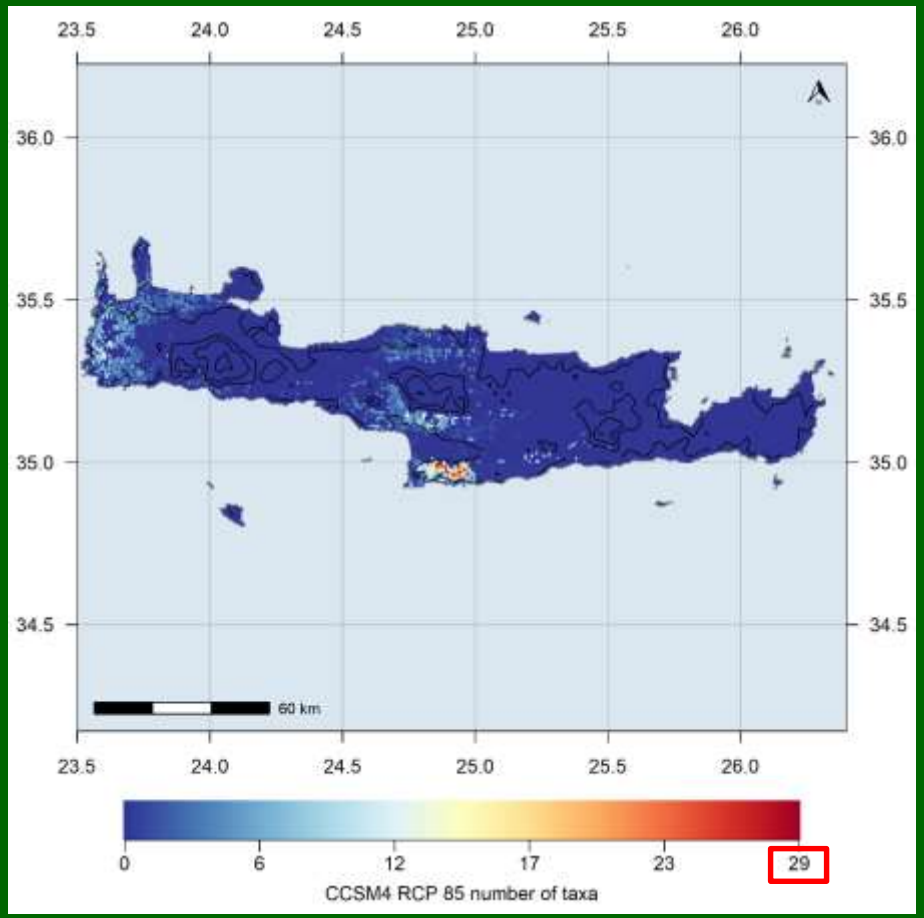




Results - Discussion

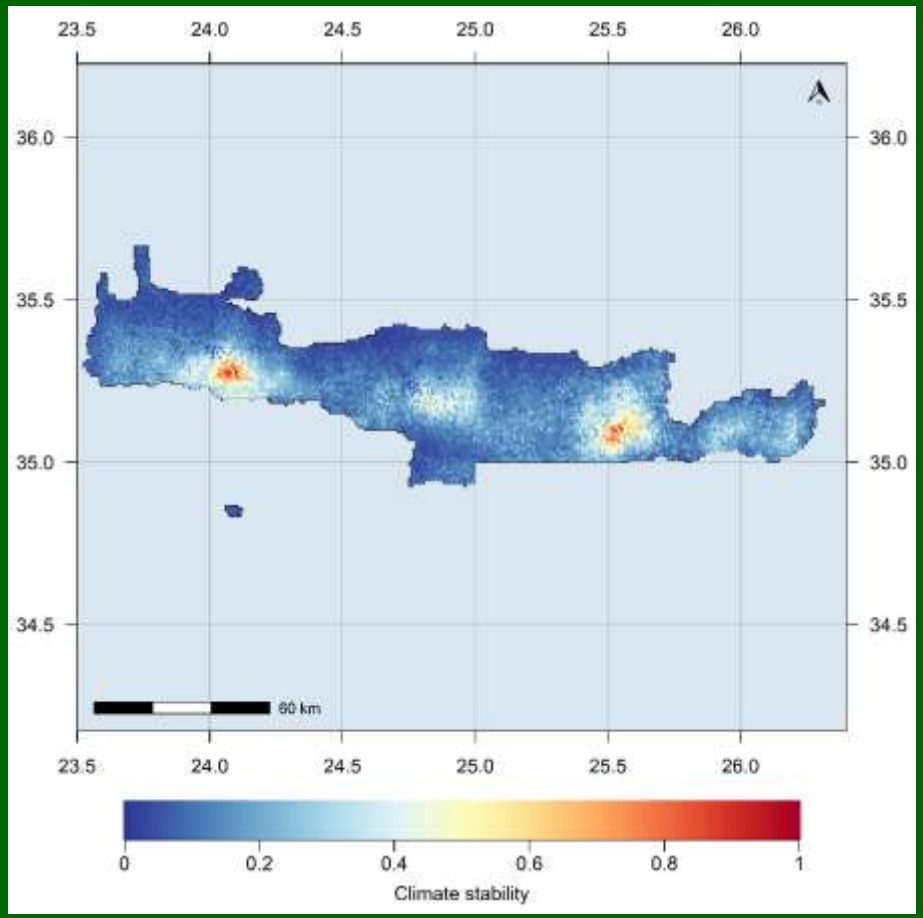
- What about the hotspots?

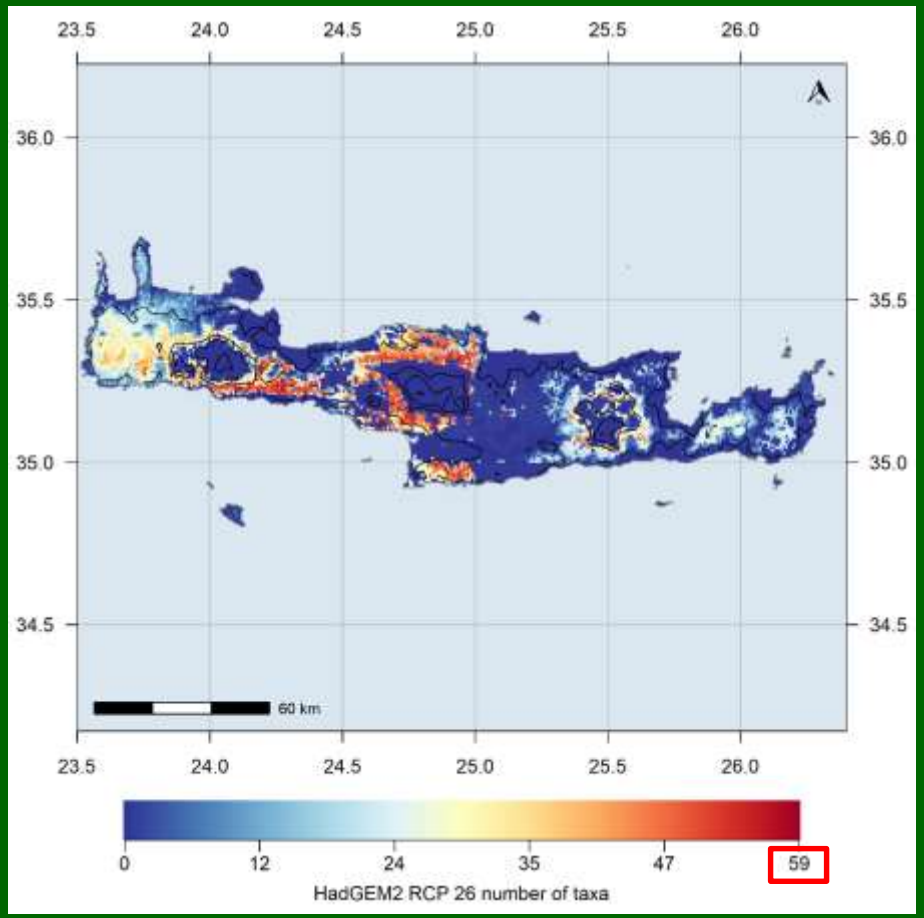




Results - Discussion

- What about the hotspots?





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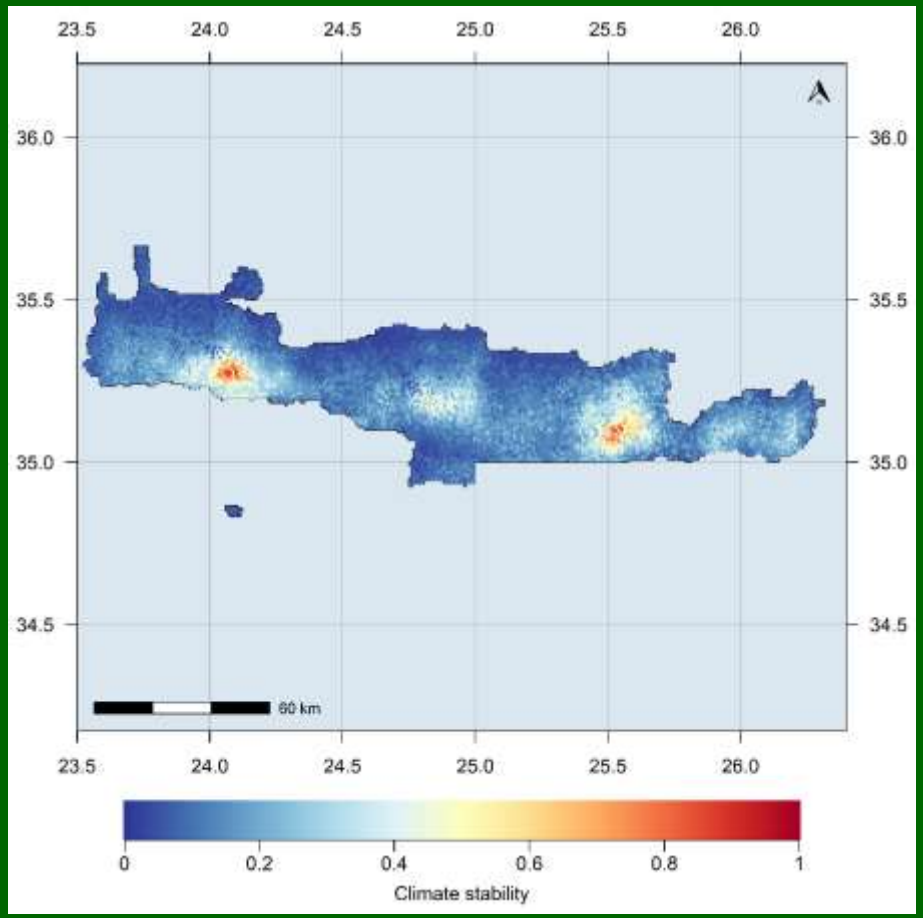
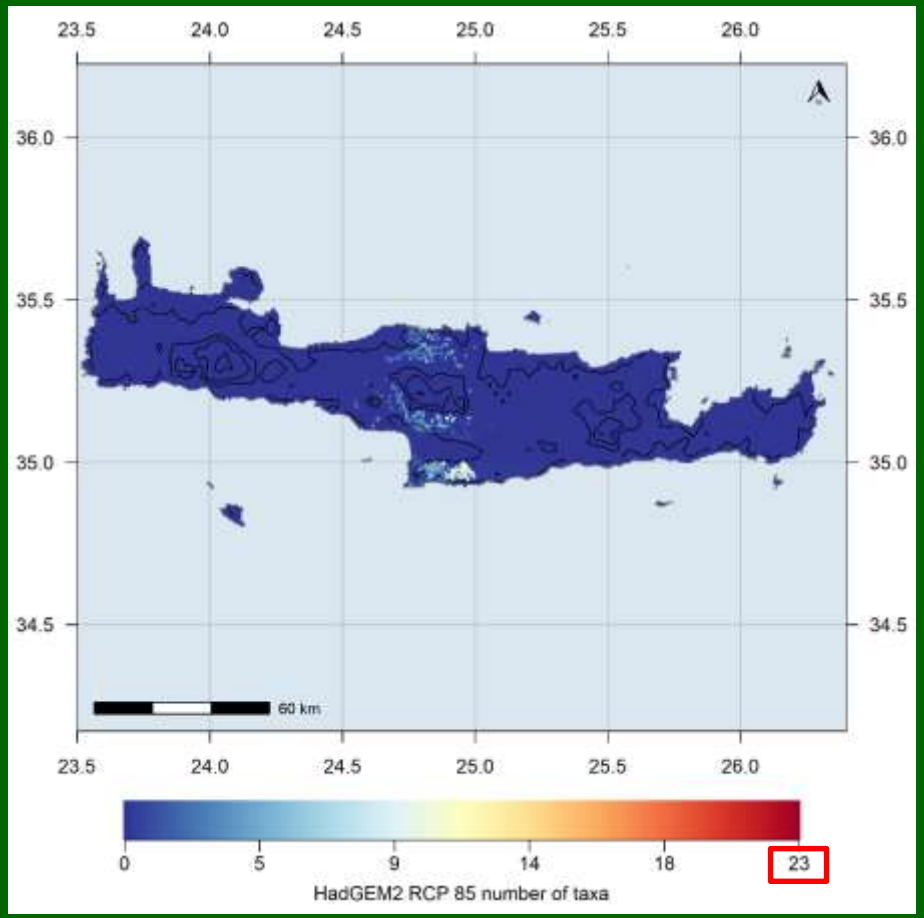
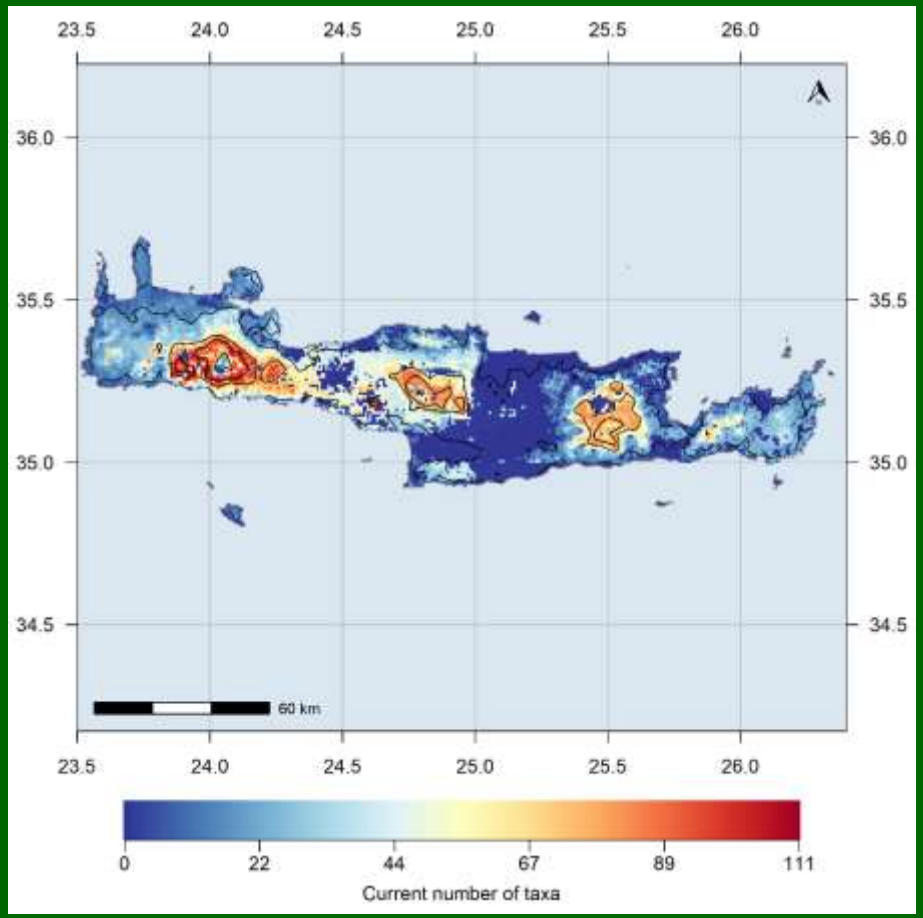
- What about the hotspots?





Results - Discussion

- What about the hotspots?



Will they continue to be?

The eastern, central and high altitude parts of Crete are more likely to lose the vast majority of the SIE occurring there

The SIE hotspots are currently located above 1500 m a.s.l. in Crete, but all of them are expected to shift downwards – even below 1000 m a.s.l. under all GCMs and RCPs

Effectiveness of NATURA 2000? → 97.1% cover

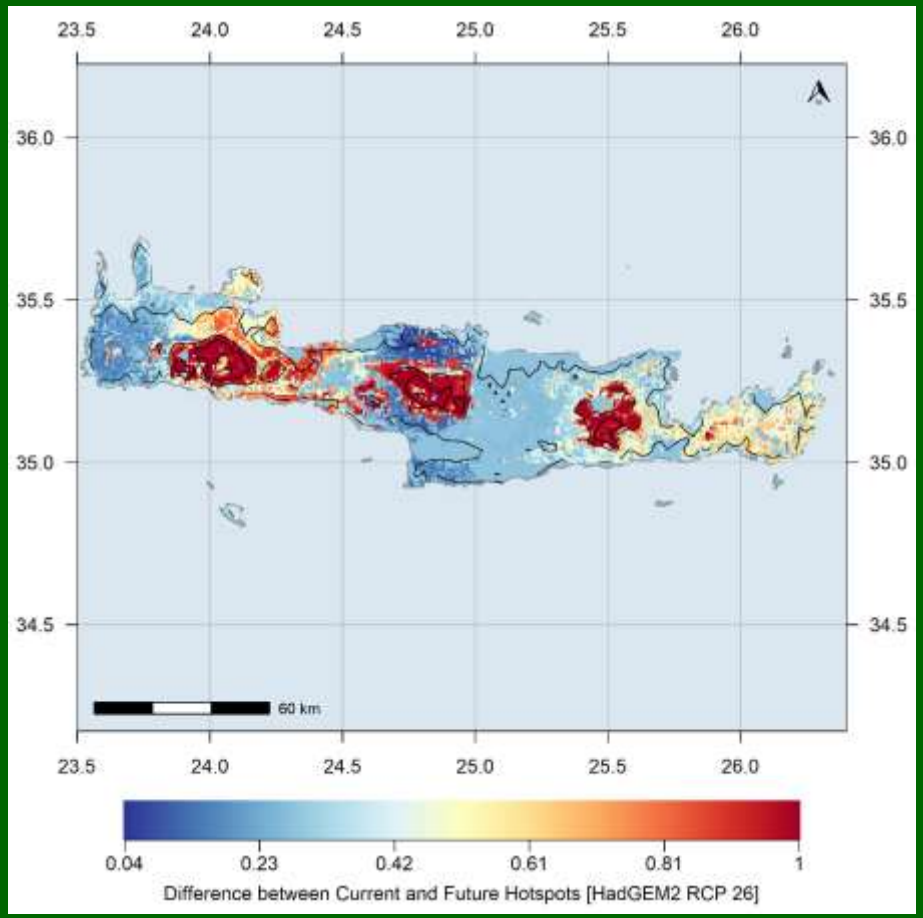
Results - Discussion

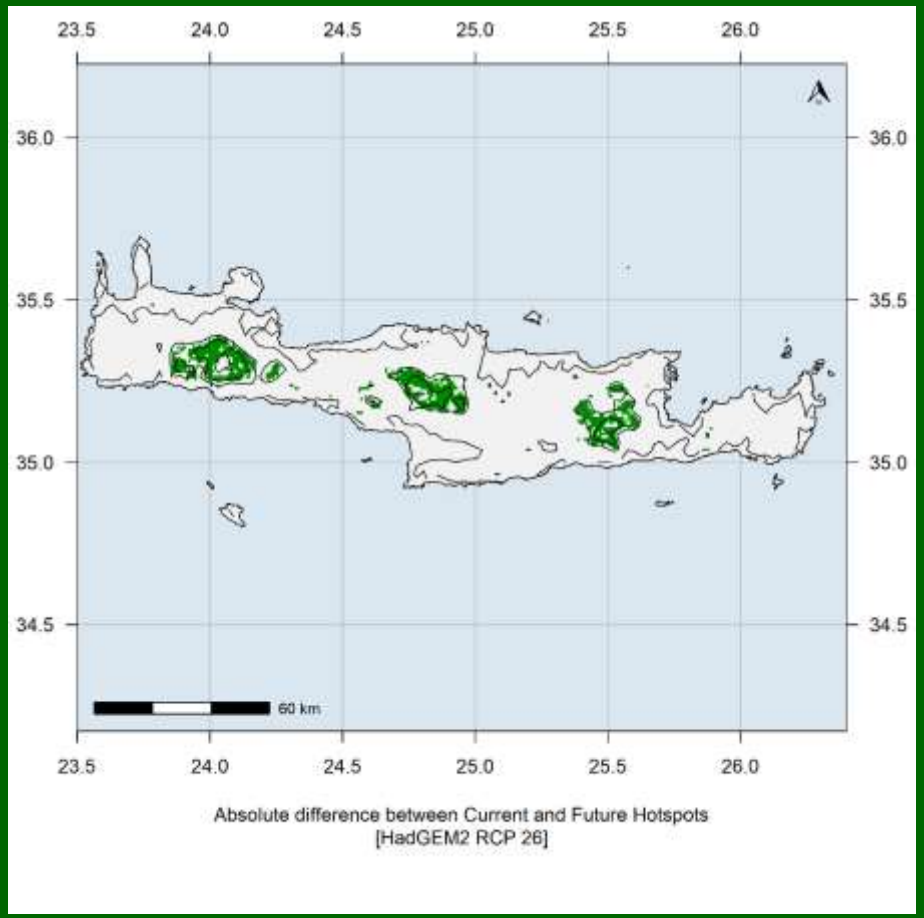
- What about the hotspots?

Are these differences statistically significant?

Results - Discussion

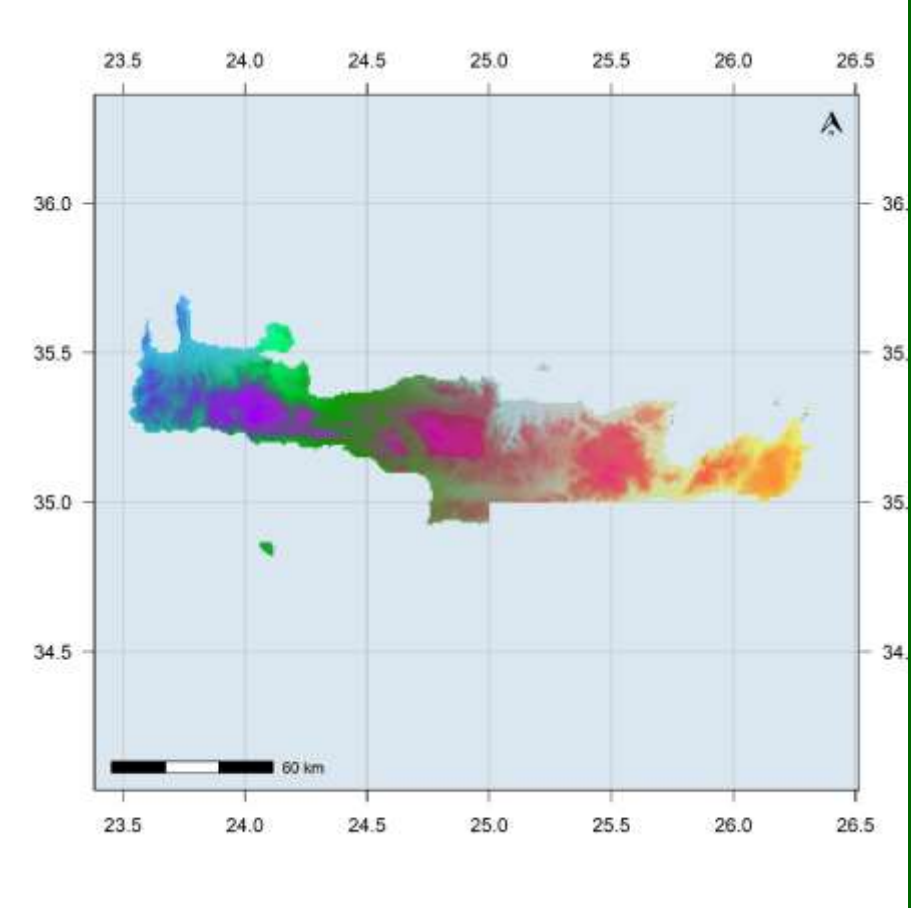
- What about the hotspots?





Results - Discussion

- Impact on biogeography?

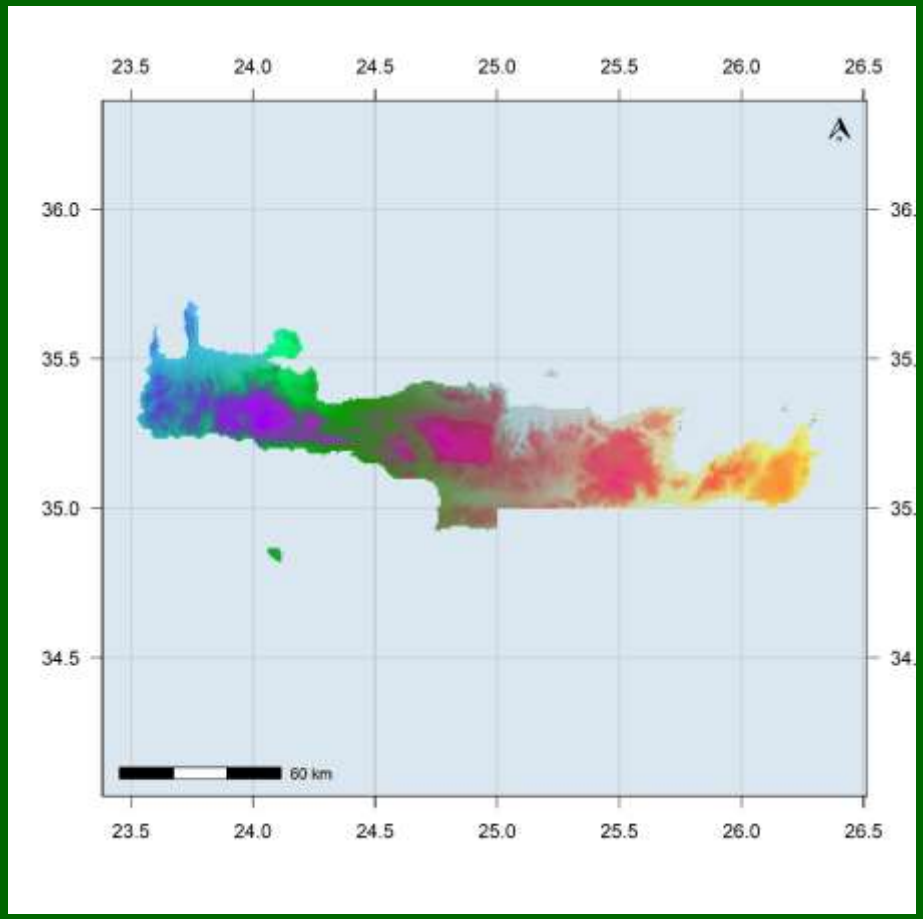


What's the current state of Crete's biogeographical compartmentalization?

The Cretan mountain massifs, as well as the island's topographical heterogeneity, seem to have largely shaped its biogeographical subdivision

Results - Discussion

- Impact on biogeography?

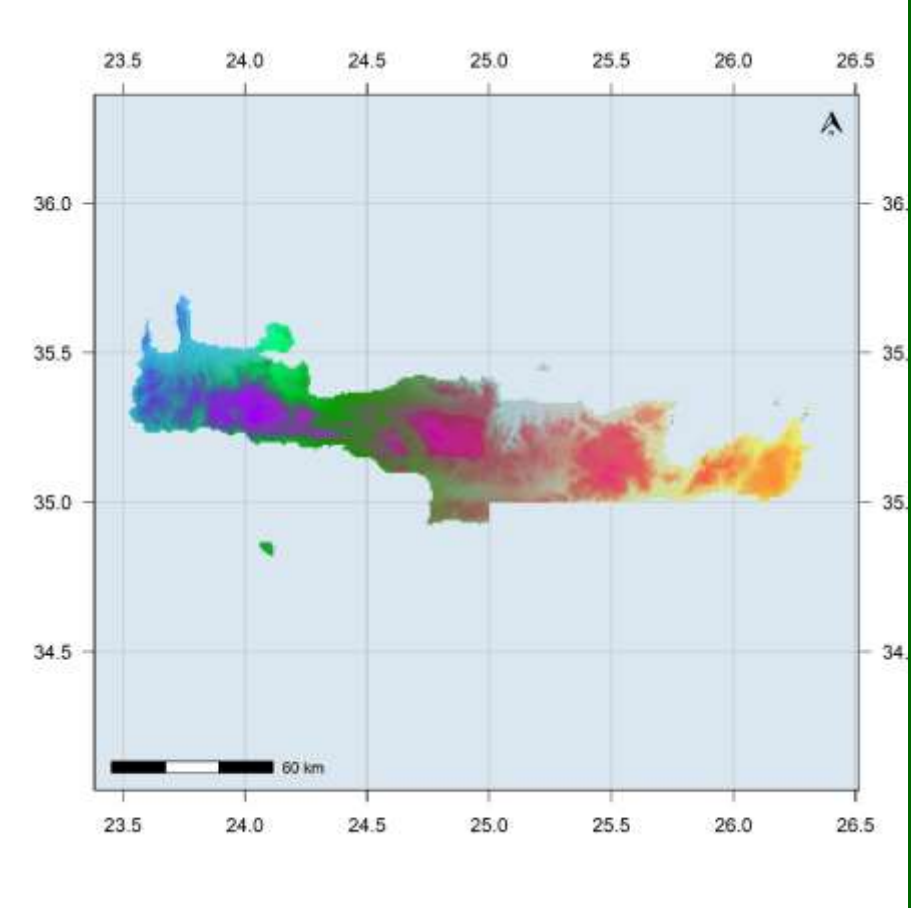


What's the current state of Crete's biogeographical compartmentalization?

Figure from: Trigas et al. (2015). Topographic map of Crete with the three main mountain massifs, PLOS ONE, https://doi.org/10.1371/journal.pone.0059425.g001

Results - Discussion

- Impact on biogeography?



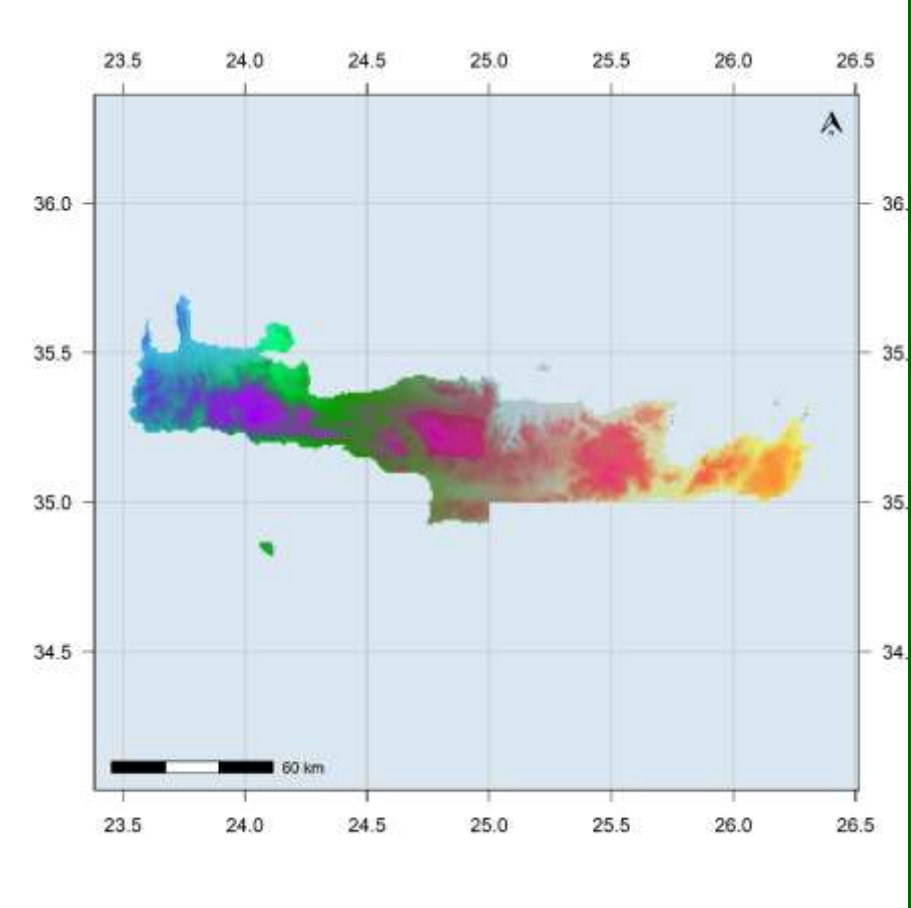
What's the current state of Crete's biogeographical compartmentalization?

The Cretan mountain massifs, as well as the island's topographical heterogeneity, seem to have largely shaped its biogeographical subdivision

A smooth transition zone is apparent in a W-E axis along the island's entire altitudinal range, which is in line with the prevailing climate regime

Results - Discussion

- Impact on biogeography?



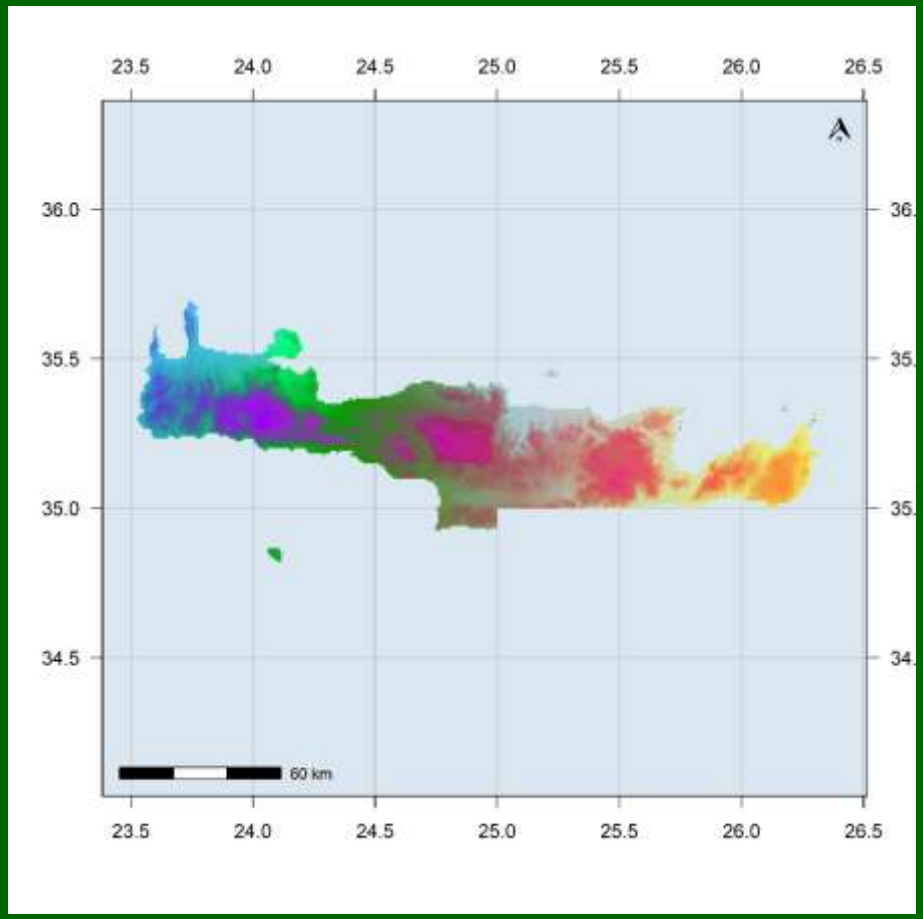
What's the current state of Crete's biogeographical compartmentalization?

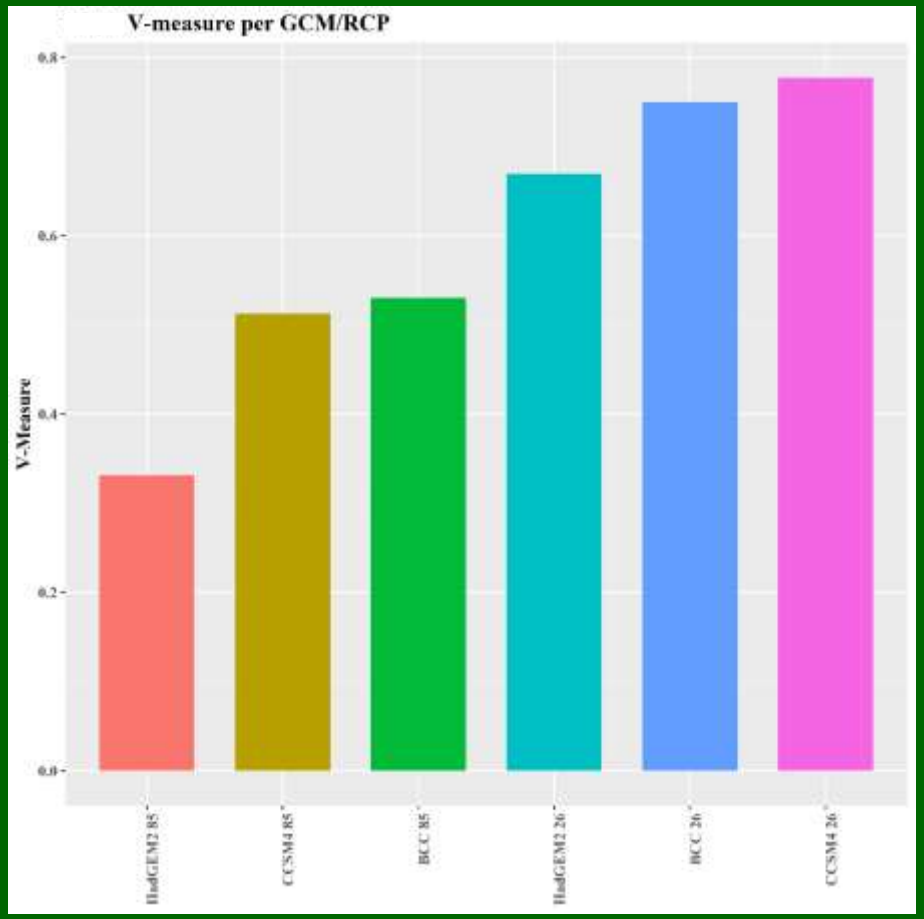
How will it change?

Crete is expected to lose a significant portion of its biogeographical heterogeneity in the coming decades under any GCM/RCP

Results - Discussion

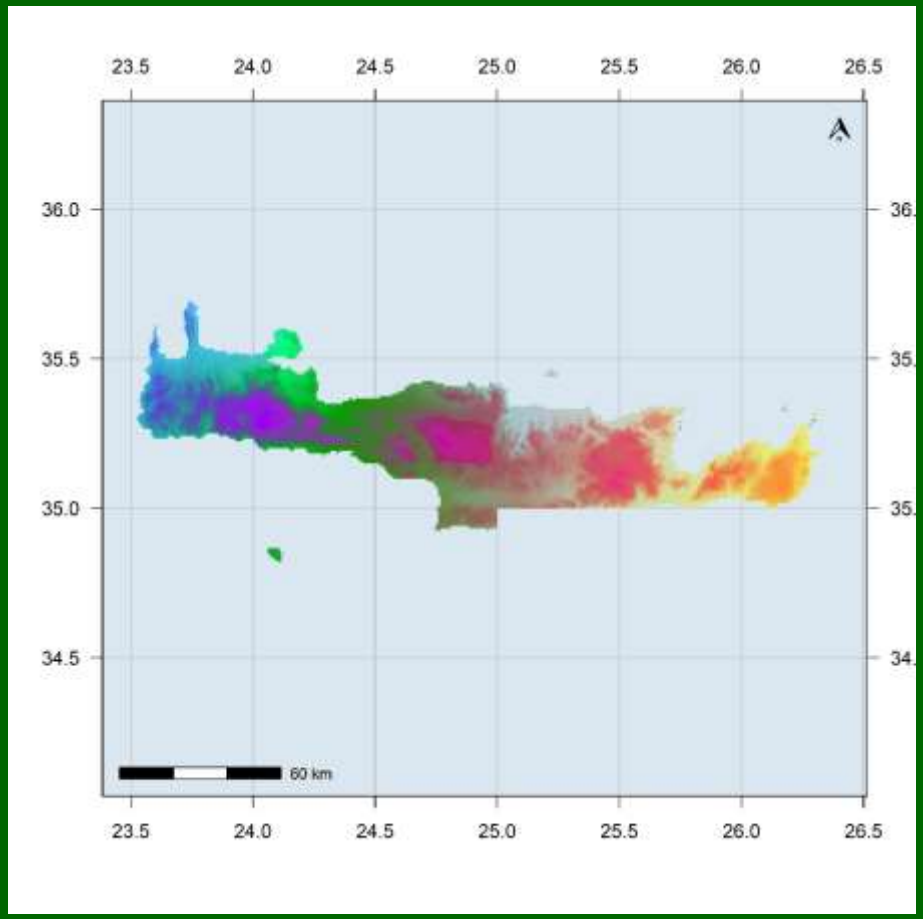
- Impact on biogeography?

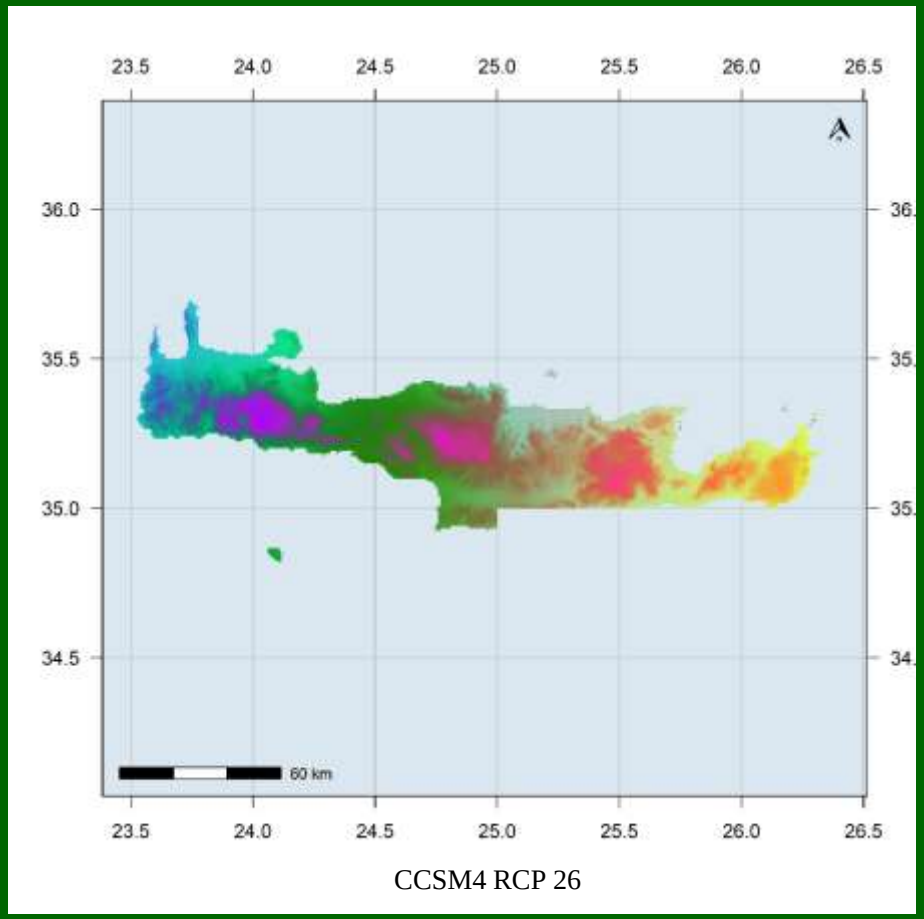




Results - Discussion

- Impact on biogeography?

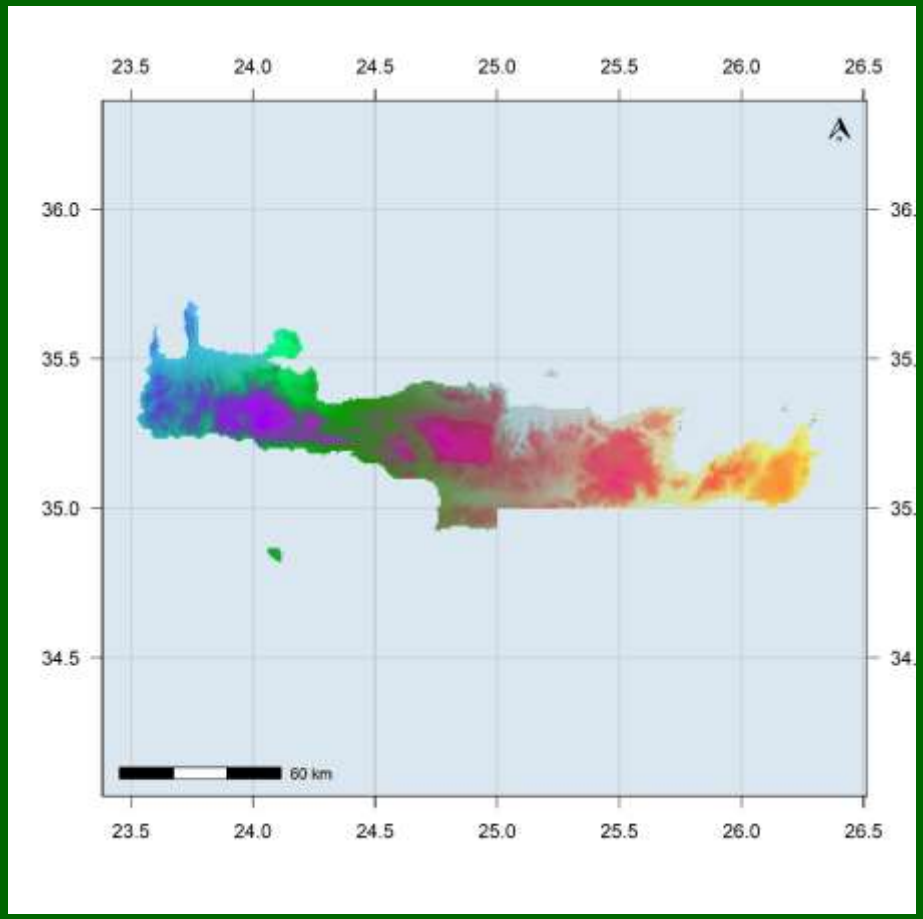


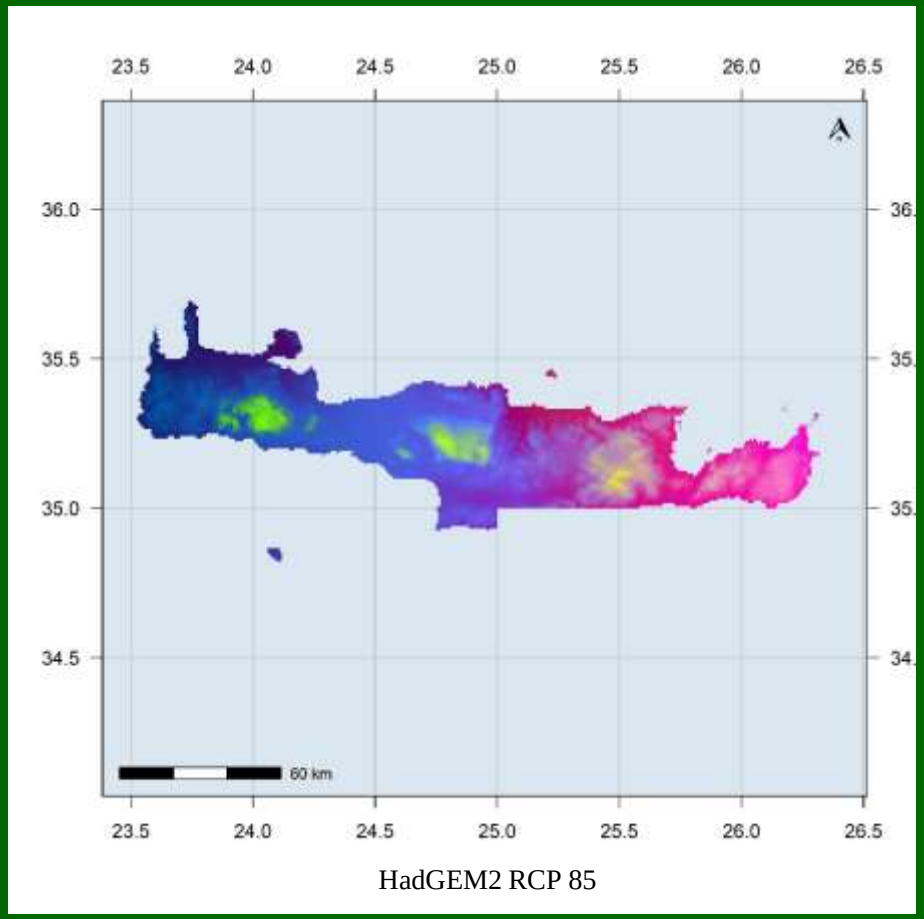


CCSM4 RCP 26

Results - Discussion

- Impact on biogeography?



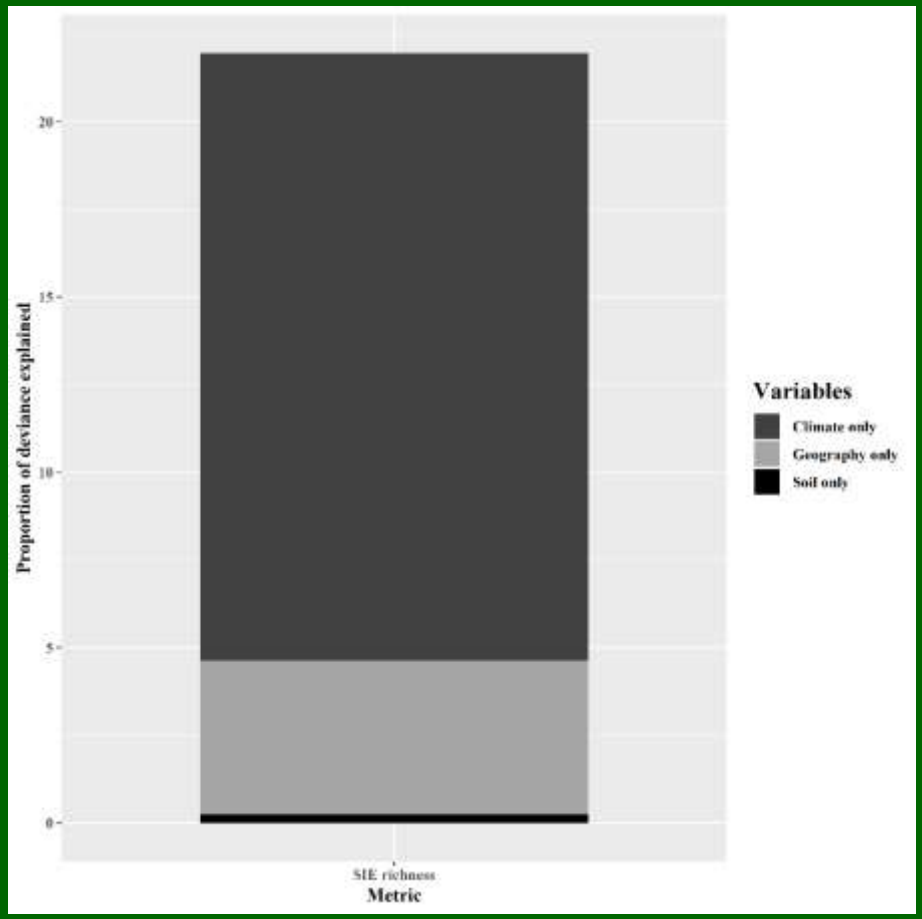


HadGEM2 RCP 85

Results - Discussion

- Impact on community composition?

Which are the most important variables in shaping Cretan SIE community assemblages?



Results - Discussion

- Impact on community composition?

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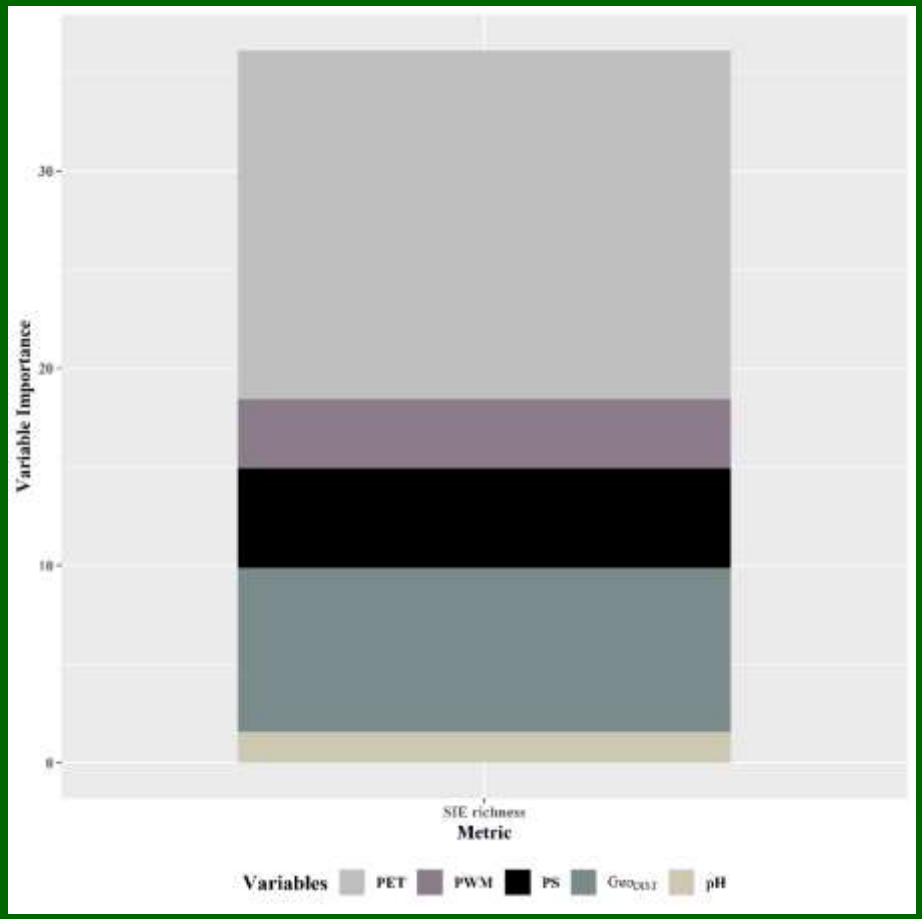


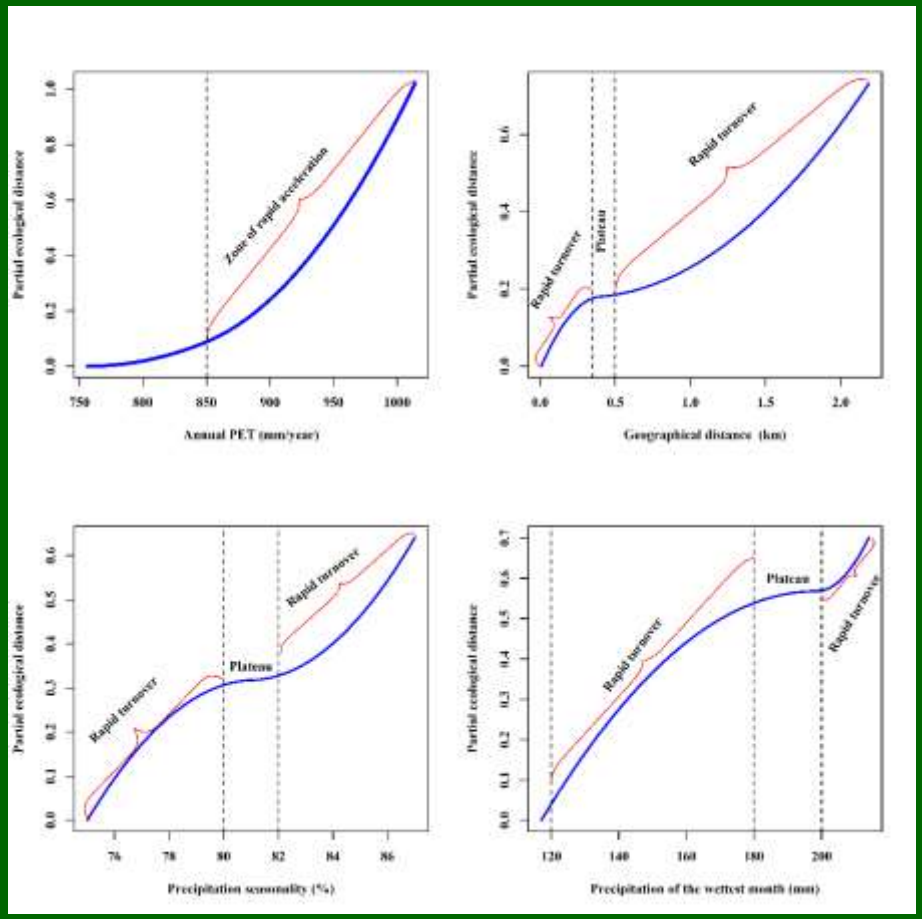
Results - Discussion

- Impact on community composition?

Which are the most important variables in shaping Cretan SIE community assemblages?

Non-linear relationships

Abrupt changes



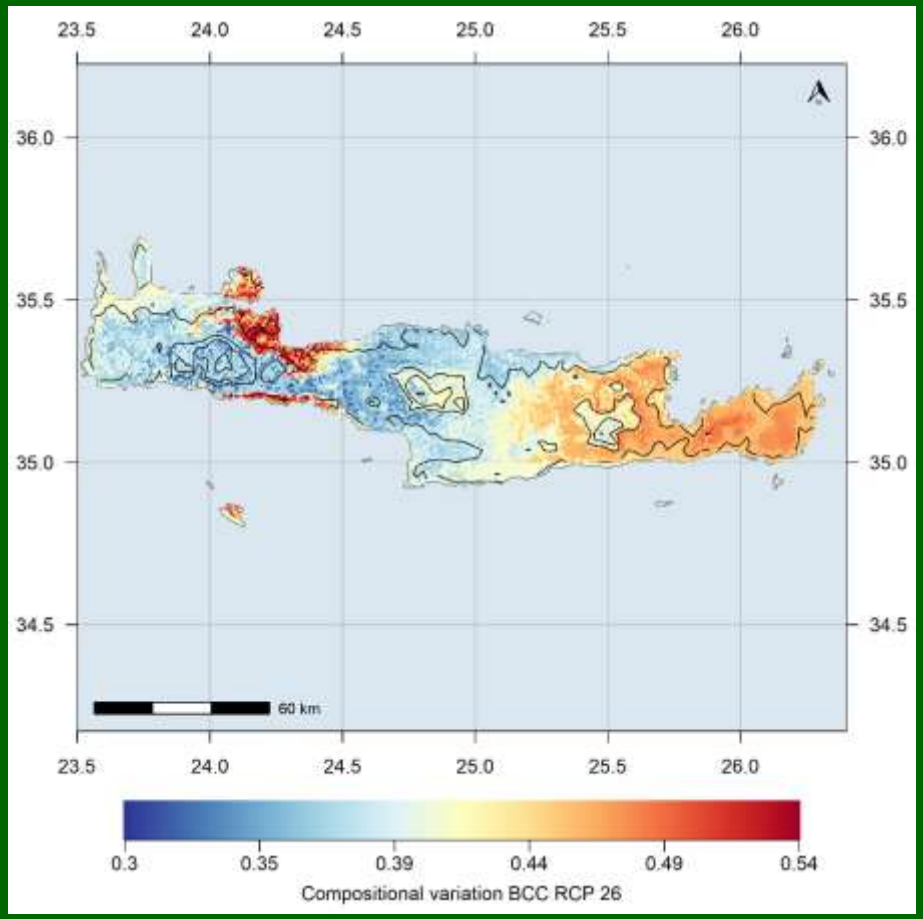
Results - Discussion

- Impact on community composition?

At which locations are the largest differences anticipated?

Results - Discussion

- Impact on community composition?

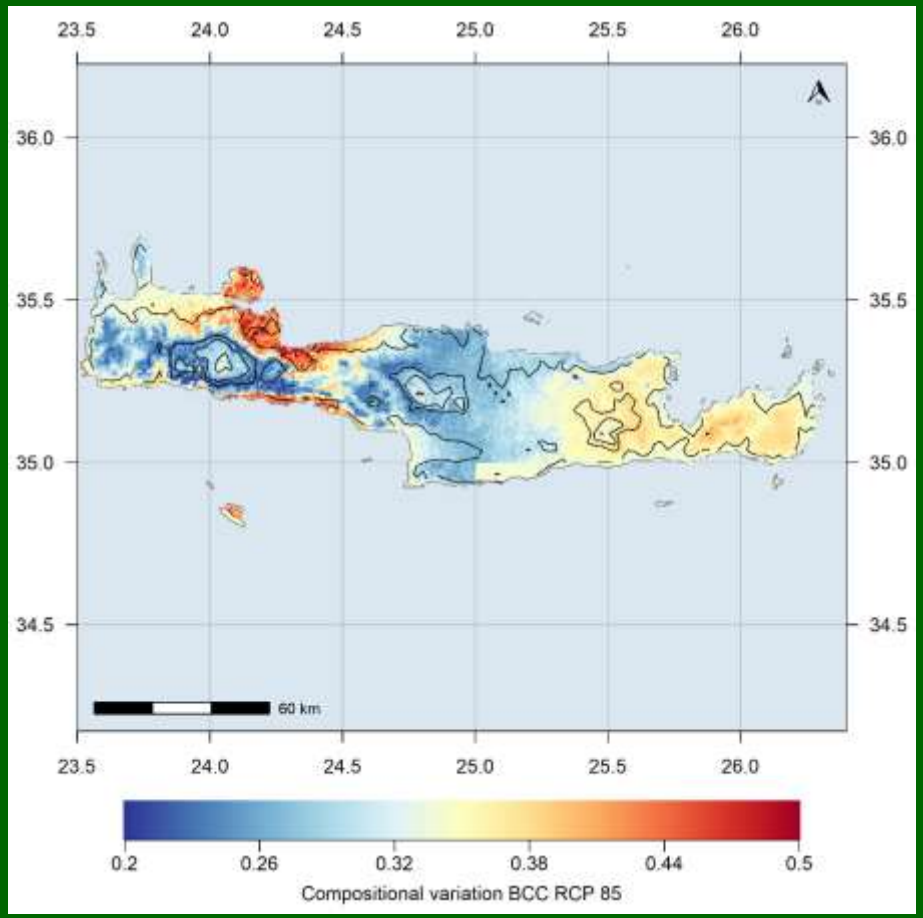


At which locations are the largest differences anticipated?

In every GCM and RCP, the low-elevation area between Rethymno and Chania is predicted to exhibit the greatest floristic turnover than any other region in Crete, followed by the high-altitude mountain ranges

Results - Discussion

- Impact on community composition?



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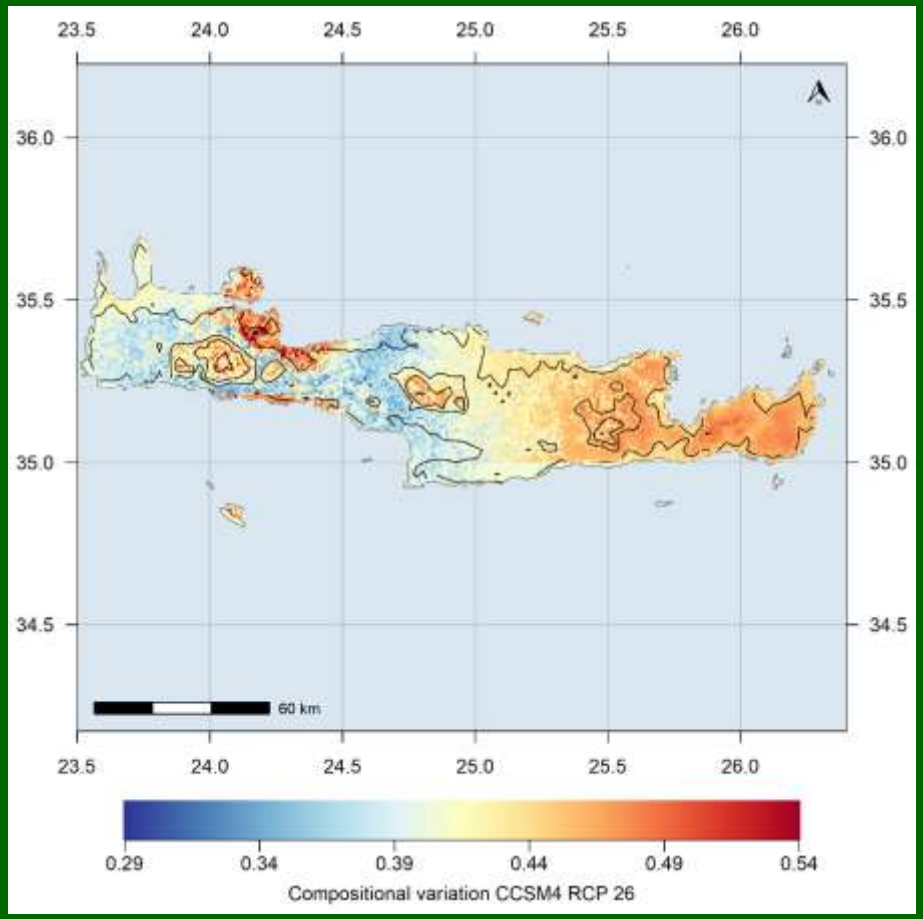
Results - Discussion

- Impact on community composition?



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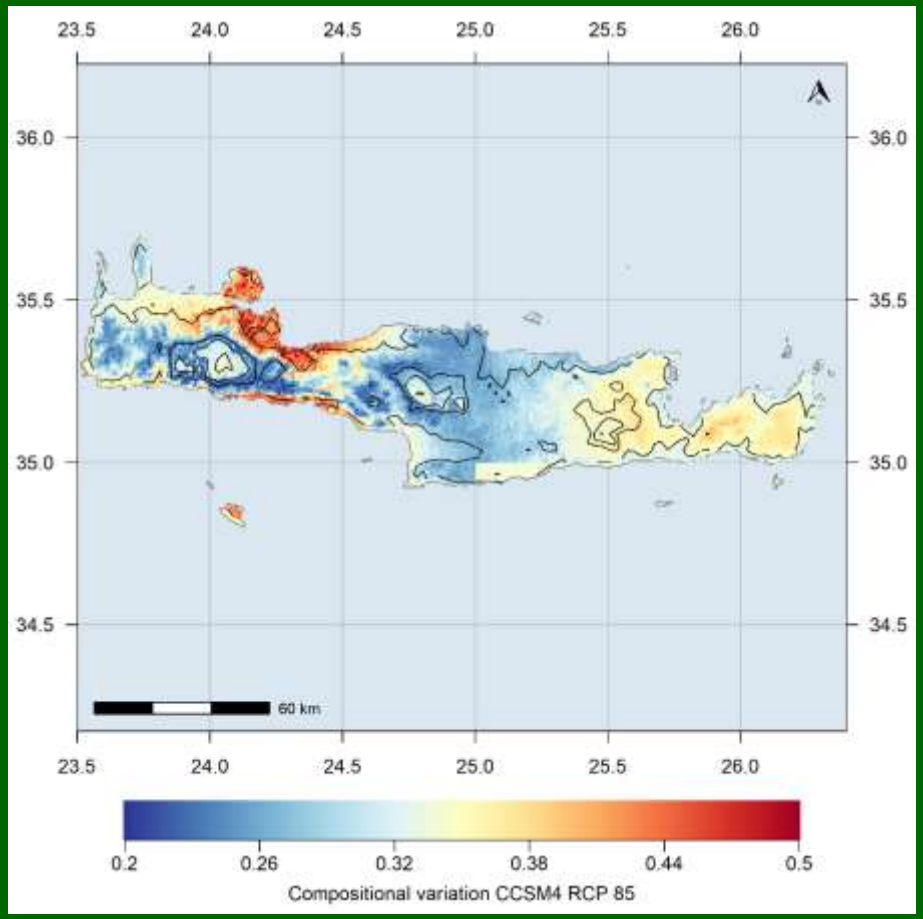
Results - Discussion

- Impact on community composition?



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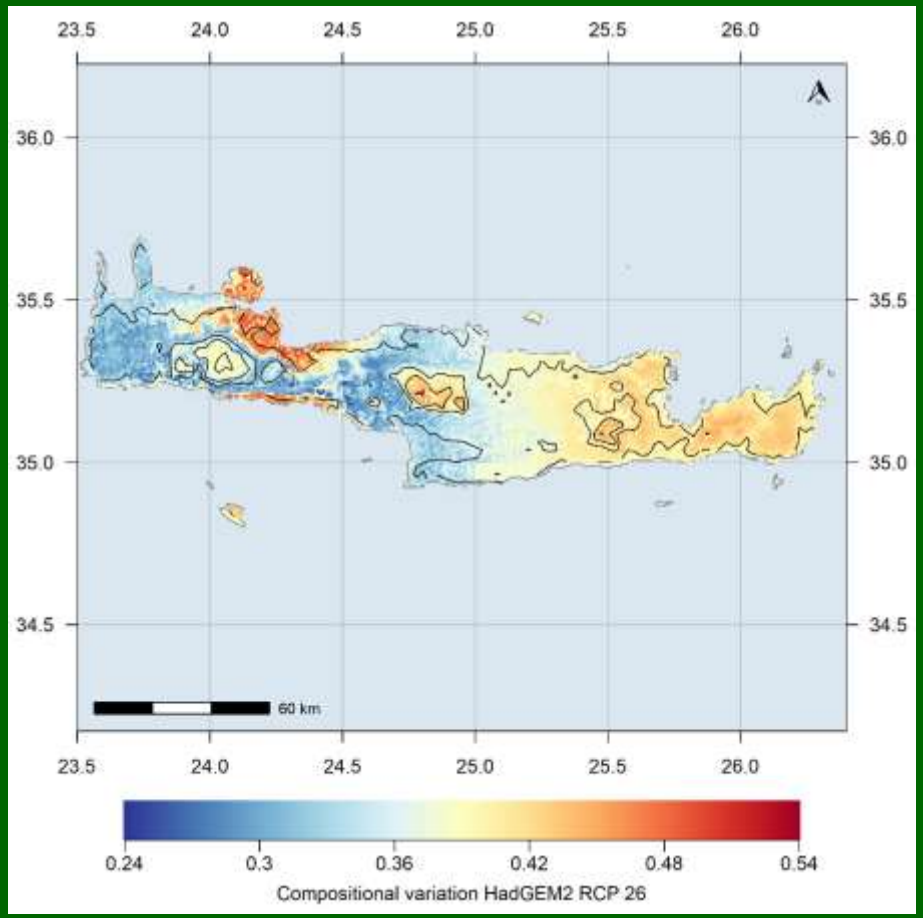
Results - Discussion

- Impact on community composition?



At which locations are the largest differences anticipated?

In every GCM and RCP, the low-elevation area between Rethymno and Chania is predicted to exhibit the greatest floristic turnover than any other region in Crete, followed by the high-altitude mountain ranges

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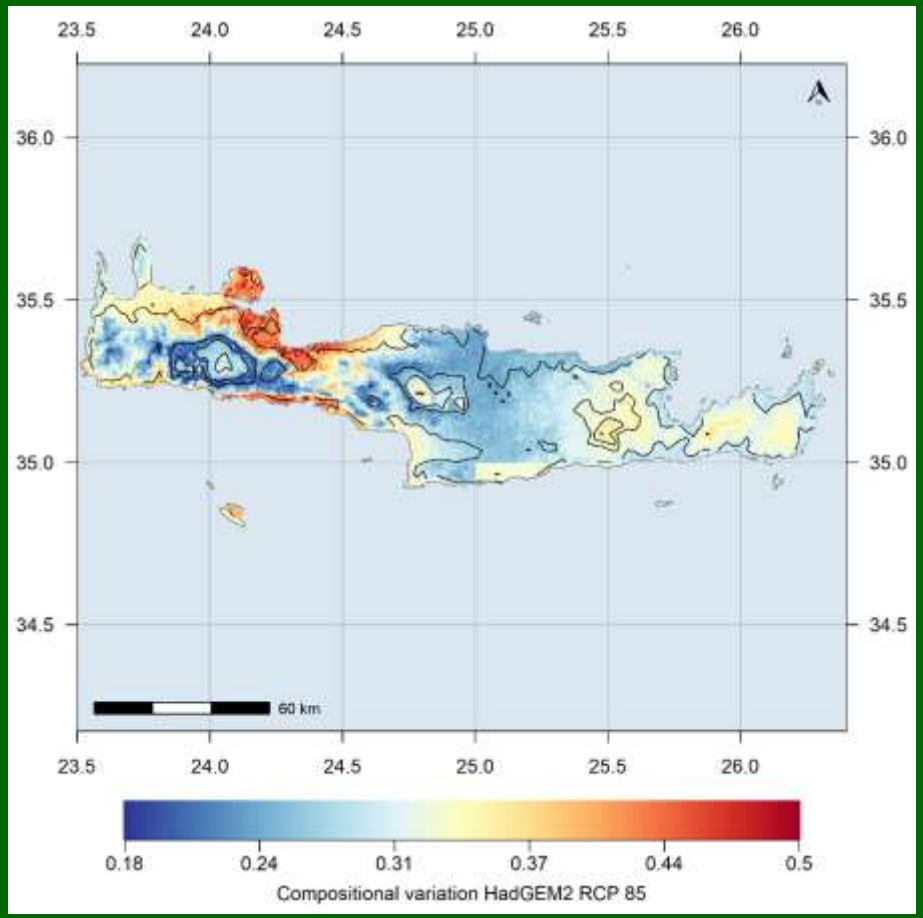

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Conclusions

Conclusions

- The wider area of Lefka Ori and Dikti mountain massifs were climatically stable for the past ca. 4 Myr
- TD hotspot: Sfakia county
- PD hotspot: Ierapetra county
- 24 SIE considered Critically Endangered
- 25% SIE have a narrow niche
- 32.8 – 80.9% SIE are projected to become extinct
- 13 SIE are projected to become extinct under any GCM/RCP
- 44 SIE should be prioritized (EDGE analysis)
- NATURA 2000 sites include mostly LC & VU SIE
- Dramatic area losses are anticipated under any GCM/RCP
- The intricate biogeographical patterns of Crete will most probably diffuse under any GCM/RCP

Conclusions

- What could/should be done?

Closely monitor at least those SIE taxa that emerged as highly significant from the EDGE analysis – An effort should be made for their ex situ conservation → MAICH, NHMC

Establish interdepartmental collaborations for the assessment of their population genetic diversity and in situ conservation status → SoBEx

Inform the relevant local, regional and national authorities and raise public awareness

Thank you for your attention

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