


Insect diversity in a changing world: significance of the forest canopy in conservation and biogeography

Aki Nakamura (中村彰宏)

27 May 2022

XTBG

GBIF

Forest Canopy Ecology Group

林冠生态学研究組

My short bio

- Left Japan after high school in 1996
- BSc 2000, BSc (1st Class Hons.) 2001 & PhD 2007 from Griffith University, Australia

  Supervisors: Profs Carla Catterall & Roger Kitching
- 2007-2013 Postdoctoral fellow at Queensland Museum & Griffith University
- 2013- Xishuangbanna Tropical Botanical Garden, Chinese Academy of Science

Outline

- Taxonomic and geographic biases in biodiversity conservation
- Insect diversity along elevational gradients
- Forest canopy ecology
  - Manipulative experiment 1: Vertical stratification in trophic cascading
  - Manipulative experiment 2: Vertical stratification of community assembly in phytotelm microcosms
  - Field survey: Relative importance of species interactions in arboreal ants in rubber plantations and rainforests
- Concluding remarks:
  - Forest canopies as an integral part of biogeography and conservation

Taxonomic and geographic biases in biodiversity conservation

Insect apocalypse?

Biological Conservation 242 (2020) 108426

Contents lists available at ScienceDirect

Biological Conservation

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

ELSEVIER

Perspective

Scientists' warning to humanity on insect extinctions

Pedro Cardoso[a,*], Philip S. Barton[b], Klaus Birkhofer[c], Filipe Chichorro[a], Charl Deacon[d], Thomas Fartmann[e], Caroline S. Fukushima[a], René Gaigher[d], Jan C. Habel[f], Caspar A. Hallmann[g], Matthew J. Hill[h], Axel Hochkirch[i,j], Mackenzie L. Kwak[k], Stefano Mammola[a,l], Jorge Ari Noriega[m], Alexander B. Orfinger[n,o], Fernando Pedraza[p], James S. Pryke[d], Fabio O. Roque[q,r], Josef Se
Carlien Vorster[d], Michael J

Biological Conservation 242 (2020) 108427

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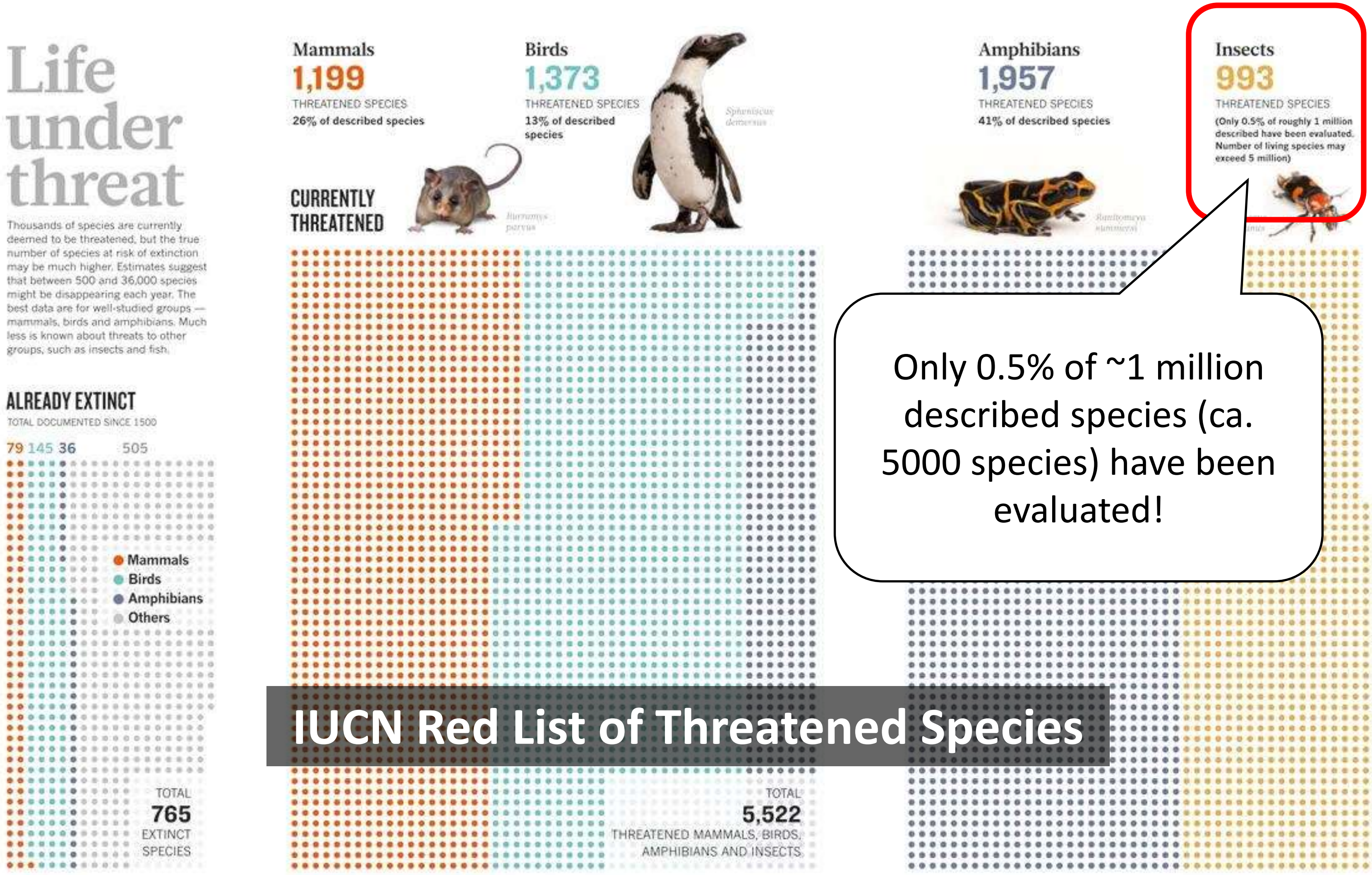
ELSEVIER

Review

Solutions for humanity on how to conserve insects

Michael J. Samways[a,*], Philip S. Barton[b], Klaus Birkhofer[c], Filipe Chichorro[d], Charl Deacon[a], Thomas Fartmann[e], Caroline S. Fukushima[d], René Gaigher[a], Jan C. Habel[f,g], Caspar A. Hallmann[h], Matthew J. Hill[i], Axel Hochkirch[j,k], Lauri Kaila[l], Mackenzie L. Kwak[m], Dirk Maes[n], Stefano Mammola[d,o], Jorge A. Noriega[p], Alexander B. Orfinger[q,r], Fernando Pedraza[s], James S. Pryke[a], Fabio O. Roque[t,u], Josef Settele[v,w,x], John P. Simaika[y,z], Nigel E. Stork[aa], Frank Suhling[ab], Carlien Vorster[a], Pedro Cardoso[d]

Taxonomic bias in biodiversity conservation

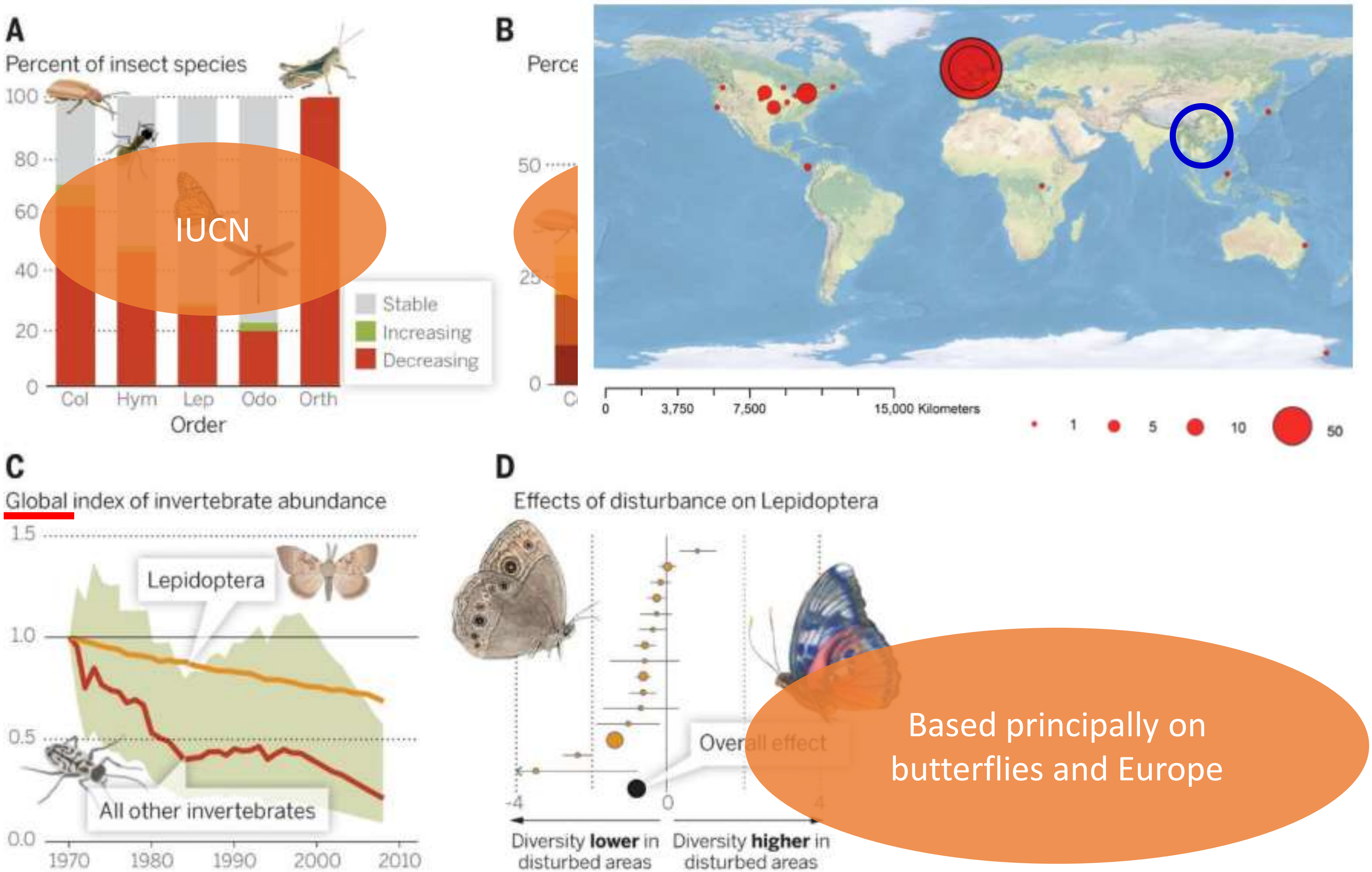


Only 0.5% of ~1 million described species (ca. 5000 species) have been evaluated!

IUCN Red List of Threatened Species

Monastersky 2014 *Nature*

Taxonomic and geographic biases in biodiversity conservation



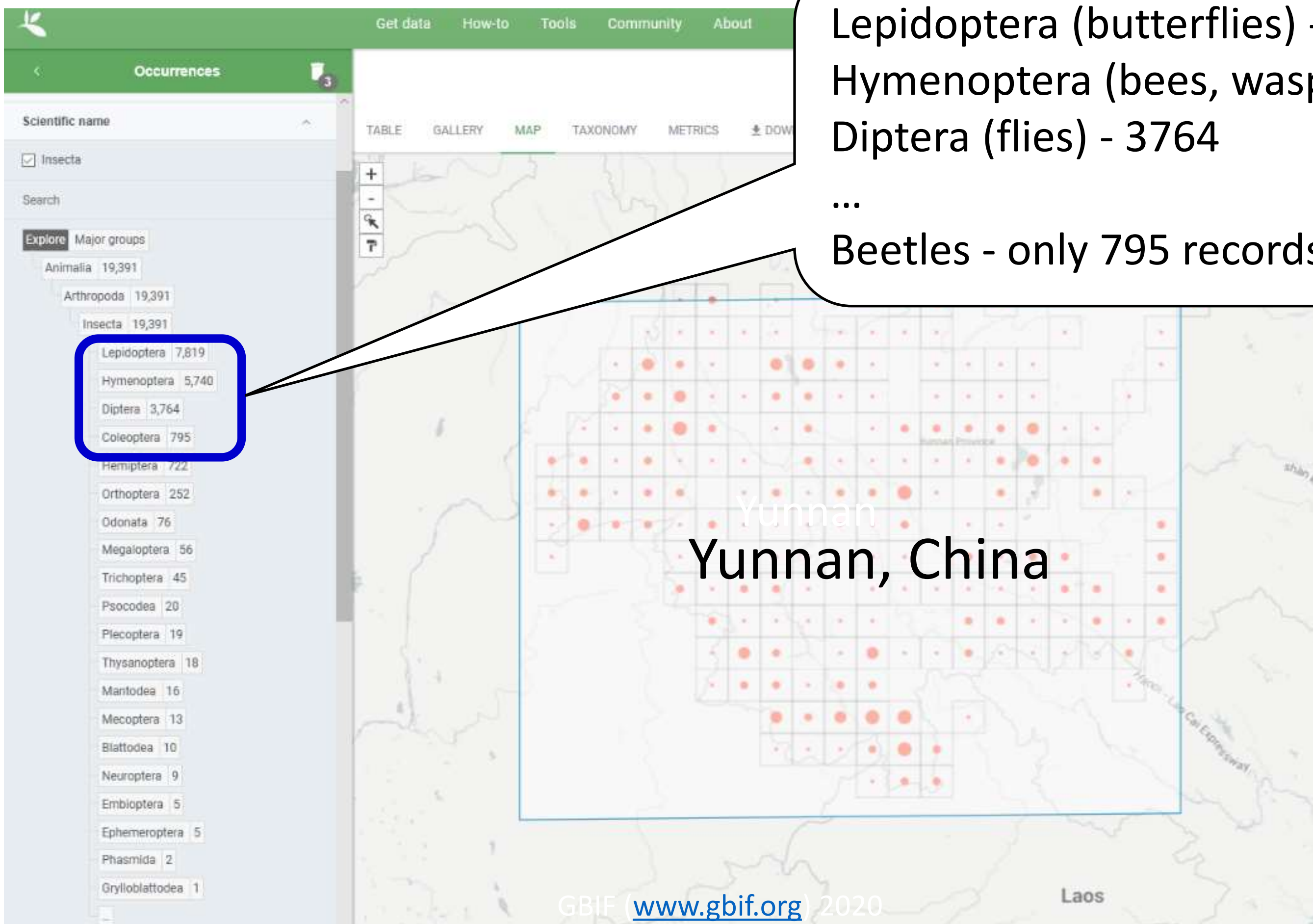
Dirzo 2014 *Science*

Taxonomic and geographic biases for biodiversity conservation

200 000 record of plant species and 83 000 records of birds

Yet insects only represent 19 000!!!! Most of them being butterflies

Lepidoptera (butterflies) - 7819 records
Hymenoptera (bees, wasps) - 5740
Diptera (flies) - 3764
…
Beetles - only 795 records!



GBIF (www.gbif.org) 2020

More “boots” for biodiversity research

MENU
nature ecology & evolution

Comment | Published: 24 October 2017

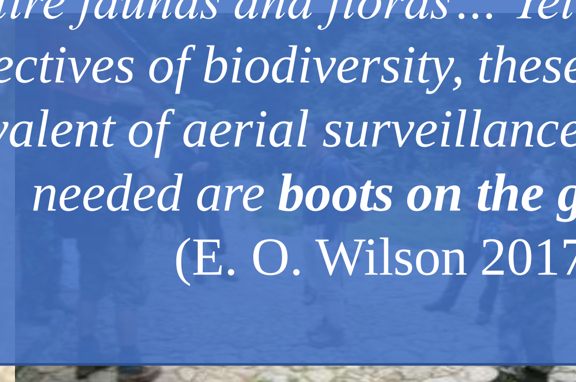
Biodiversity research requires more boots on the ground

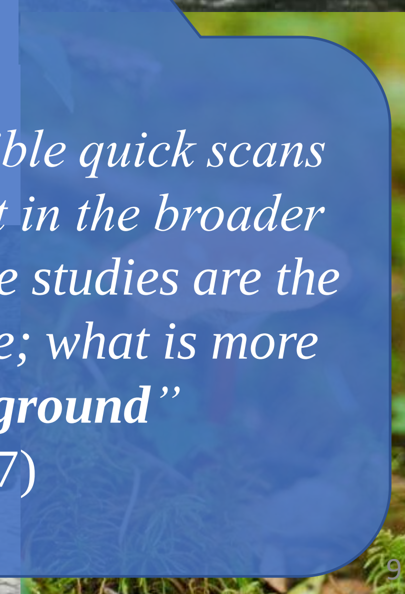
Edward O. Wilson

Nature Ecology & Evolution **1**, 1590–1591(2017) | Cite this article

Our incomplete taxonomic knowledge impedes our attempts to protect biodiversity. A renaissance in the classification of species and their interactions is needed to guide conservation prioritization.

“Complete genomes make possible quick scans of entire faunas and floras… Yet in the broader perspectives of biodiversity, these studies are the equivalent of aerial surveillance; what is more needed are ***boots on the ground****”*
(E. O. Wilson 2017)





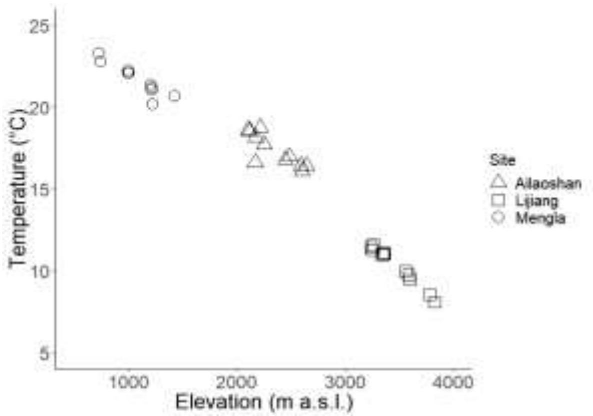
My previous work (2010-)
Insect diversity along elevational gradients

Climate change and forest biodiversity

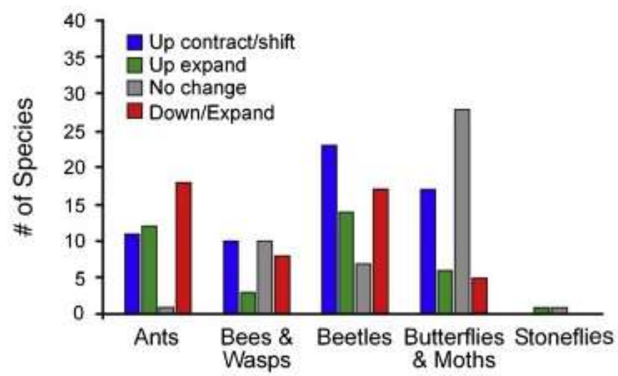
• Increase in temperature and change in rainfall regime

• Poleward and upward shifts of species

Lenoir et al. 2008 *Science*, Chen et al. 2011 *Science*



Fontanilla, Nakamura* et. al. 2019 *Insects*



McCain & Garfinkel. 2021 *Curr Opi in Insect Sci*

• Paucity of baseline information on the elevational distribution of insects

IBISCA and QCAS projects

QCAS 2010-2013 – **Q**ueensland and **C**hinese **A**cademy of **S**ciences Biodiversity Project (led by Profs Roger Kitching and Min Cao)

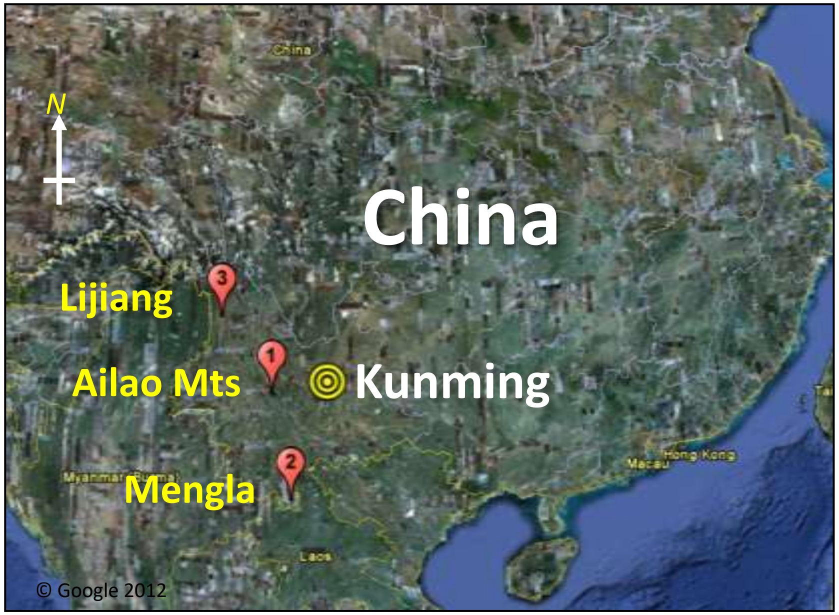
• Documented the elevational distribution of insects and plants at intercontinental scale

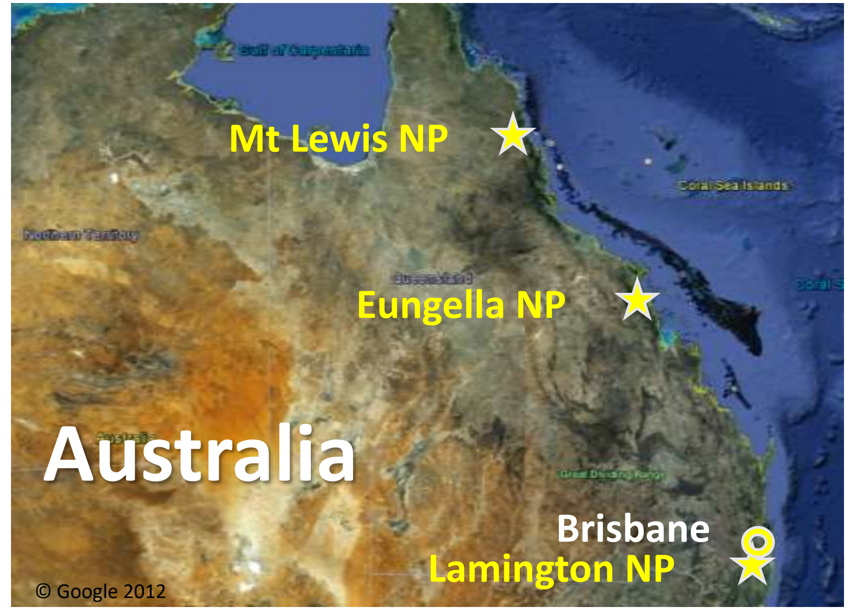
Funded by: 中國科學院 CHINESE ACADEMY OF SCIENCES Queensland Government

QCAS BIODIVERSITY



Elevational transects in China and Australia

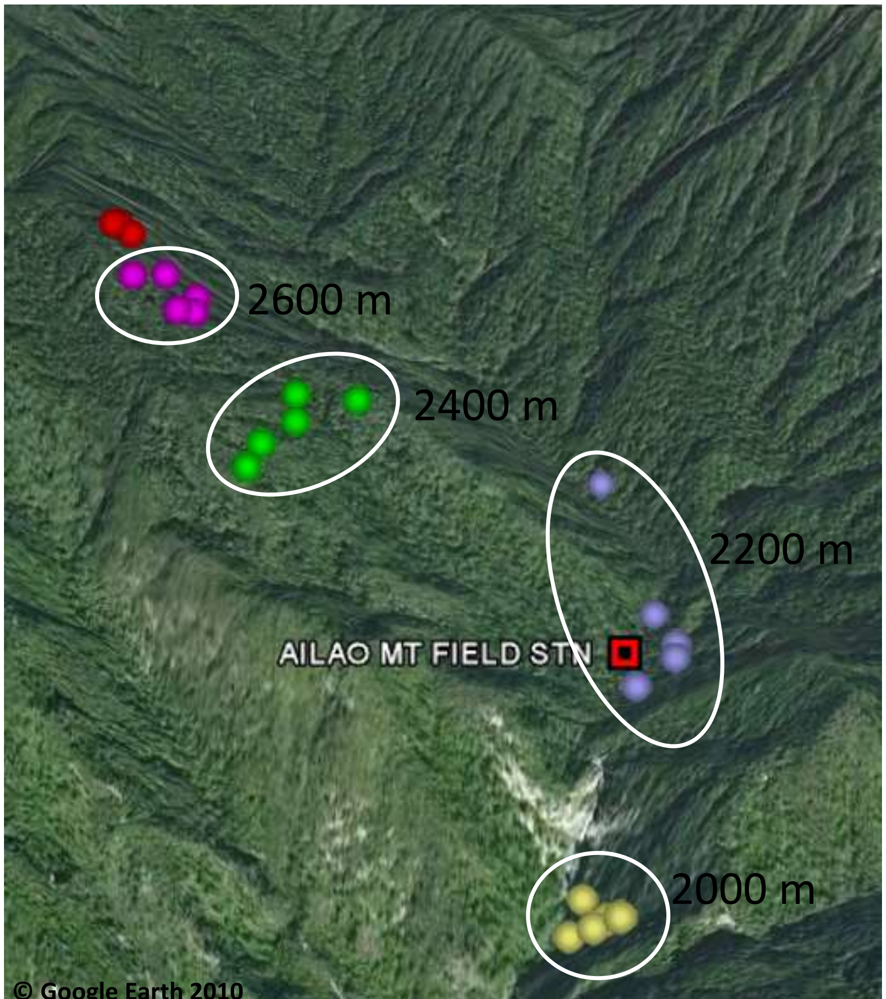




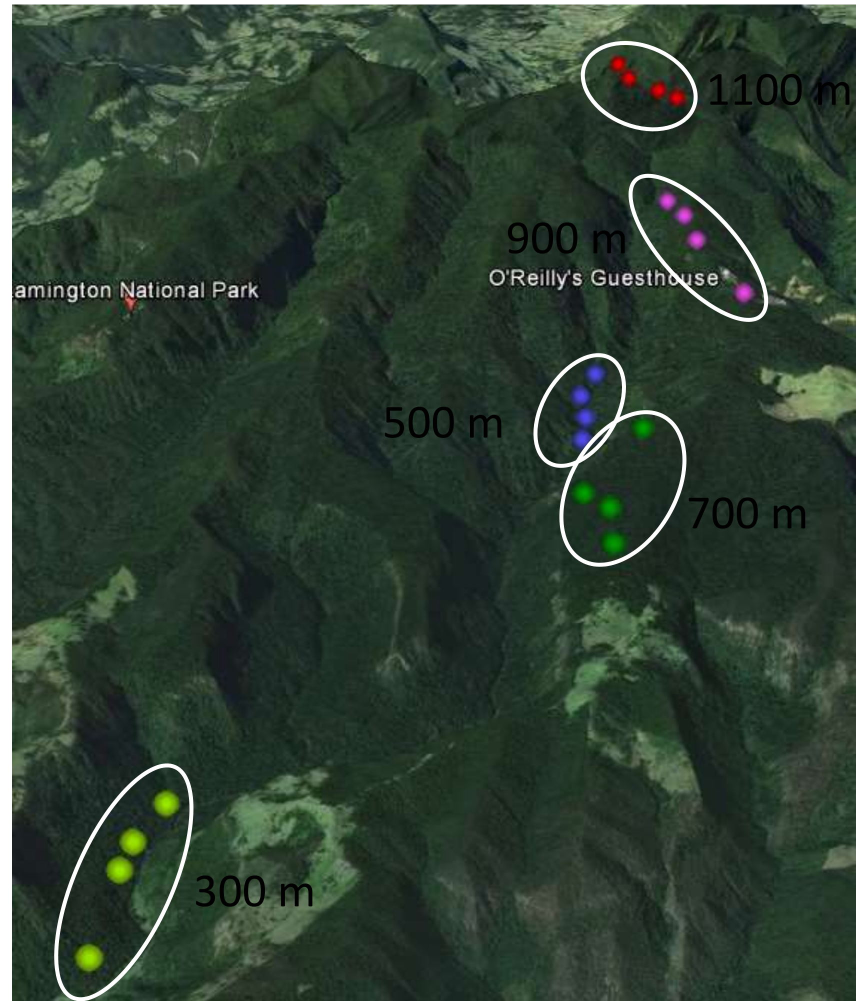
Transect location	Survey date	Latitude	Climate	Ave. temp.	Ave. annual rainfall	Survey altitudes
Lijiang	Aug 2012	27.0°N	Sub-alpine	5°C	664 mm	3200-3800 m
Ailao Mts	Aug 2011	24.5°N	Sub-tropical	11°C	1900 mm	2000-2700 m
Mengla	July 2012	21.5°N	Tropical	22°C	1211 mm	800-1400 m
Mt Lewis NP	March 2012	16.3°S	Tropical	24°C	2038 mm	400-1200 m
Eungella NP	2013-2014	20.5°S	Tropical	22°C	1593 mm	200-1200 m
Lamington NP	2006-2008	28.1°S	Sub-tropical	21°C	1361 mm	300-1100 m

All transects with 200 m elevational intervals

Ailao Mts



Lamington NP



Botanical survey

- All trees > 5 cm dbh tagged & identified
- Saplings and seedlings
- Epiphytes
- Litter fall and seed rain
- Phenology

Environmental data

- **Temperature and humidity** (1~2 year)
  - Leaf litter
  - Understorey
  - Canopy

- **Soil properties**
  (soil organic/inorganic matter, acidity, etc.)

Invertebrate survey

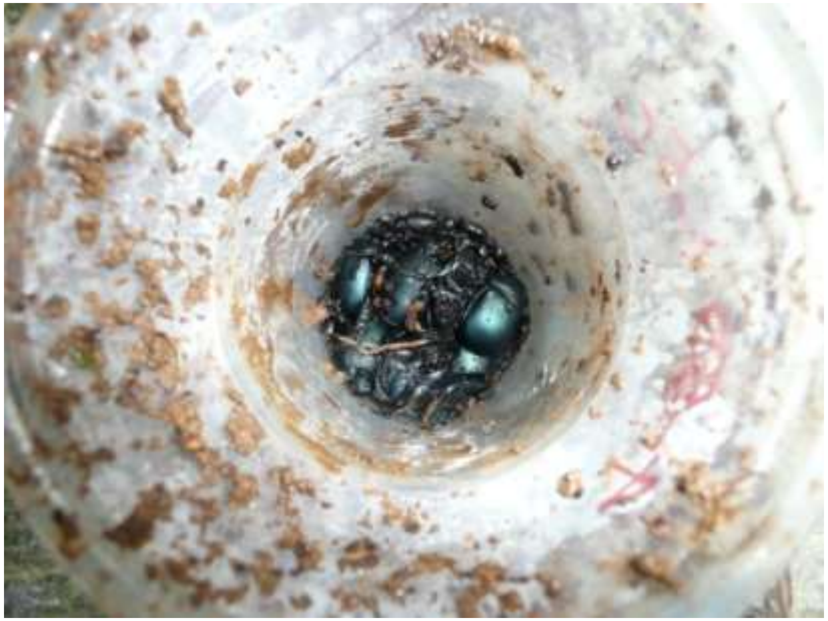
• **Light traps in canopy and understorey** (moths and beetles)

Invertebrate survey

- **Light traps in canopy and understorey** (moths and beetles)
- **Pitfall traps** (ants and beetles)

Invertebrate survey

- **Light traps in canopy and understorey** (moths and beetles)
- **Pitfall traps** (ants and beetles)
- **Dung traps** (scarabs)



Invertebrate survey

- **Light traps in canopy and understorey** (moths and beetles)
- **Pitfall traps** (ants and beetles)
- **Dung traps** (scarabs)
- **Malaise traps** (beetles and wasps)



Invertebrate survey

- **Light traps in canopy and understorey** (moths and beetles)
- **Pitfall traps** (ants and beetles)
- **Dung traps** (scarabs)
- **Malaise traps** (beetles and wasps)
- **Litter extraction** (ants and beetles)

Invertebrate survey

- **Light traps in canopy and understorey** (moths and beetles)
- **Pitfall traps** (ants and beetles)
- **Dung traps** (scarabs)
- **Malaise traps** (beetles and wasps)
- **Litter extraction** (ants and beetles)
- **Bark sprays** (ants and beetles)

Invertebrate survey

- **Light traps in canopy and understorey** (moths and beetles)
- **Pitfall traps** (ants and beetles)
- **Dung traps** (scarabs)
- **Malaise traps** (beetles and wasps)
- **Litter extraction** (ants and beetles)
- **Bark sprays** (ants and beetles)
- **Hand collecting** (ants and beetles)

Elevational diversity patterns

- Moths – 48358 specimens (>4000 morphospecies)

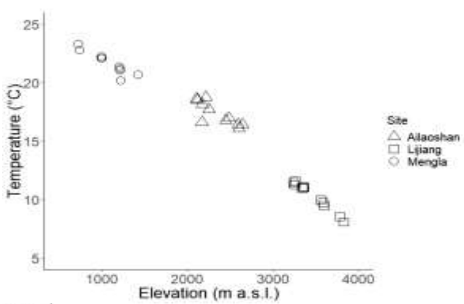
Ashton, Nakamura* et al. 2016 *Scientific Reports*

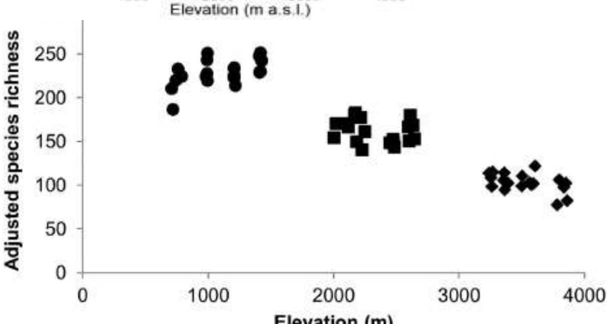
- Beetles – 25753 specimens (1041 morphospecies)

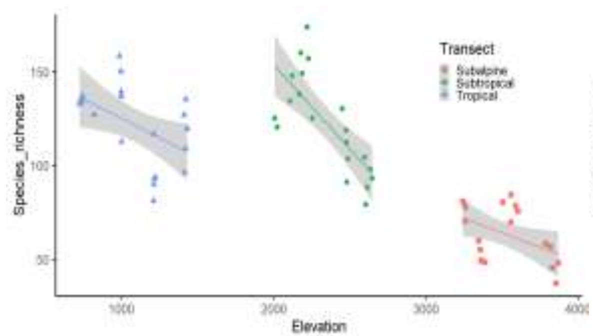
Chalise, Nakamura* et al. *in prep*

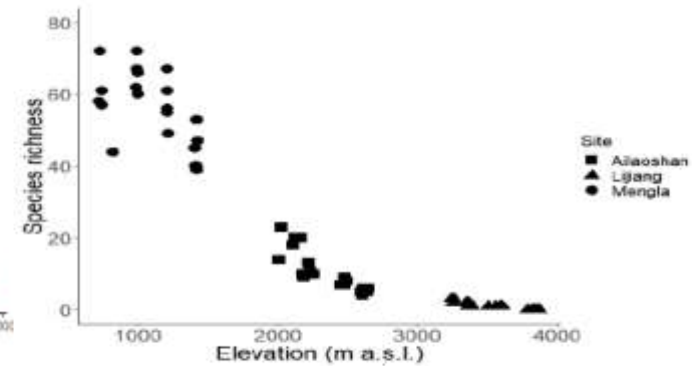
- Ants – 3487 specimens (263 morphospecies)

Fontanilla, Nakamura* et al. 2019 *Insects*





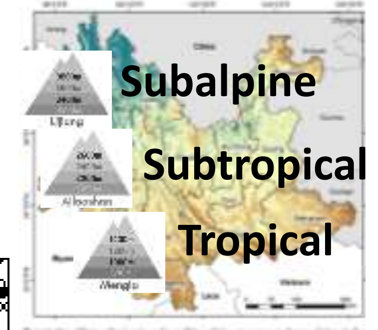




Elevational "sensitivity": elevational distance decay curves

Almost all herbivores

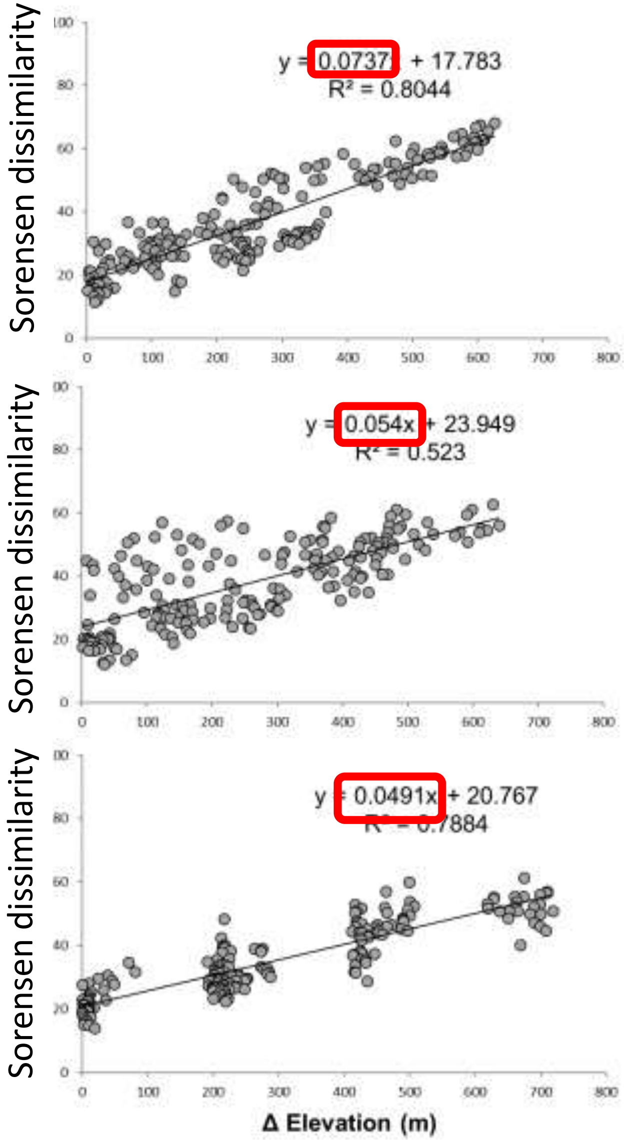
Herbivore guild Chrysomelidae etc

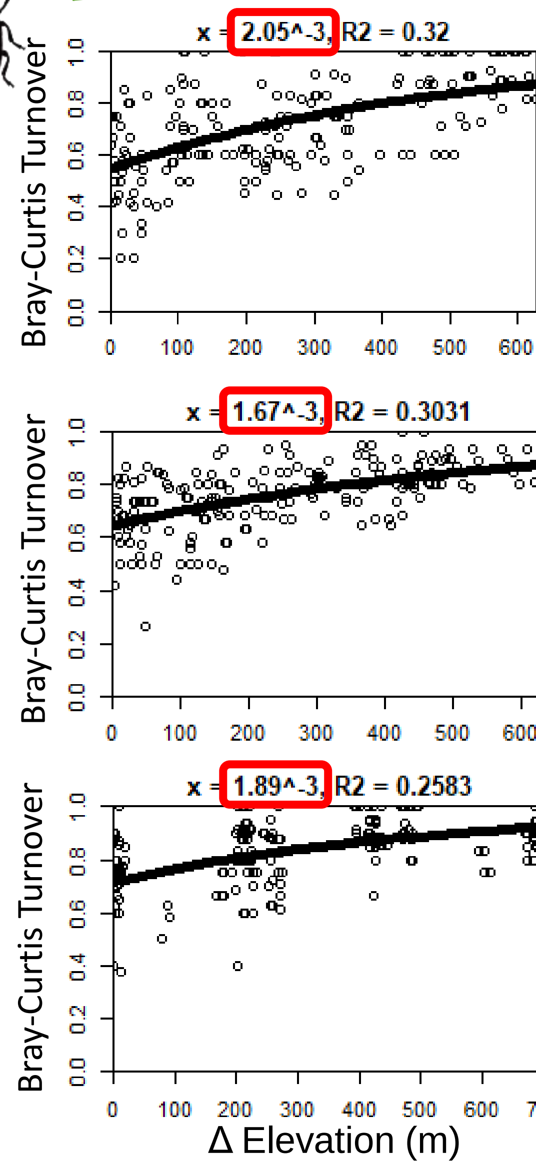


Subalpine

Subtropical

Tropical





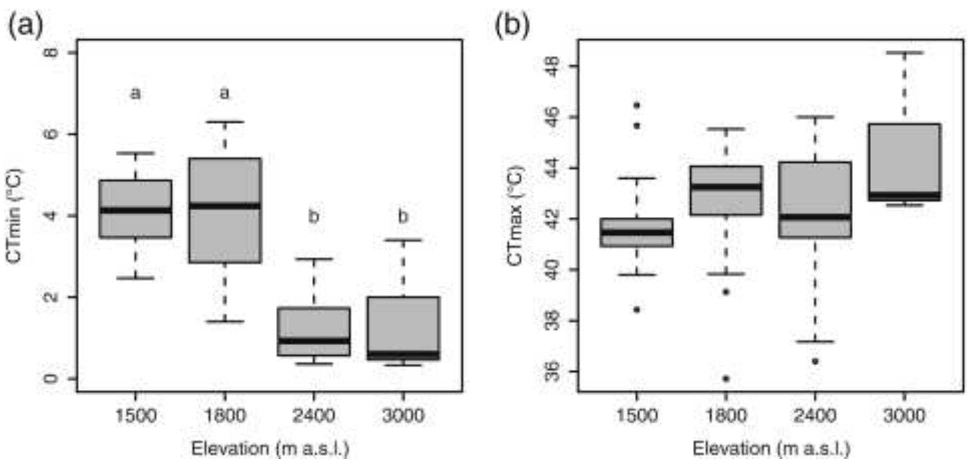
Increase in slope (elev. diffentiation)

Ashton, Nakamura* et al. 2016 *Scientific Reports*

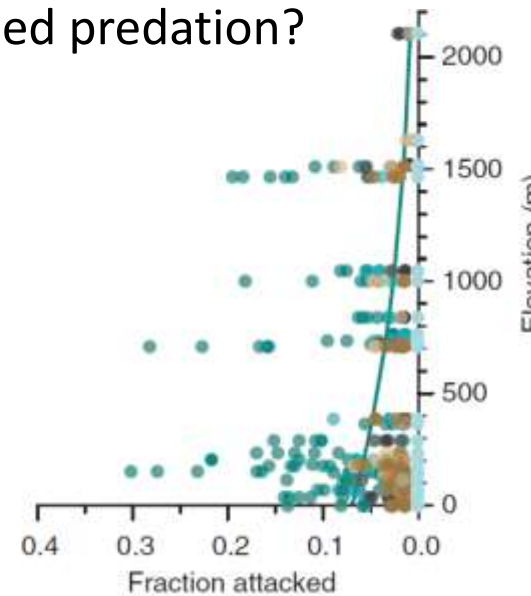
Chalise, Nakamura* et al. *in prep*

Implications

- Herbivore communities are more “sensitive” to elevational gradients in cooler than warmer biomes – more vulnerable to climate change?
- BUT – **heat tolerance is generally less variable and more phylogenetically conserved than cold tolerance** (thermal niche asymmetry) with elevation
  Aarujo et al. 2013 *Eco Lett*, Nowrouzi et al. 2018 *Oecologia*, Bishop et al. 2017 *Eco Ento*, Leahy et al in press *Ecology*
- Climate change – the impacts of warming *per se* may be unimportant in cooler biomes?
- What are the threats? Invasion from below? Increased predation?



Bishop et al. 2017 *Eco Ento*



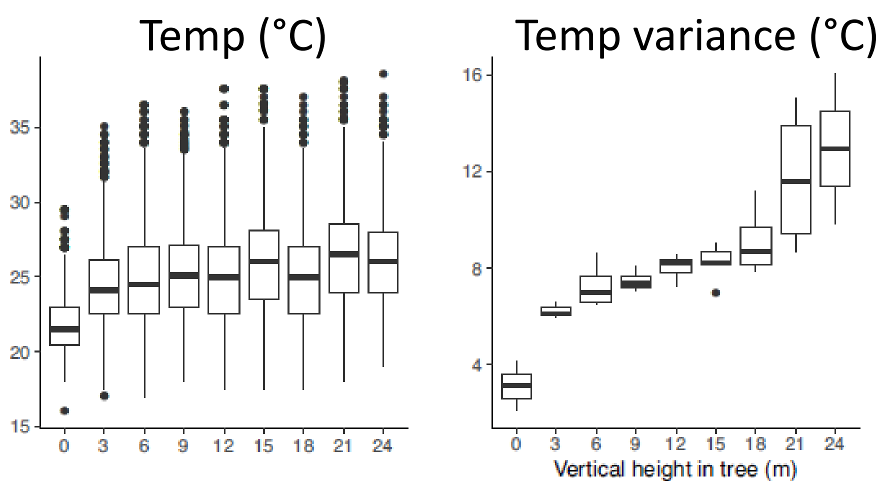
Roslin… Nakamura et al. 2017 *Science*

Manipulative experiment 1: Effects of predation on trophic cascading

Forest canopies

- ‘Hotspot’ of biological diversity – greater species interactions?

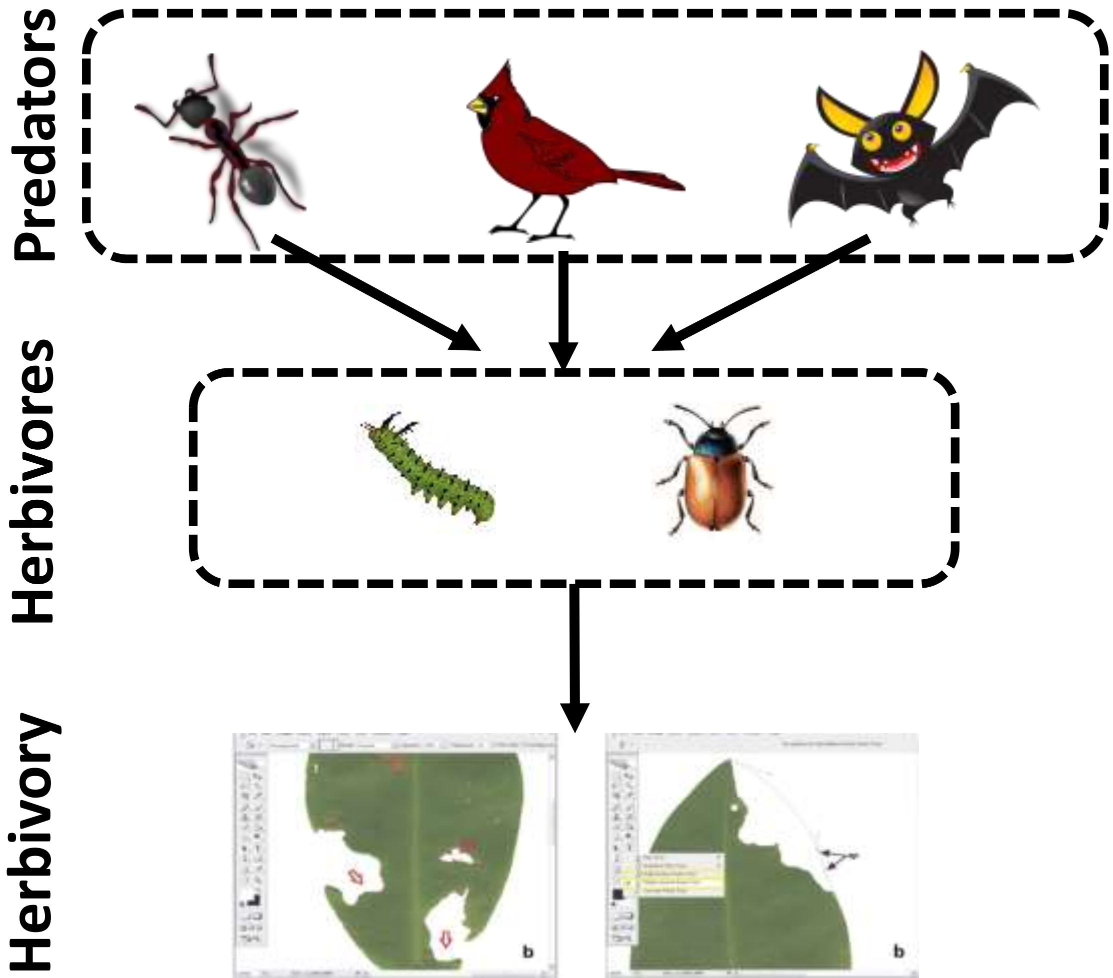
- Distinct vertical changes in microclimatic condition



Leahy et al. 2021 *Div and Dist*

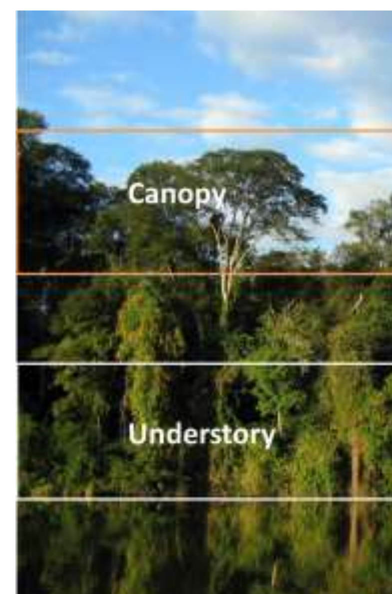
Vertical stratification in trophic cascading

Tri-trophic interactions of predators, arthropod herbivores and herbivory in the forest understory and canopy
(by Yuanyuan Quan, MSc project)



Collaboration with Katerina Sam

The Czech Academy of Sciences



Manipulative Field Experiment

Duration: 3 months
Replicated across 4 tree species

4 treatments (canopy and understorey)

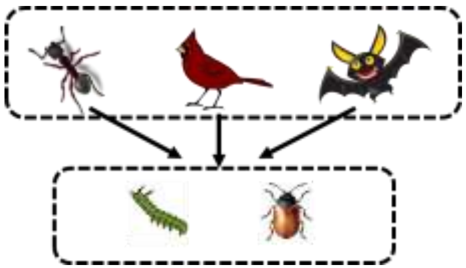
- Control (no exclusion)
- Vertebrate excl.
- Ant excl.
- Ant and vertebrate excl.

Experiment set-ups in a Xishuangbanna tropical seasonal rainforest

Setting a canopy exclosure cage

Canopy crane (80 m high, 60 m jib)

Results: arthropod abundance

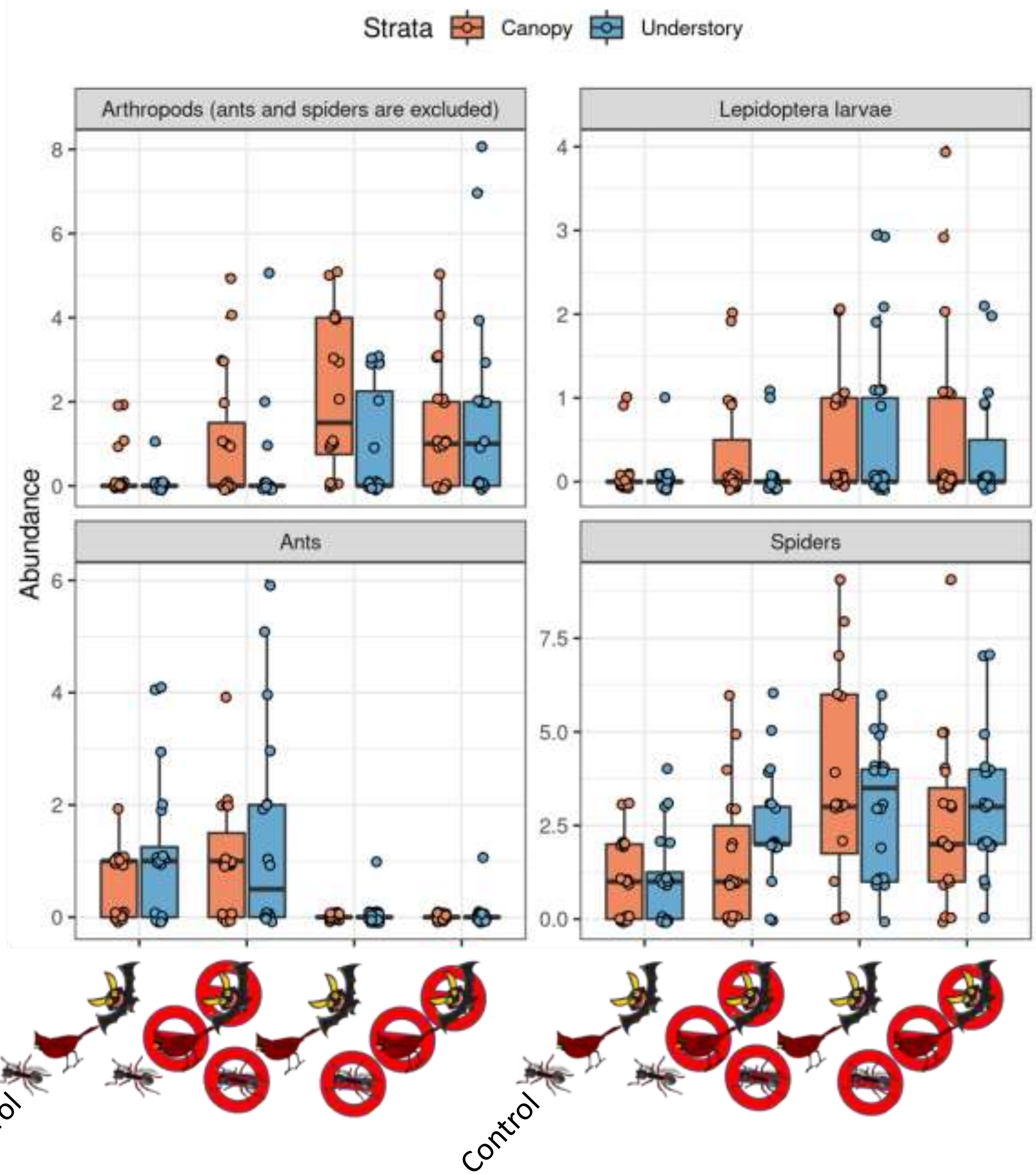


Trophic control on herbivore richness and abundance

Vertebrates + Ants = Ants > Vertebrates

Spider abundance increased with ant exclusion

Quan, Sam … and Nakamura*. *In prep*.

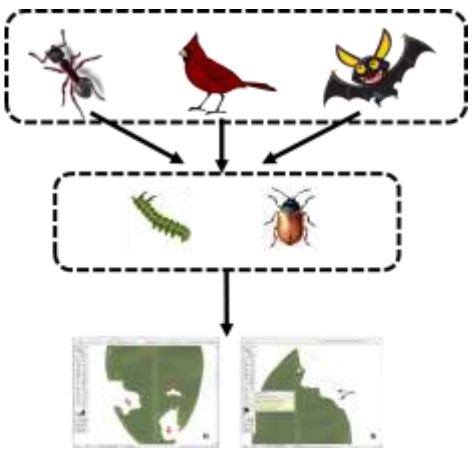


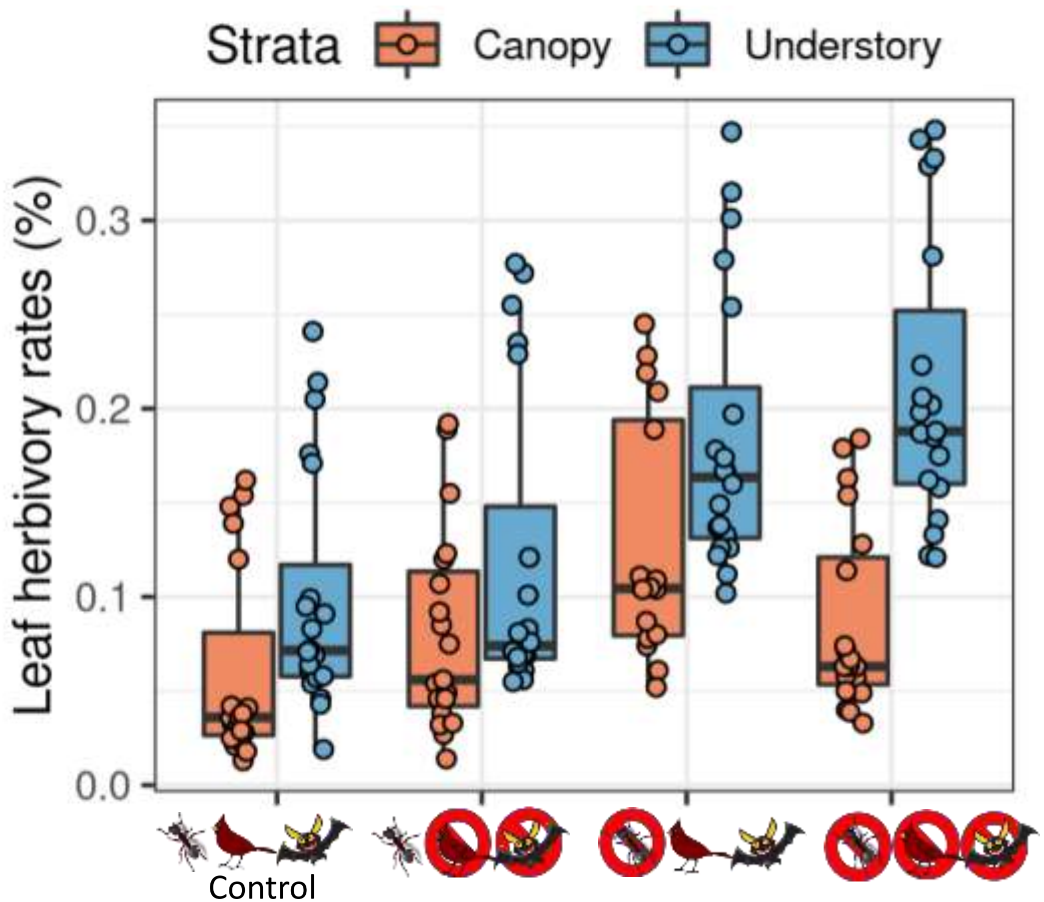
Results: trophic cascading to herbivory

Trophic control on herbivory

Understorey: **Vertebrates + Ants > Ants > Vertebrates**

Canopy: NS





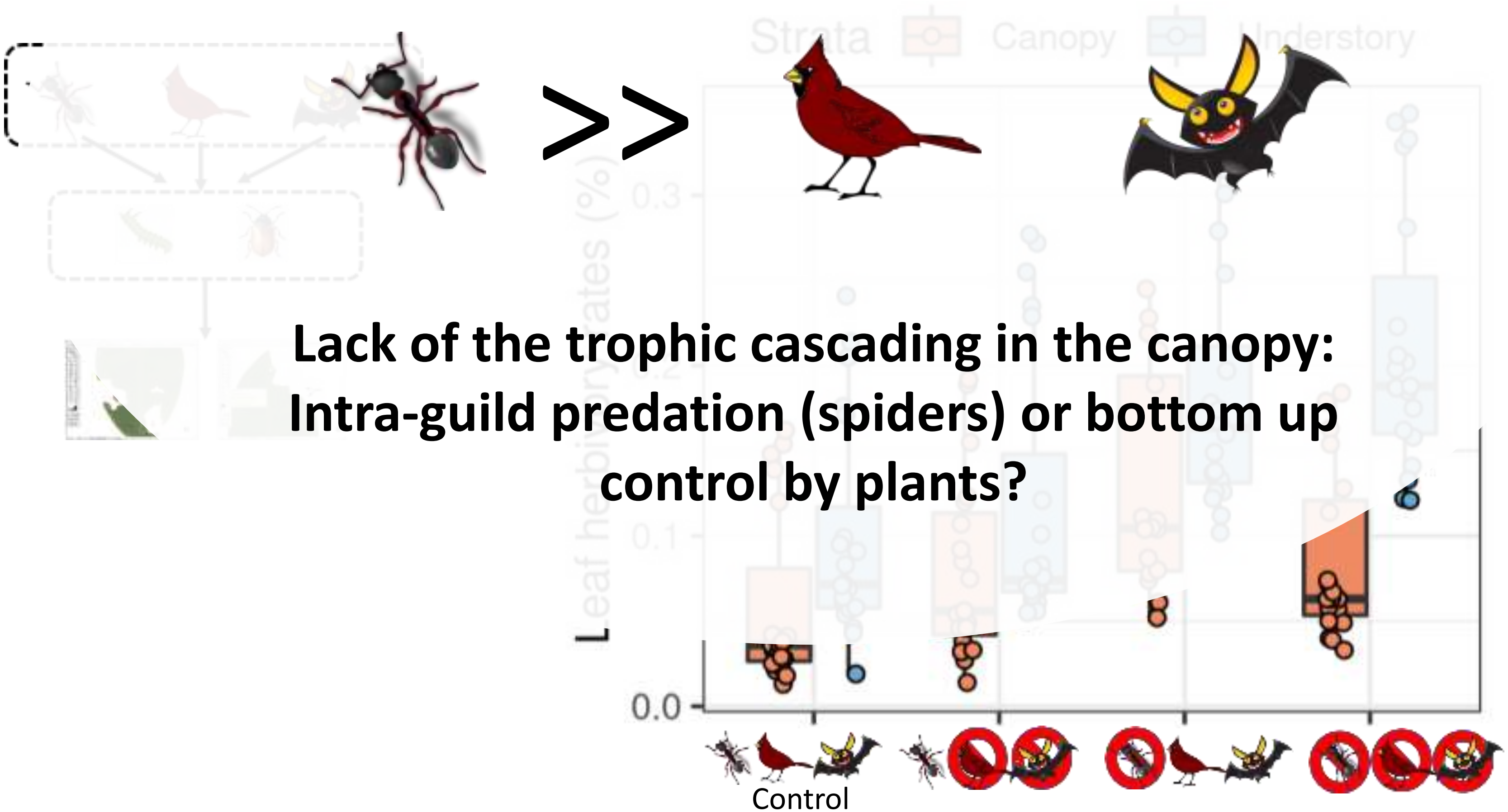
Quan, Sam … and Nakamura*. *In prep.*

Results: trophic cascading to herbivory

Trophic control on herbivory

Understorey: **Vertebrates + Ants > Ants > Vertebrates**

Canopy: Vertebrates + Ants = Ants > Vertebrates



Lack of the trophic cascading in the canopy: Intra-guild predation (spiders) or bottom up control by plants?

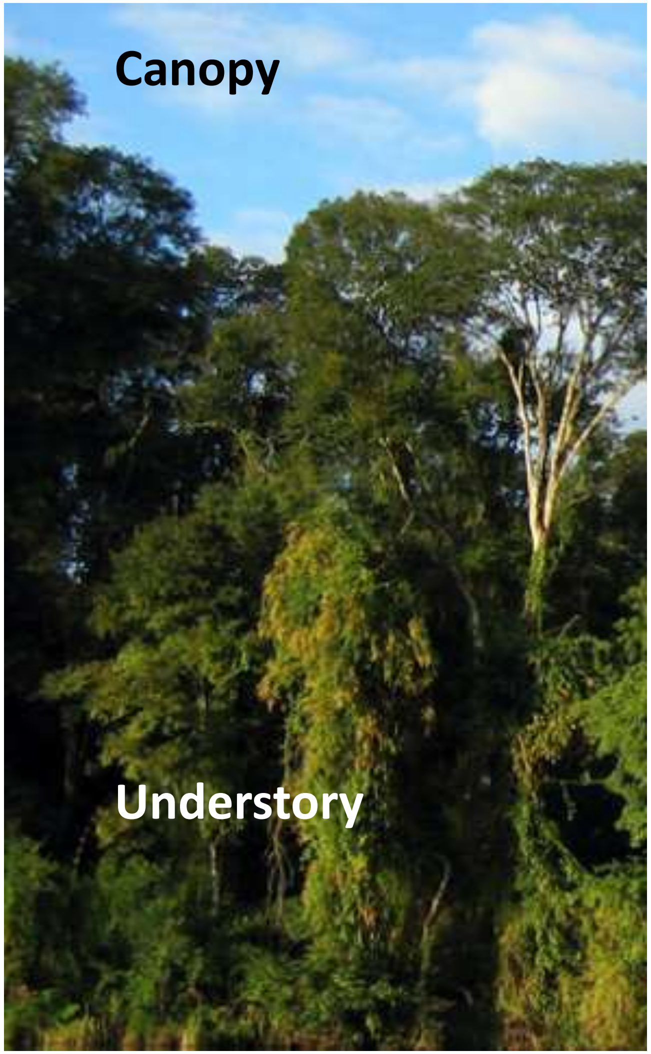
Quan, Sam … and Nakamura*. *In prep.*

Manipulative experiment 2: Vertical stratification of community assembly in phytotelm microcosms

Vertical stratification in community assembly

Phytotelma (tree holes) communities along vertical gradients

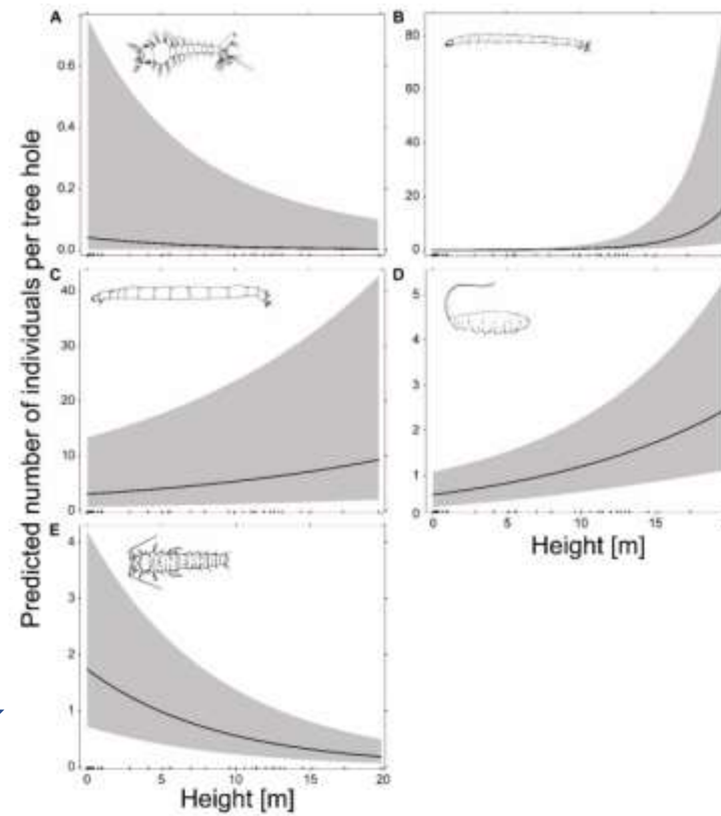
(by Lifang Deng, MSc project)



Temperature (mean and variability)

Humidity (low vapor pressure deficit)

Nutrient input (litter fall and stem flow)

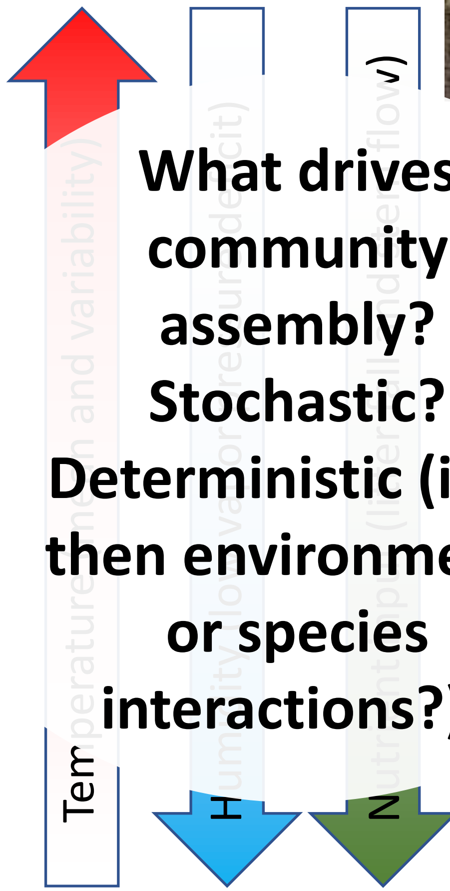


Gossner and Petermann 2022 *Frontiers in For Global Change*

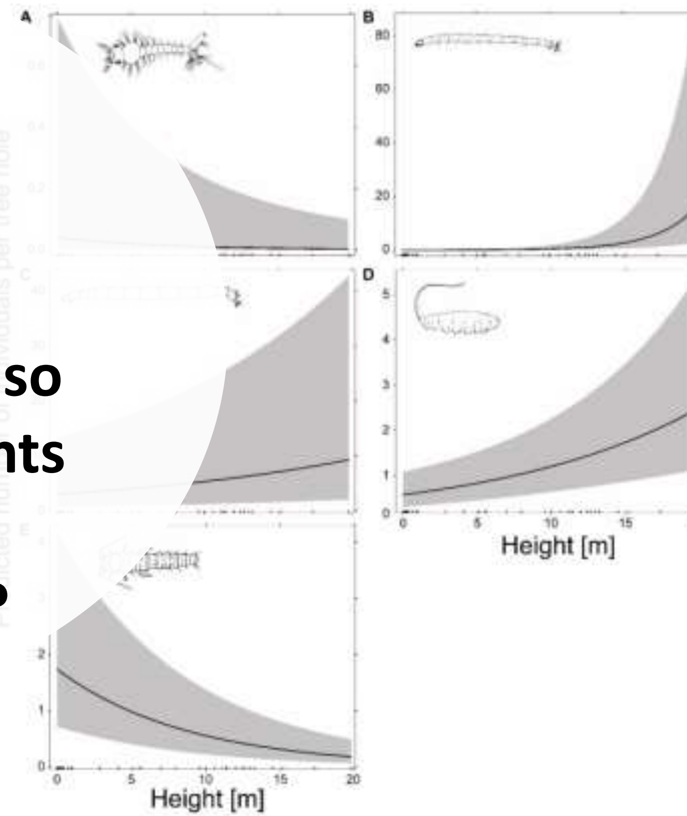
Vertical stratification in community assembly

Phytotelma communities along vertical gradients

(by Lifang Deng, MSc project)

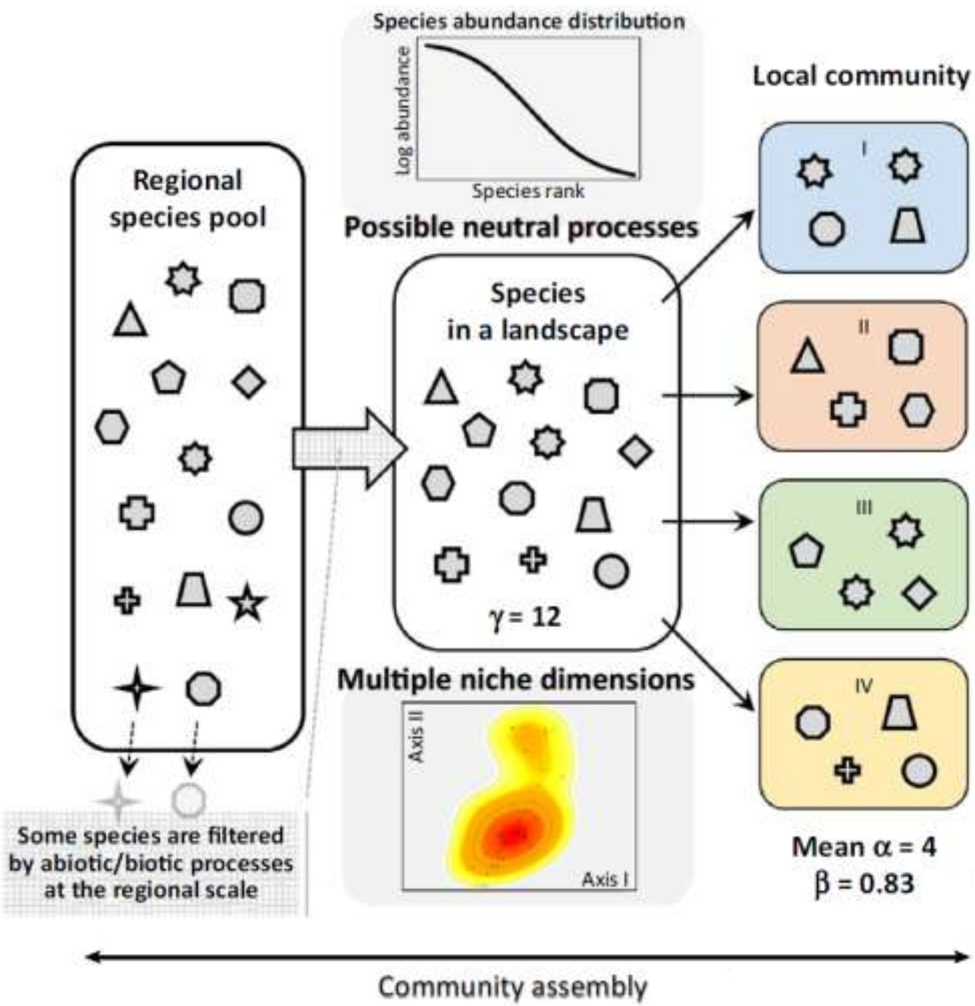


What drives community assembly? Stochastic? Deterministic (if so then environments or species interactions?)?



Gossner and Petermann 2022 *Frontiers in For Global Change*

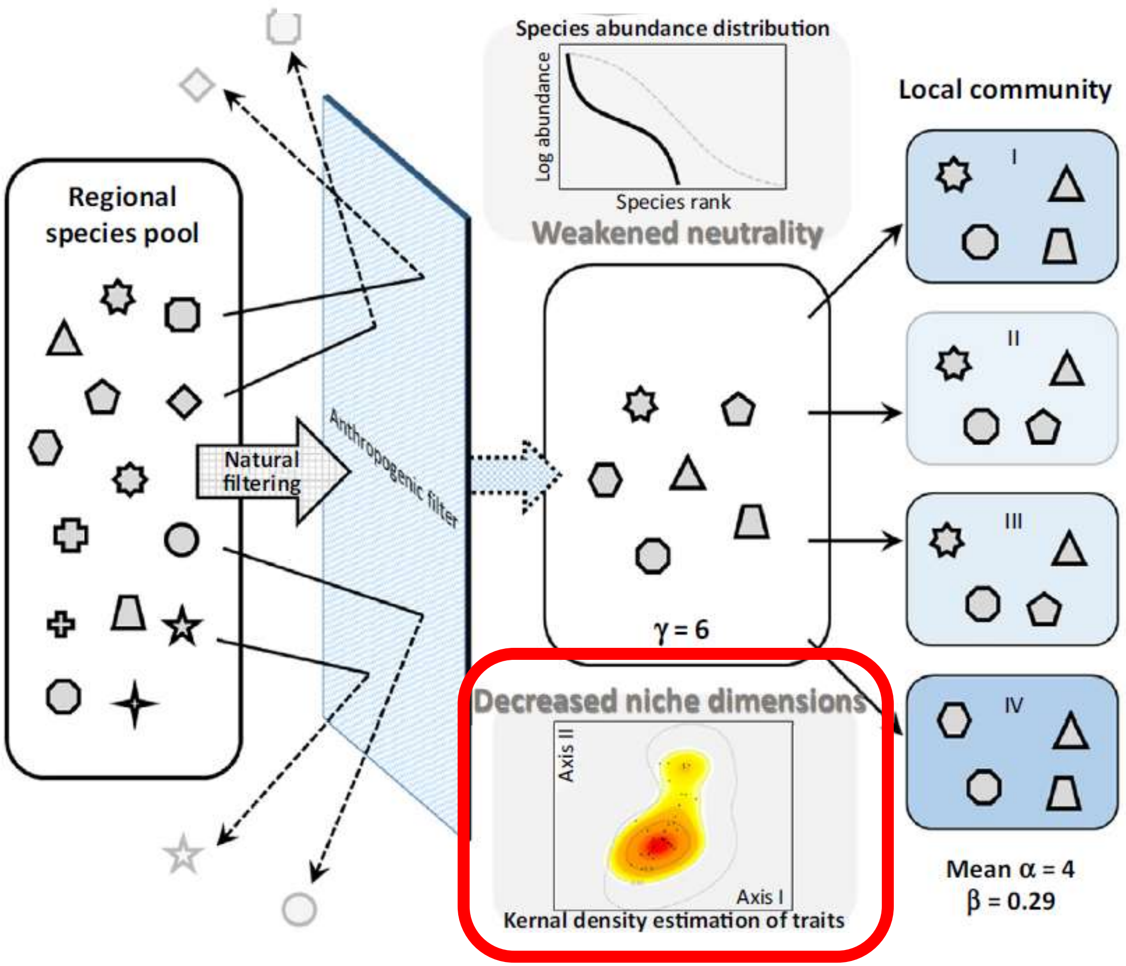
Key Processes of Community Assembly



- Regional species pool -> Species in a landscape (e.g. rainforests)
- Coexistence of rare and common species may be explained by <u>neutral processes</u>, and <u>multiple niche dimensions</u>
- These mechanisms and local habitat heterogeneity maintain high local β diversity

Mori et al. 2018 *TREE*

Community Assembly and Biodiversity–Ecosystem Functioning with an **“additional” filter**

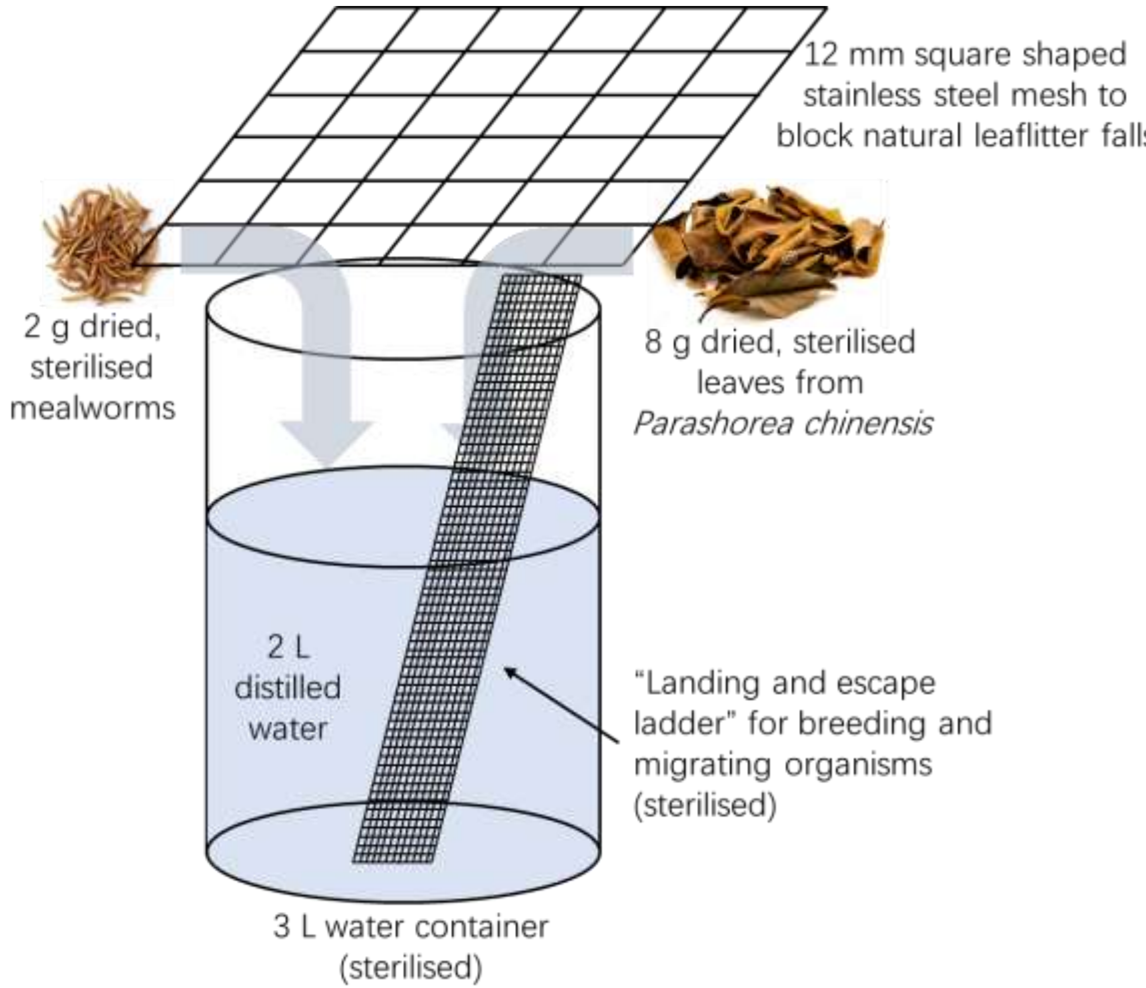


- An “additional” filter (unfavourable habitat conditions) removes available species
- Reduction of both common and rare species may result in <u>weakened neutrality</u> and <u>decreased niche dimensions</u>

Strong environmental filtering
Decreased niche dimensions = more competition?

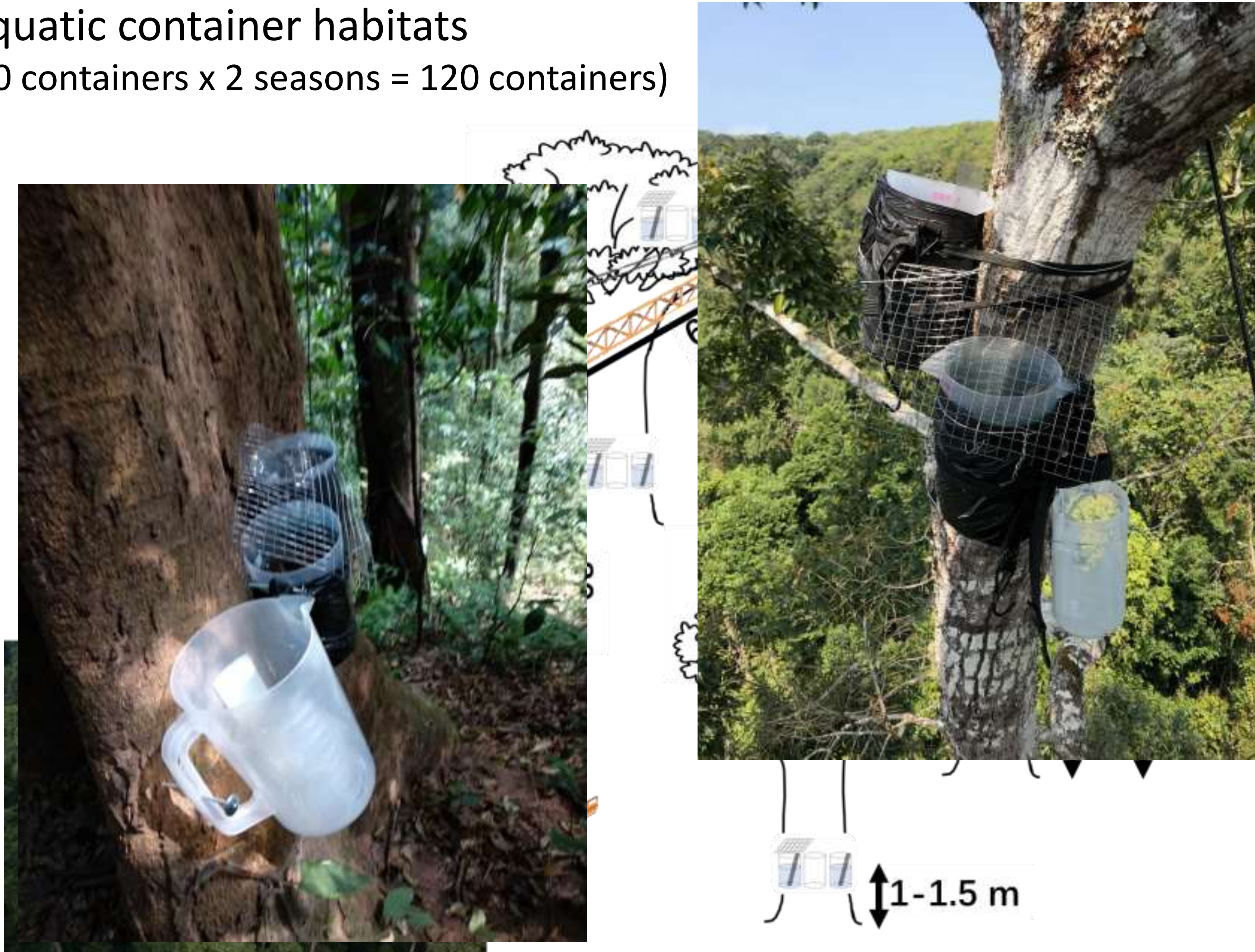
Trends in Ecology & Evolution
Mori et al. 2018 *TREE*

Artificial aquatic container habitats (microcosms)



Set in dry and wet seasons (April-June & July-Sept 2019)

Aquatic container habitats
(60 containers x 2 seasons = 120 containers)



Results: Community assembly

- Communities in forest understory

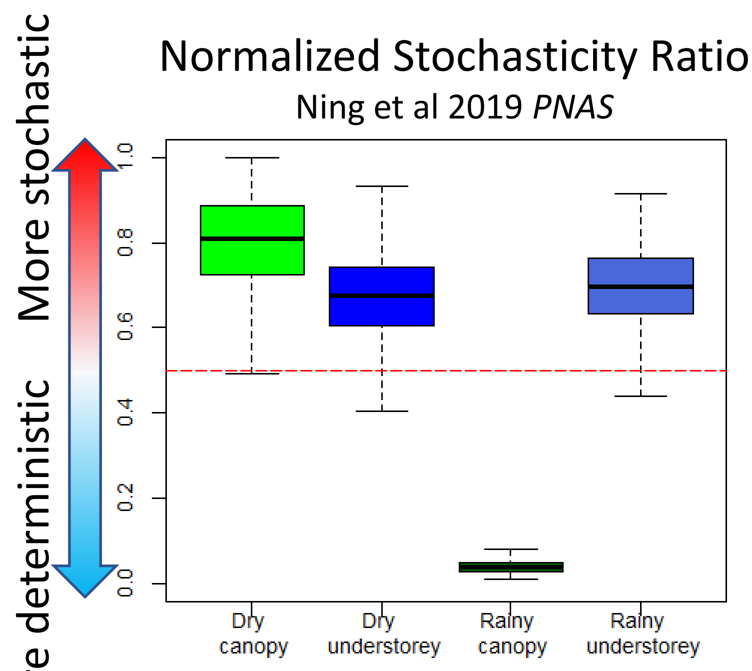
  Highly stochastic

- Communities in forest canopy

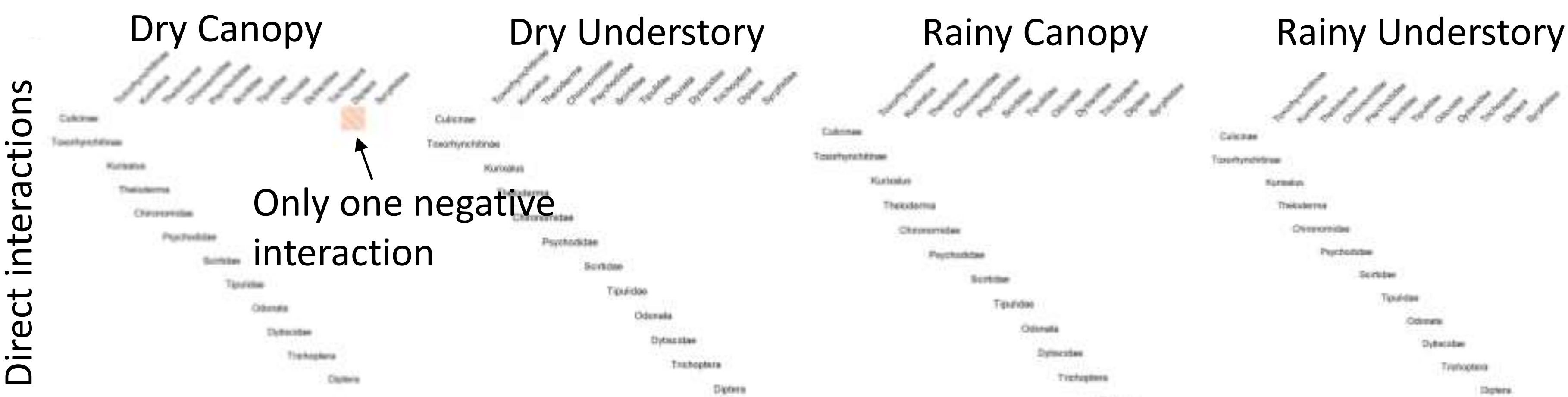
  Highly deterministic in rainy season

- Almost no species interactions despite the presence of predators

  Deterministic processes driven by environmental filtering?



Deng, Yoshida, Nakamura* et al. *in prep*

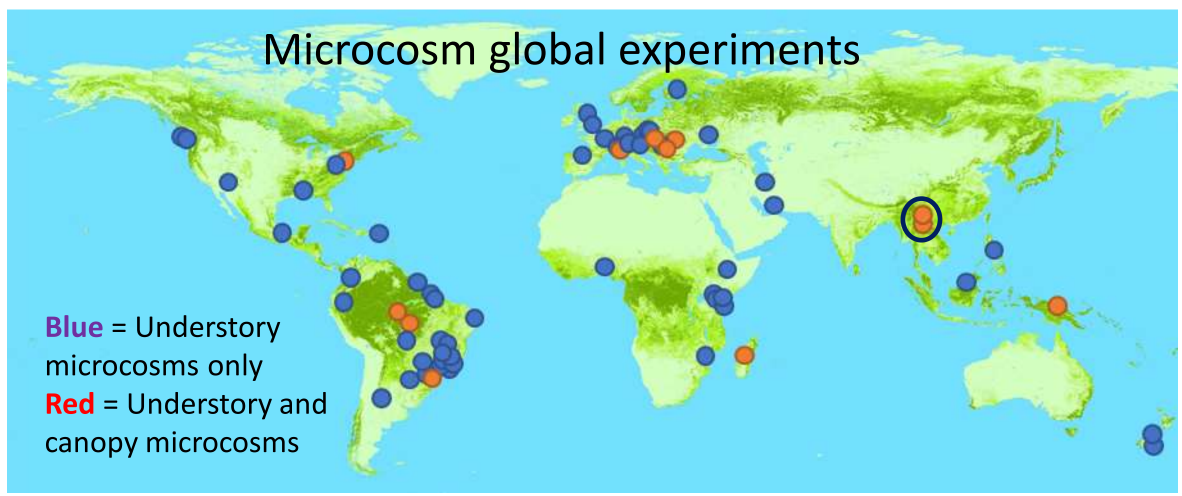


Gaussian Copula Graphical Model (GCGM): visualises direct interspecific interactions after controlling for environmental factors Popovic et al 2019 *MEE*

Rise of global-scale manipulative experiments

Canopy crane sites used for the trophic cascading experiments

The Czech Academy of Sciences



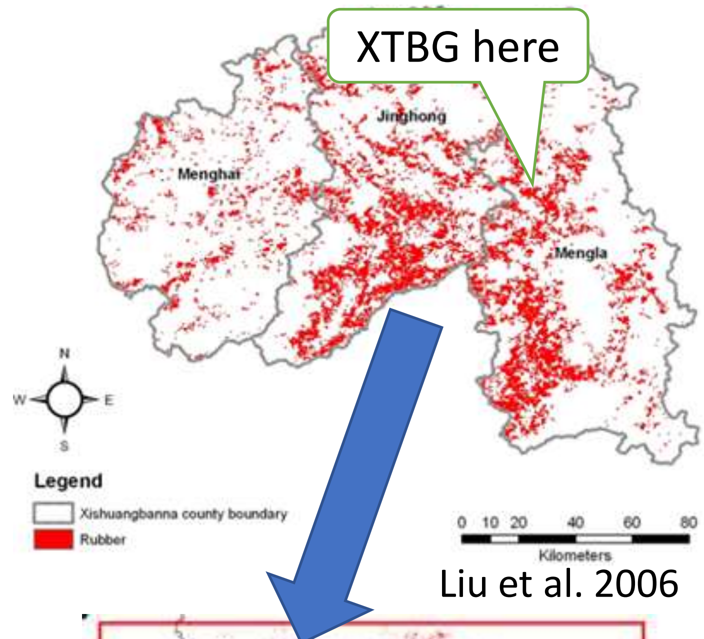
Field survey: Relative importance of species interactions in arboreal ants in rubber plantations and rainforests

Rubber plantations in Xishuangbanna

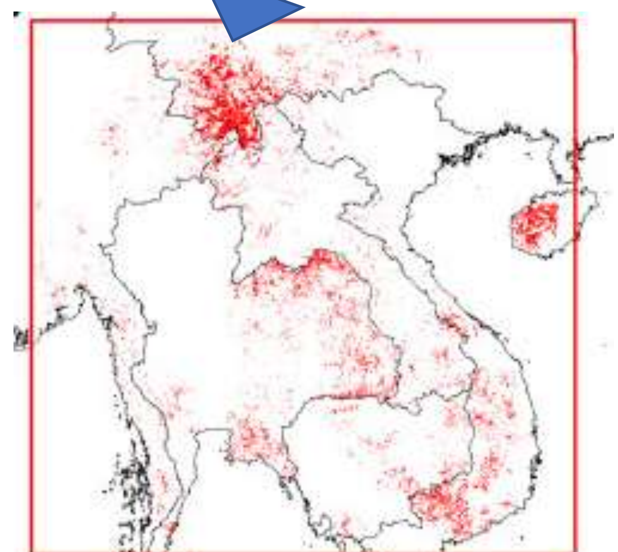
- **Rubber plantation: most dominant landscape in Xishuangbanna** (Hammond et al. 2015, *ICRAF Working Paper*)

- **In the study area, 324% increase in rubber plantation from 1988 to 2003** (Liu et al. 2006 *Mountain Research and Development*)

- **Subsequent loss of biodiversity** (Ahrends et al. 2015 *Global Environmental Change*)

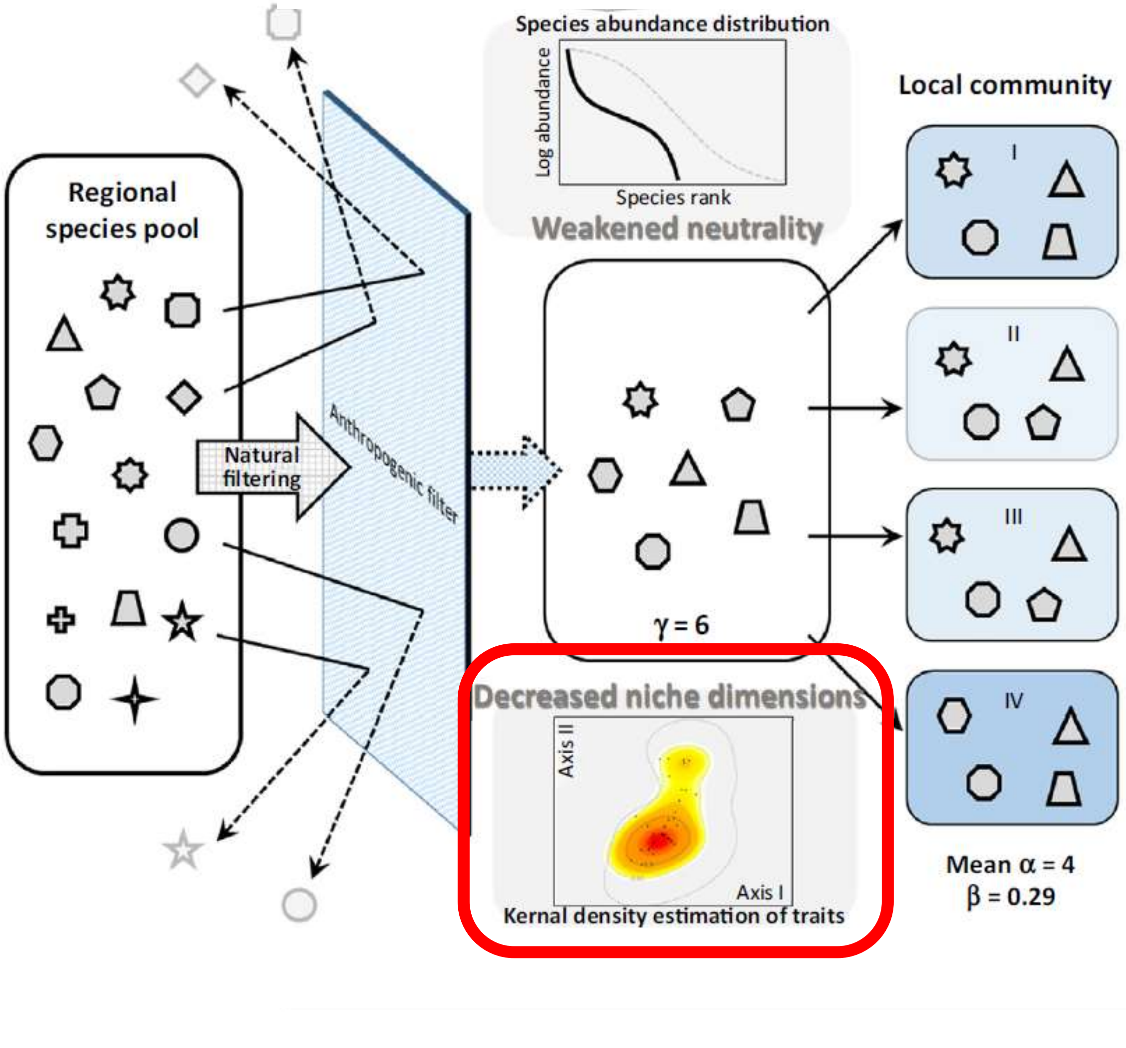


Liu et al. 2006



Ahrends et al. 2015

Community Assembly and Biodiversity–Ecosystem Functioning with an **"additional" filter**

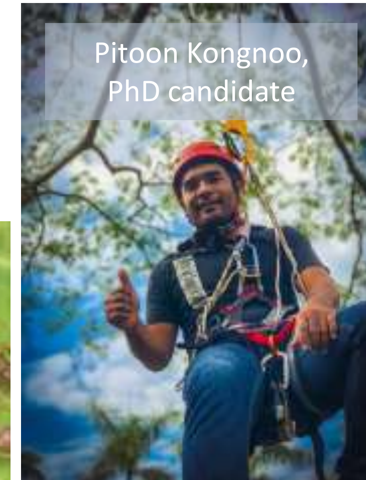


- An "additional" filter (unfavourable habitat conditions) removes available species
- Reduction of both common and rare species may result in <u>weakened neutrality</u> and <u>decreased niche dimensions</u>

Strong environmental filtering
Decreased niche dimensions = more competition?

Mori et al. 2018 *TREE*

The role of competition in arboreal ant diversity

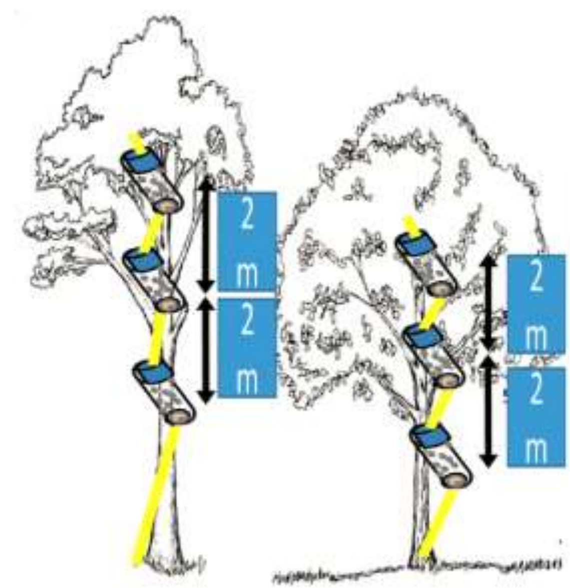






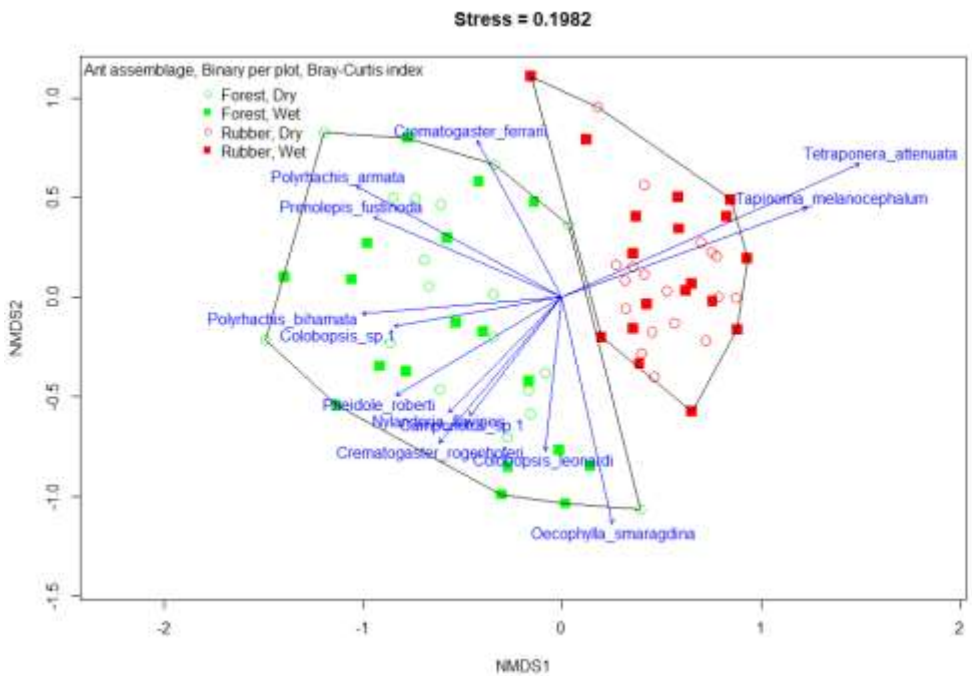
- Spatial structure of arboreal ant assemblages: thought to be driven by **competitive interactions** (Bluthgen and Stork 2007 *Austral Eco*)
- **"Ant mosaics"**: competitively superior species exclude other species, creating mosaics of dominant ant species across trees (Bluthgen & Stork 2007 *Austral Eco*)
- Classical studies about ant mosaics primarily come from plantations
- Ant mosaics may or may not work in complex primary forests (Fayle et al. 2013 *Ecography*)
- We know little about how the strength of interactions change across habitats

Arboreal ant baiting in Xishuangbanna



Habitat	Tree species	Sampling seasons	Number of locations	Number of plots per location	Number of trees per plot	Number of traps per tree
Rubber plantation	*Hevea brasiliensis*	2	3	6	10	3
Rain forest	Mix tree species	2	3	6	10	3
				Total number of samples:		2160

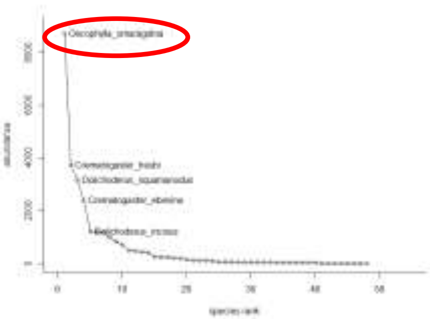
Arboreal ant diversity in rainforests and rubber plantations



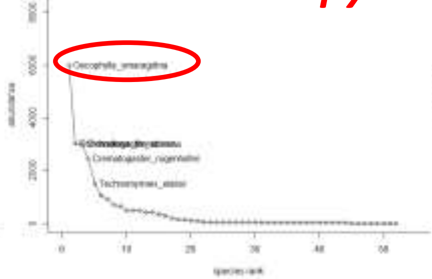
- **Lower γ diversity** in rubber plantations:
  - Dry season rainforest = 48 species
  - Wet season rainforest = 52 species
  - Dry season rubber = 22 species
  - Wet season rubber = 30 species
- **Lower β diversity** in rubber plantations
  - F=19.3 df=3 p<0.001 (from betadisper)
- Significant **differences in ant species composition** between rainforests and rubber but no seasonal differences

- Reduced common and rare species = **weaker neutrality in rubber plantations**

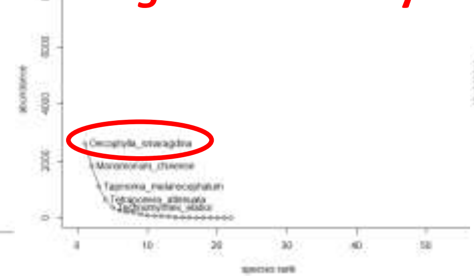
Oecopylla smaragdina **is always the most dominant!**



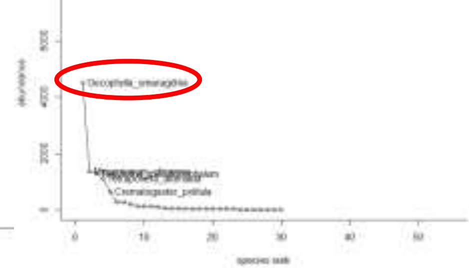
Dry rainforest



Wet rainforest



Dry rubber



Wet rubber

Challenges in measuring species interactions (incl. competition)

Blanchet et al. 2020 *Eco Lett*

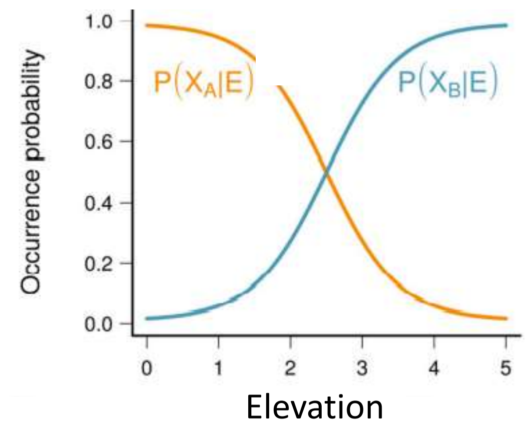
1. Conventionally, probability of species co-occurrence is understood by presence/absence (e.g. Fayle et al. *Ecography*)

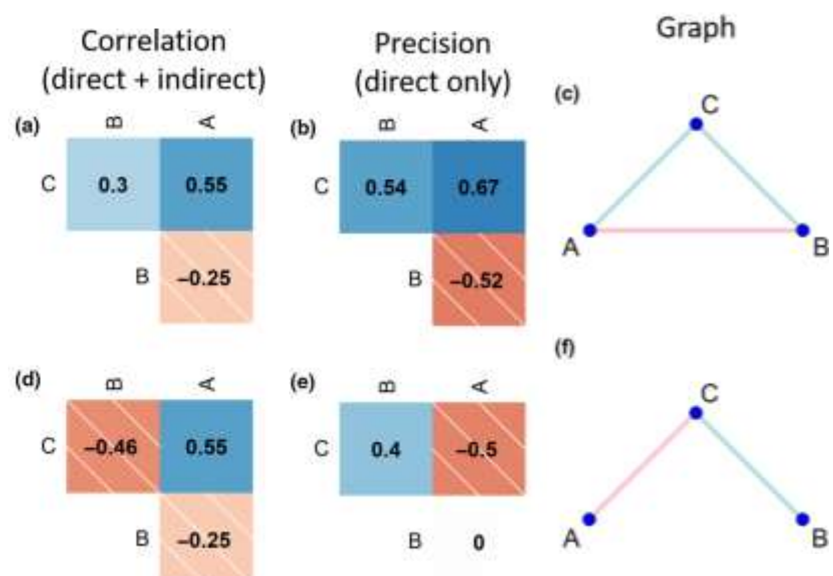
2. Environmental conditions may confound species interactions (i.e. species that have no interactions appear to have interactions due to their habitat requirements)

2. Indirect vs direct species interactions

3. Interaction between two species diminish when more species are associated

P(Xa)=P(Xa|Xb)P(Xb)+P(Xa|Xc)P(Xc)+…





Popovic et al. 2019 *MEE*

Gaussian copula graphical model (GCGM)

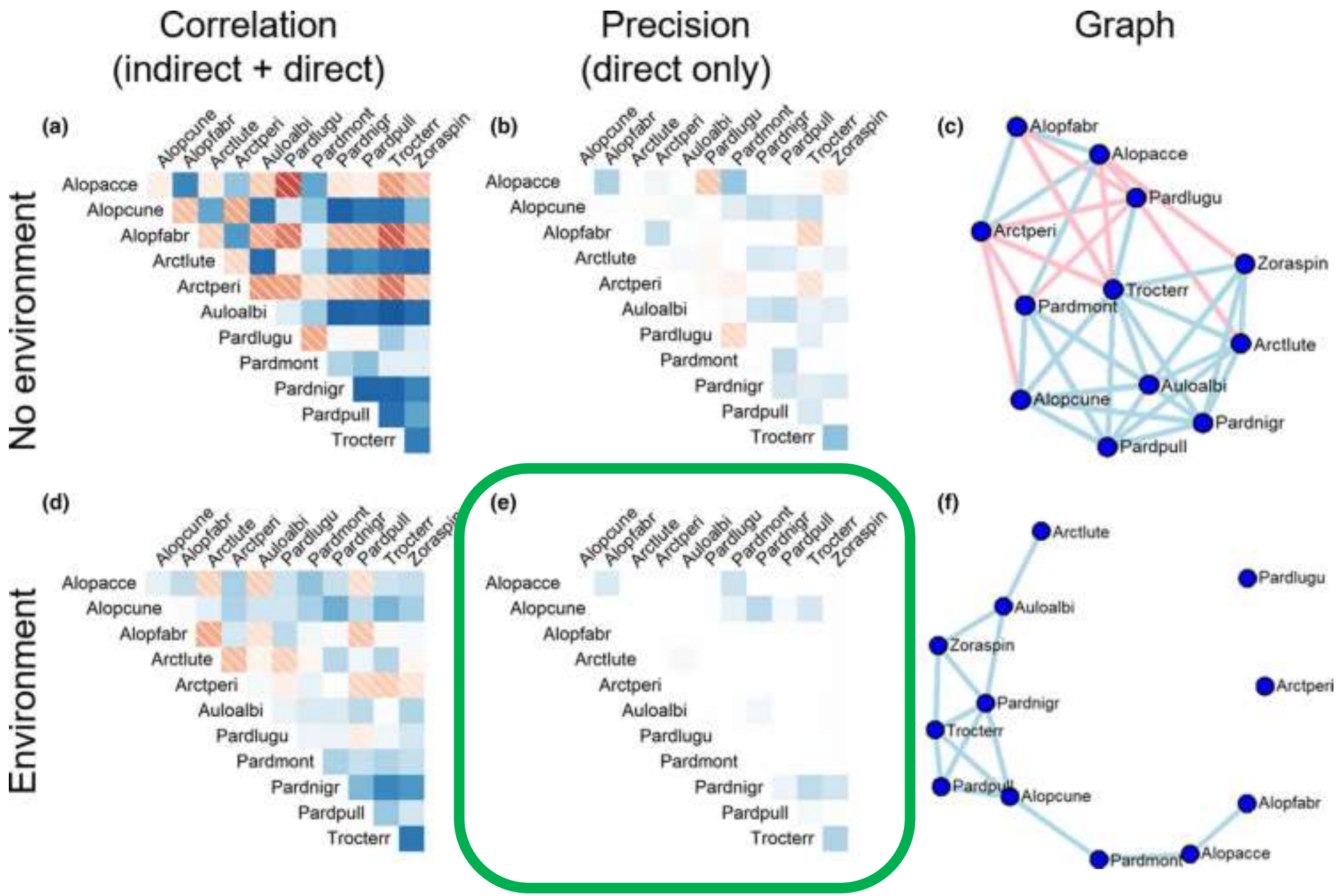
(Popovic et al. 2019 *MEE*)

- This model fits generalized linear models for multivariate abundance data (manyglm, Wang et al. 2012 *MEE*)
  - ➢ Can **accommodate wide variety of data types** (abundance instead of presence/absence)
  - ➢ Direct interactions can be calculated **after controlling for environmental variables** (e.g., elevation)

- The R package, ecoCopula, is available on github (beware – the original R package returns errors when associations are weak)
  - ➢ Bug fix available from github written by Buchi ("mattocci27/ecoCopula@fix")

Gaussian copula graphical model (GCGM)

(Popovic et al. 2019 *MEE*)



Strength of positive (blue) and negative (pink) associations can be visually assessed

Popovic et al. 2019 *MEE*

GCGM

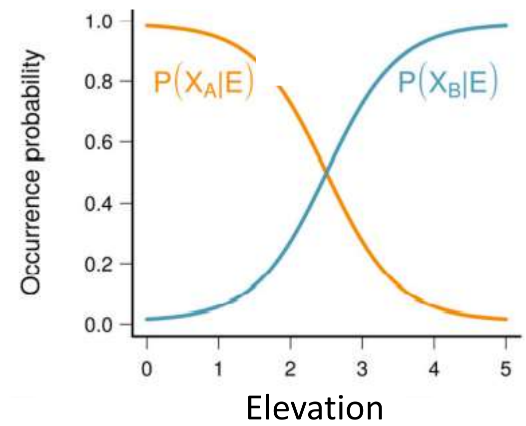
1. Conventionally, probability of species co-occurrence is understood by presence/absence (e.g. Fayle et al. *Ecography*) ✓

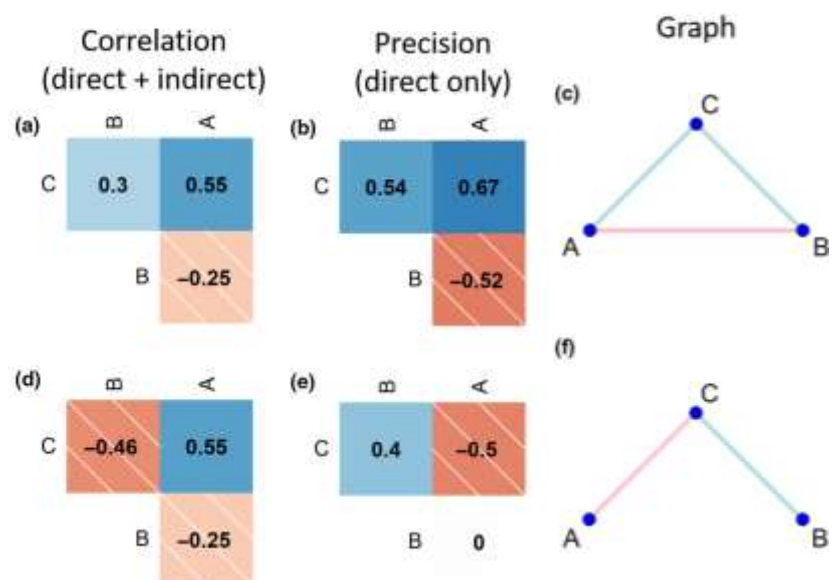
2. Environmental conditions may confound species interactions (i.e. species that have no interactions appear to have interactions due to their habitat requirements) ✓

2. Indirect vs direct species interactions ✓

3. Interaction between two species diminish when more species are associated ✗

P(Xa)=P(Xa|Xb)P(Xb)+P(Xa|Xc)P(Xc)+…



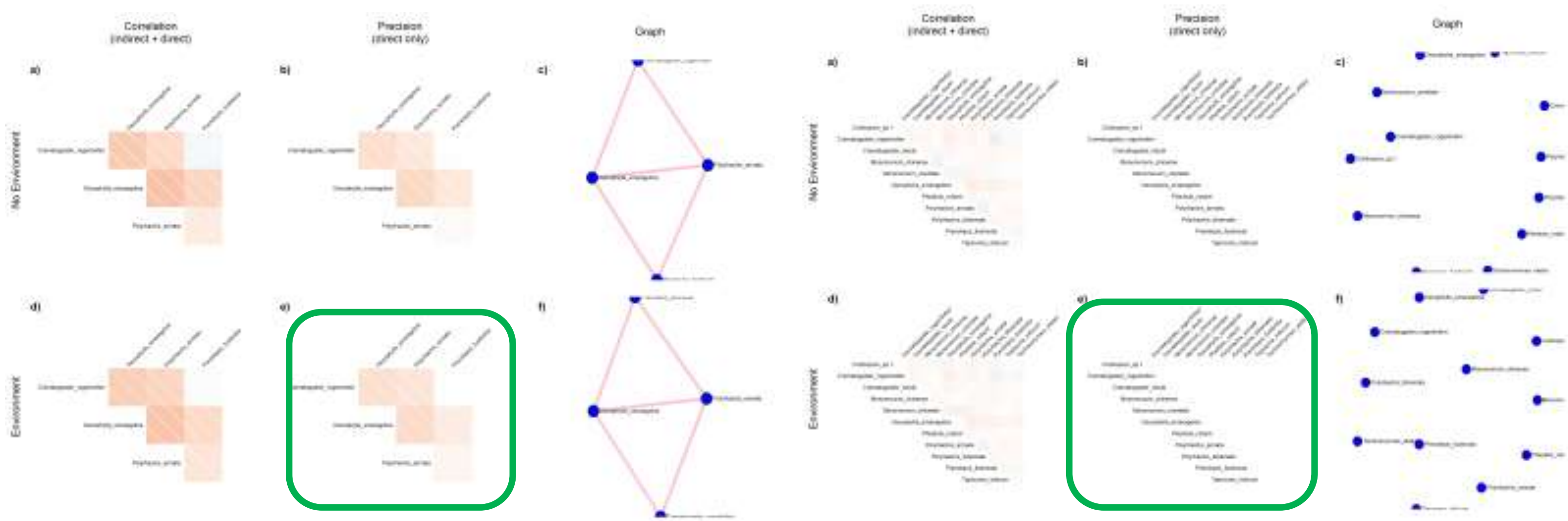


Popovic et al. 2019 *MEE*

Unsolved problem in GCGMs

- Interaction between two species diminish when more species are included

P(Xa)=P(Xa|Xb)P(Xb)+P(Xa|Xc)P(Xc)+…



N=4

N=12

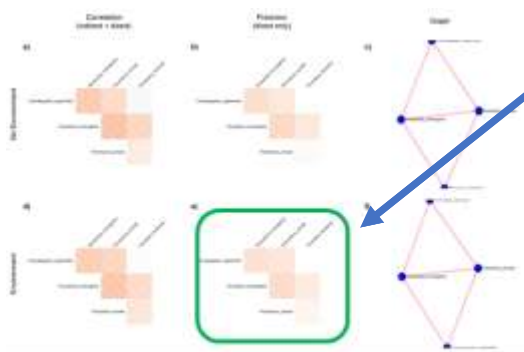
It is unclear whether the interactions do not exist OR interactions were masked by inclusion of many species

This is the problem when comparing the strength of interactions between two habitats (e.g., primary vs disturbed forests) with different number of species

Unsolved problem in GCGMs – our solution (so far)

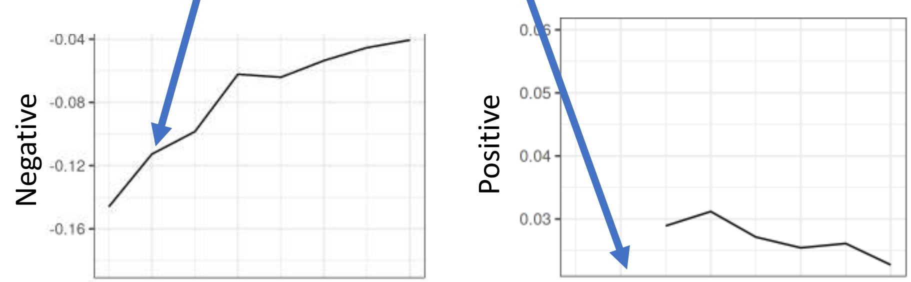
Compare the strength of association given a number of species in GCGMs

Negative = -0.11 ; Positive = 0



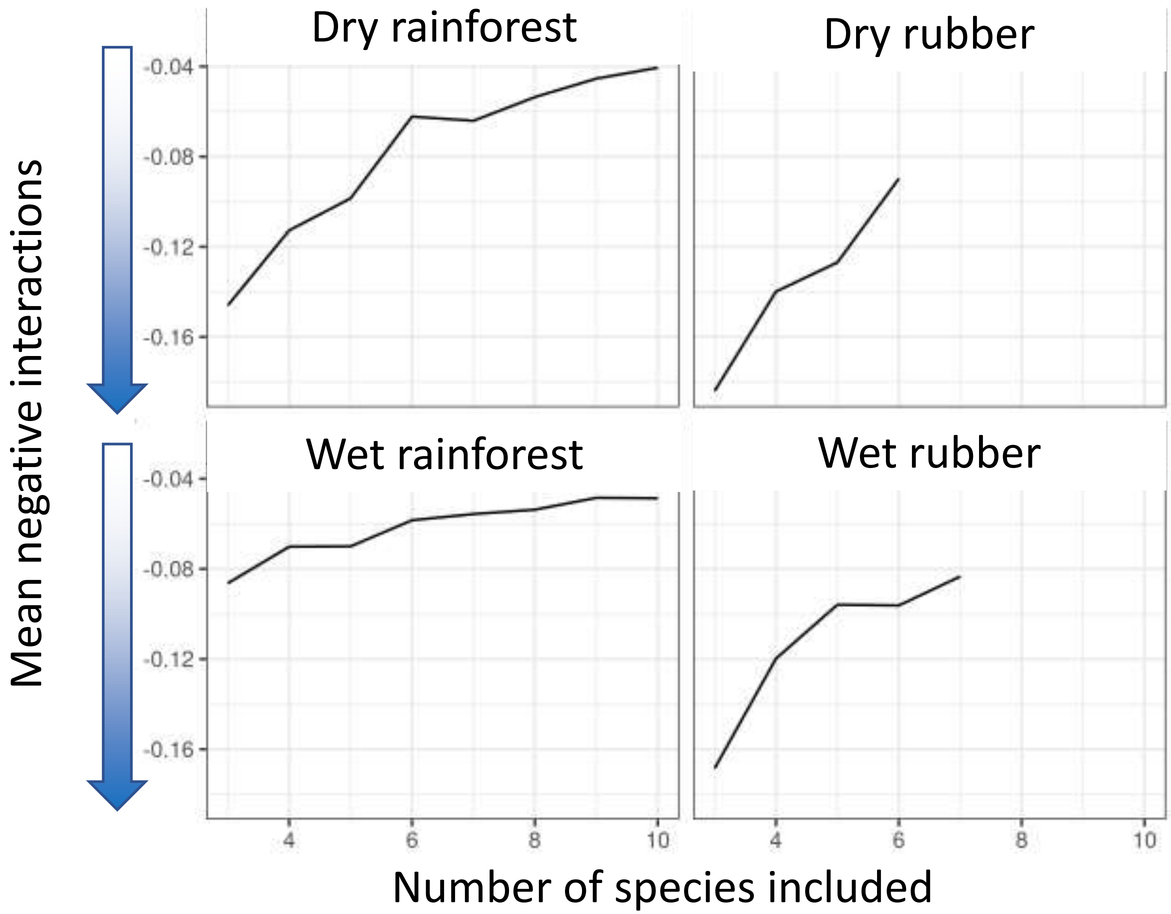
N=4

Dry rainforest

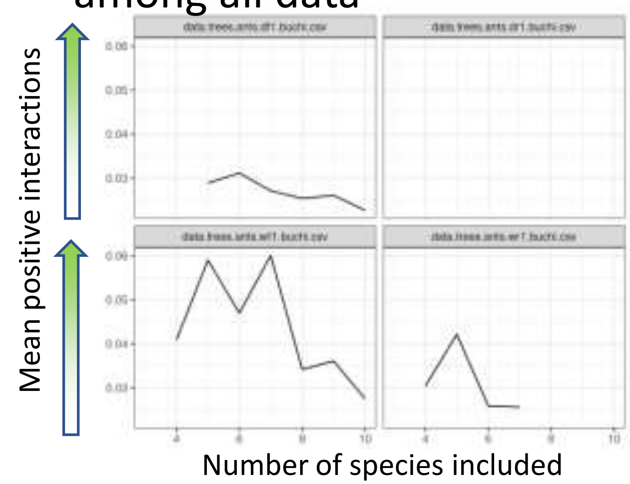


Number of species included

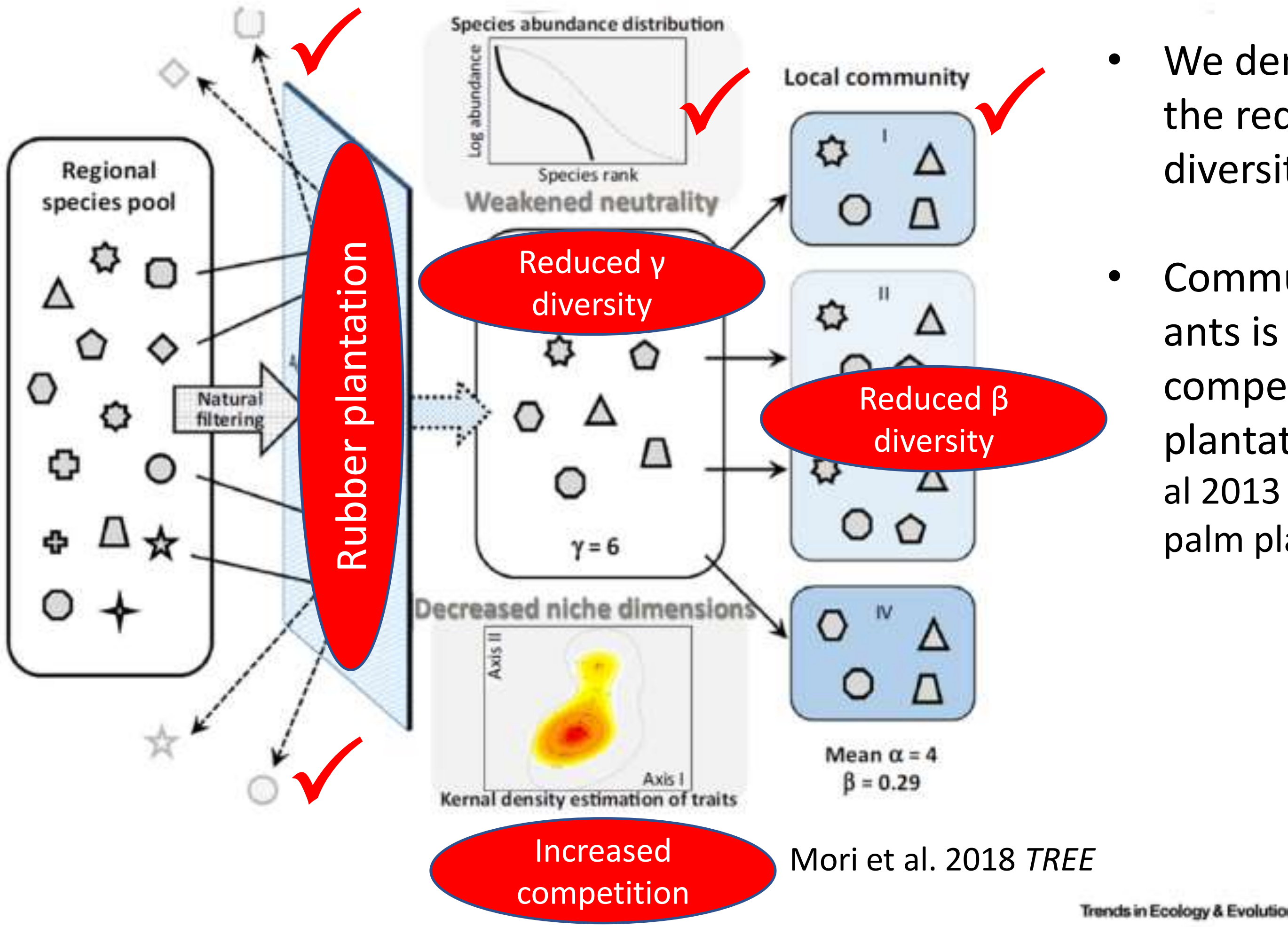
Strength of species interactions between rainforests and rubber plantations



- Stronger negative interactions (competition) during dry season in the rainforests
- Competition became stronger in the rubber plantations in both dry and wet seasons
- Little positive interactions among all data



Summary



Mori et al. 2018 *TREE*

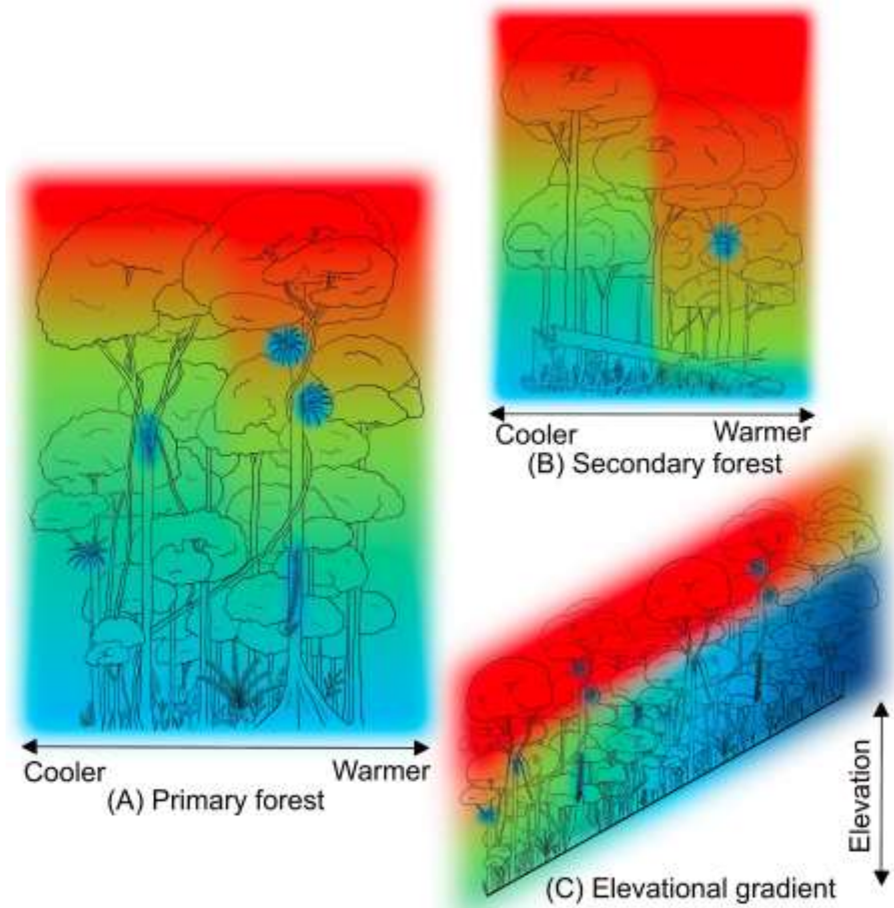
- We demonstrated not only the reduction in γ and β diversities (also α)
- Community assembly of ants is likely driven by competition in rubber plantations (same as Fayle et al 2013 *Ecography* from oil palm plantations)

Environment drives assembly mechanisms in rainforests

Competition drives assembly mechanisms in rubber plantation

Concluding remarks:

- Conservation and biogeographic studies often neglect the forest canopies…
- But vertical gradients are an integral component of forest ecology
- Many implications can be drawn by studying forest canopies



Hypothetical depictions of how vertical stratification created by forest canopies interact with anthropogenic disturbance and elevational patterns across seasons. Colours represent differences in microclimatic conditions and corresponding changes in biodiversity and ecosystem functions.

Nakamura et al. in press *Frontiers in Forests and Climate Change*

8th International Canopy Conference, Xishuangbanna

Theme: **Roles of forest canopy in a changing world**

Host: Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences

Contact: Aki Nakamura (canopy.aki@gmail.com) and via Canopy Science Forum (groups.google.com/g/canopy-science)

17-20 Oct 2022
Hopefully onsite, but likely to be online for international participants…

Plenary speakers for 6 themed symposia:

- **Vojtech NOVOTNY**, Czech Academy of Sciences, Czech Republic
- **Hans CORNELISSEN**, Vrije Universiteit Amsterdam, Netherland
- **Stefan A. SCHNITZER**, Marquette University, USA
- **Jin WU**, Hong Kong University, China
- **Margaret LOWMAN**, TREE Foundation, USA
- **Roger L. KITCHING**, Griffith University, Australia

Post conference tree climbing courses (Level 1 and 2) by certified trainers

Acknowledgements

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- Professor Min Cao (XTBG)
- Dr Chris Burwell (Queensland Museum)
- Dr Louise Ashton (Hong Kong University)
- Dr Ekgachai Jeratthitikul (Mahidol University, Thailand)
- Dr Akira Yamawo (Hirosaki University)
- Dr Harue Abe (Niigata University)
- Dr Masatoshi Katabuchi (XTBG)
- Dr Louise Ashton (Hong Kong University)
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Last but def not the least: MY FAMILY! (Ratchaneekorn, I love you!)

Forest Canopy Ecology Group

林冠生态学研究組

Thank you! 谢谢大家！

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