Forest canopy science: achievements and horizons

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and

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My background

• Lived in Australia for 17 years
• PhD from Griffith University, Australia in 2008
• Worked at Griffith University, Queensland Museum and now at XTBG
• Arthropod diversity along environmental gradient at various spatial scales
• Associate editor for *Biodiversity and Conservation* (Springer)
• 36 peer reviewed papers, a book chapter, government biodiversity reports etc published so far
Outline

Background - Canopy science – achievements and horizons

1. Canopies, insects and climate change

2. Vertical stratification of moths across altitude and latitude + metabarcoding

3. Global canopy infrastructure and new technology – frontiers of canopy science
Canopy workshop XTBG, China

Forest Canopies: Frontiers of Ecosystem Services
Xishuangbanna Tropical Botanical Garden (XTBG), Chinese Academy of Sciences,
Menglun, Mengla, Yunnan, China
59 people attended
October 27th – 29th, 2015
Canopy review – achievements and horizons

- A review of canopy literature since last major review (Ozanne et al. 2003 Science)
- Half way point between 2003 and 2030 goal to end forest destruction
- Key papers which have pushed forward our understanding of canopy science (Basset et al. 2012 Science)
- Promote new canopy crane network
- New technologies
- Outstanding issues in canopy science
Canopy review (Nakamura et al. in review)

- Forest canopies are ‘hotspots’ of biological diversity – estimates of global diversity
- New technologies – LiDAR, drones, metabarcoding
- Canopy cranes – Experimental approaches
- Atmospheric interactions, drivers and functions of bVOC emissions
- Climate change, human livelihoods
- Ecophysiology
- Epiphytes
1. Canopies and climate change

- Predicted increase 1.8–4.0° over the next 100 years
- The importance of forests and their canopies is being reflected in global environmental policy
- 2015 Paris Climate Summit – agreement to 2°C
- The New York Declaration – halving deforestation by 2020
Canopies and climate change

- Matrix of microclimates - UV, temperature and evapotranspiration
- Climate change impacts may be seen first in the canopy
- Distribution shifts
- Some trees will increase range
- Barriers to dispersal may also lead to species loss
- Phenological mismatches, shifts in growth rate, reproduction, photosynthesis and respiration
Canopies, insects and climate change

- Documented distribution shifts in a number of taxa – mainly in EU and USA where historical data is available (Thomas et al., Hughes et al., Wilson et al.)
- Phenological mismatches
- Local extinction
- Shifting host plants
- Tropics – little field data, mainly lab studies of thermotolerances
- Are tropical species more sensitive to climate?
Insects and climate change

- Leaf flushes followed by herbivore surges
- CO₂ enrichment changes plant quality (e.g. C/N ratio) with knock on effects for herbivore communities
- Number of generations/year increasing – greater herbivory
- Decreased parasitism – increased herbivory
- The end of specialization in the canopy?
- Very variable, little data from tropical canopies

Cornelissen et al. 2011
Canopies, insects and climate change

• Arthropods are already moving range – higher latitudes and altitudes

• Many have restricted distributions & few options to ‘move house’

• Pest outbreaks, pollination mechanisms, vector spread - shifting ecosystem function

• Very little data on canopy arthropods
Changes to canopy distributions

- Rainforest frog decrease arborality with increasing elevation, compensating for increasing temperature (Scheffers et al. 2013)
- Climate change driven ‘flattening’ of biodiversity as organisms shift towards the ground
- May lead to greater competition, disease, parasitism
- These vertical shifts may precede altitudinal and latitudinal range shifts
- What about canopy specialists/ inverts with canopy hot plants?
Canopies and climate change

• More data required! Observational and experimental – responses to changing temp, precipitation, CO$_2$, interactions between these factors, in the tropics

• Tropical canopy may already be at optimum temp for photosynthesis (TRACE)
2. Vertical stratification of moths across elevation and latitude

Louise Ashton
With Aki Nakamura et al.
Vertical stratification – across altitude and latitude

- Is the canopy more diverse?
- Is there vertical stratification of moths?
- How does this change across forest type, altitude, latitude, biogeographic areas
Why are moths useful as ecological tools?

- Ectotherms - sensitive to climatic variables such as temperature and precipitation
- Close relationship with host plants
- Fine-grained distribution patterns
- Highly diverse, many easy to ID
- Easy to catch large numbers of moths with light traps
Study sites
Methods

Light traps in the canopy and understory

All moths with a wing length >1cm sorted
Results – 105 522 moths

The magnitude of difference in species richness did not change with increasing elevation and latitude.
Results – 105 522 moths

Vertical stratification of moth assemblages at all locations

Beta turnover between canopy and ground increased with elevation in the northern hemisphere (?)
What could be driving distribution of moths across elevation?

<table>
<thead>
<tr>
<th>BIOTIC</th>
<th>ABIOTIC</th>
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<tbody>
<tr>
<td>Host plants</td>
<td>Temperature</td>
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<td>Predator avoidance</td>
<td>Wind speed</td>
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<td>Location as adults reflects</td>
<td>UV</td>
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<tr>
<td>larval and oviposition</td>
<td>Range of microclimates –</td>
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<tr>
<td>preferences</td>
<td>complex architecture</td>
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<tr>
<td>Looking for mates</td>
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Universal vertical stratification – across altitude and latitude

• Vertical stratification not uniformly related to elevation and latitude

• Two independent resident assemblages - location as adults reflects larval and oviposition preferences

• Behavioural - moths move vertically Nectar? Mates?

• Link these results to host plants – barcoding, rearing, sampling in places with existing natural history info
Ecological relationships across environmental gradients

• Do insect communities function differently (in terms of their interactions with plants) across adjacent elevations and, by implication, climates?

• Novel question concerning the interactions between changing climate and biodiversity

• How will canopy food-webs respond to climate change?
Metabarcoding to overcome the taxonomic impediment

- Collaboration with Dr Doug YU (IoZ, CAS, China; UEA, UK)

- Samples in Yunnan were, in general, so large we could split them into two piles

- Half comprised our standard samples – sorted the ‘old’ way

- Half were turned into DNA soup and run through YU’s next generation sequencer
Study sites
Meta DNA barcoding

- Mass-PCR and mass-sequence the COI barcode gene from homogenised slurries (DNA ‘soups’) of arthropods

- Requires no taxonomic expertise and parataxonomists assistance

- Provides ecological, taxonomic and phylogenetic information from bulk samples of arthropods

- Increasingly affordable
Metabarcoding produced the same results as traditional sorting.

NOTE: no information about the ecology of these organisms is produced with metabarcoding – a combination of approaches is the most powerful.
3. Global canopy infrastructure and new technology – frontiers of canopy science

Akihiro Nakamura
Roger Kitching
Claire Ozanne
Vojtech Novotny
Andrew Mitchell
Tom Fayle
Yadvinder Mahli
Nick Hewitt
Lian Pin Koh
Han Wang
Takao Itioka
Thomas Creedy
Min Cao
Canopy cranes: a growing network

- Cranes – provide access to a range of canopy heights, allow for detailed studies of the canopy
- Cost – highly variable
- Diameter of crane access – usually 1ha
- Criticism of poor spatial replication – global approach, multiple canopy access methods
Canopy crane network

Nakamura et al. in review
EXAMPLE PROJECT PROPOSAL: Canopies, compartments and continents: food-web structure across spatial scales

- Insect herbivores - essential energetic link between primary producers and layers of consumers, driving food-web structure
- Insect richness related to plant richness – host specificity
- Specialisation in herbivores and parasitoids directly related to complexity of food-webs
- Implications for functional resilience of community to environmental change
So, ideally, canopy research infrastructure should be based on sets of sites.
Methods

20 tree species at each plot

5 herbivore feeding guilds:

- exposed chewers
- exposed mesophyll suckers
- semi-concealed chewers
- miners
- gallers

Focusing only on endophages at satellite plots

COMBINATION of traditional rearing and DNA barcoding techniques for identification of plant-herbivore-parasitoids food-webs

COMBINATION of traditional canopy access and cranes

(Source: S. Maunsell, V Novotny)
Methods – Pacific rim tropical – temperate gradient

• 4 (or 5) crane sites:
  North Queensland, Australia
  Madang, Papua New Guinea
  Lambir Hills, Malaysia
  Xishuangbanna, China
  Hokkaido, Japan

• Five plots at each crane - the crane and four separate sampling sites

• Latitudinal, continental, regional and local scales

• Working with different lab groups from each of the crane host countries – multi-taxon approach to answer broader, more generalizable questions
Study questions

1. *Latitudinal diversity hypothesis*

Latitudinal trends (diversity, generality, vulnerability) of food webs driven by plant diversity (bottom up vs. top down)

2. *Food web compartmentalisation hypothesis*

Vertical stratification of trophic food-webs with limited connectivity

3. *Herbivore guilds and host-specificity hypothesis*

Endophagae/ectophagae food-webs different (host specificity, plant vulnerability, connectance)
- Crane network *plus*
- Rope or other access
- Remote sensing
- Manipulative experiments
Global, collaborative approaches to canopy

- Spatial replication at each crane essential – additional access methods required (single-rope access, ladders, towers, cherry picker, felling)
- Nested design – detailed study at each crane, less detail at replicate access points, macro-replication across cranes
- Comparative studies allow for powerful results
- Combining new methods of food web determination with new combinations of access methods across a latitudinal gradient, different forest types, biogeographical histories
What are the unanswered questions in canopy ecology?

- Climate change impacts
- How do canopy dwellers differ physiologically from ground dwellers
- Env. effects of bVOC emissions & interactions with anthropogenic pollutants
- Ecology of canopy trees - hydraulic process pollination interactions, herbivory, and phenology
- Global canopy crane network for experimental manipulations to understand common drivers of canopy community structure, physiology etc.
Future horizons in canopy science

- Funding required for multi-taxon, collaborative projects
- Understanding how canopies respond to whole ecosystem-scale anthropogenic disturbance
- How do we integrate ‘canopy’ ecology into general ecological theory/knowledge
- Integrating large-scale data (e.g. remote sensing) with small-scale (e.g. experimental manipulations)
- 8th canopy conference in Xishuangbanna - Integration with new China network?
Acknowledgments

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