Saturniid and sphingid moths as novel models for the study of insect diversity and macroecology

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Postdoc researcher
Saturniid and sphingid moths as novel models for the study of insect diversity and macroecology

PRESENTATION OUTLINE

- INTRODUCTION
  - SATURNIID & SPHINGID MOTHS AS NEW MODELS
  - ADVANCES IN SYNTHESIS OF INFORMATION
  - UNDERSTANDING PATTERNS
  - TAKE HOME MESSAGE & PERSPECTIVES
INTRODUCTION

Conservation policies are largely derived from vertebrate and plant data

Insects make up for ~ 50% of species worldwide and play important ecological role. Affected by climate change and habitat disturbance.
INRODUCTION

Loss of insects jeopardize ecosystem services.

Insect biomass (gr/day)
Blue = 1989; Orange = 2016

Seasonal variation in Insect biomass

More than 75 percent decline over 27 years in total flying insect biomass in protected areas

Caspar A. Hallmann1*, Martin Sorg2, Eelke Jongejans1, Henk Siepel1, Nick Hofland1, Heinz Schwan2, Werner Stenmans2, Andreas Müller2, Hubert Sumser2, Thomas Hörren2, Dave Goulson3, Hans de Kroon4

INTRODUCTION
Knowledge gaps and shortfalls in insects

There are important knowledge gaps and shortfalls that hinder our understanding of insect biodiversity:
- Linnean shortfall (Number of sp)
- Wallacean shortfall (Distribution of sp)
- Darwinian shortfall (Evolution)
- Raunkiaerian shortfall (Sp traits and ecological functions)
- Community ecology gap

Cardoso et al. (2011). The seven impediments in invertebrate conservation and how to overcome them. Biol. Cons. 144

INTRODUCTION
How to address the shortfalls?
Saturniid and sphingid moths as novel models for the study of insect diversity and macroecology

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SATURNIID & SPHINGID MOTH AS NEW MODELS

• Intermediate species richness (ca. 5000 sp.)
• Global distribution
• Very popular among collectors, many records! (occurrences)
Sphingidae
3454 species & ssp
- 8 sub-families
- 180 genera
- 15 tribes
- 205 species & ssp

Saturniidae
1602 species & ssp
- 4 sub-families
- 15 tribes
- 180 genera
- 14 tribes

- Macroglossinae (1200 sp)
- Smerinthinae (600 sp)
- Sphinginae (400 sp)
- Langinae (1 sp)
- Proserpinus (1 sp)

- Cercophaninae (25 sp)
- Arsenurinae (90 sp)
- Ceratocampinae (250 sp)
- Oxyteninae (70 sp)
- Salassinae (30 sp)
- Agliinae (5 sp)
- Saturniinae (1500 sp)
- Hemileucinae (1700 sp)
Saturniidae

- Most species do not feed when adults
- Relatively low flying capacities
- Short adult lifespan
- Mostly Generalist caterpillars
- Sexual dimorphism

Sphingidae

- Wide spectrum in feeding habits
- High flying capacities
- Longer adult lifespan
- Mostly specialist caterpillars
- Low sexual dimorphism
SATURNIID & SPHINGID MOTHS AS NEW MODELS

Molecular phylogenies (5 coding genes)
SATURNIID & SPHINGID MOTHS AS NEW MODELS

Comprehensive DNA barcode libraries have been compiled

*Saturniidae:* 48,391 DNA barcodes for 3,466 species

*Sphingidae:* 29,251 DNA barcodes for 1,708 species
INTRODUCTION

SATURNIID & SPHINGID MOTHS AS NEW MODELS

ADVANCES IN SYNTHESIS OF INFORMATION

UNDERSTANDING PATTERNS

TAKE HOME MESSAGE & PERSPECTIVES

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ADVANCES IN SYNTHESIS OF INFORMATION

Tackling Linnean shortfall
Taxonomy / checklist

A global checklist of the Bombycoidea (Insecta: Lepidoptera)

Kitching et al. (2018) BDJ 6: e22236

10 353 names listed for both families
Sphingidae: 205 genera, 1602 sp. & ssp.
  (+250 sp. in past 10 years)
Saturniidae: 180 genera, 3454 sp. & ssp.
  (+1500 sp. in past 10 years)

Tackling Wallacean shortfall
Distribution records

Sphingidae: 185 867 records (29 251 with barcodes)
Saturniidae: 95 410 records (48 391 with barcodes)

ACTIAS database

Data compilation
(e.g. Lemaire collection, MNHN)

Data aggregation
(e.g. Ballesteros et al. 2016; GBIF)
Designing and implementation of a dedicated workflow for data curation: Nomenclature, Geography and Taxonomic Reconciliation
ADVANCES IN SYNTHESIS OF INFORMATION

Tackling Raunkiaerian shortfall

ACTIAS database

TRAITS

Table 1. Synthetic overview of the main traits that will be database.

<table>
<thead>
<tr>
<th>Traits</th>
<th>Category</th>
<th>Sources</th>
<th>SAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wingload, body mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult feeding vs. non-feeding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(prosexis development)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult habitus (cryptic, aposomatic, etc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larval habitus, behaviour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(cryptic, gregariousness, pupation mode, etc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larval diet breadth and composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climatic preferences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetic variability</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ADVANCES IN SYNTHESIS OF INFORMATION

Tackling community ecology gap

Fieldwork/DNA metabarcoding (responses to habitat change)

ACTIAS database

Community composition

Literature surveys
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The most pervasive pattern of life on earth......

We know that there are more species in the tropics...... BUT

The most obvious question and yet the most elusive answer
UNDERSTANDING PATTERNS
How many species are there in the Tropics?

Taxonomical descriptions are not as fashionable anymore (early 20th century).

A combination of molecular information (i.e. DNA barcodes) and integrative taxonomy is changing lately the taxonomy of insects. They have also revealed many cryptic species (most of them in the tropics).

Recent inflation in species number: Sat 1500sp ; Sph 250sp (more waiting to be described!)

Uncertainty in species identification especially for historical records.

Great wealth of barcodes data after 10 years sampling ready to be used.

Estimating species richness from barcodes
Does it correlate with previously published estimates?
UNDERSTANDING PATTERNS

<table>
<thead>
<tr>
<th></th>
<th>Saturniidae</th>
<th>Sphingidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of records</td>
<td>46117</td>
<td>26096</td>
</tr>
<tr>
<td>Number of unique records</td>
<td>25716</td>
<td>15090</td>
</tr>
<tr>
<td>Number of BINS</td>
<td>4141</td>
<td>1940</td>
</tr>
</tbody>
</table>

BIN = Barcode Index Number, as proxy for species

Using DNA BARCODES: Balance between more accurate account of species diversity vs more limited sample size (30%)

Observed richness at 200km cell-size
UNDERSTANDING PATTERNS
How many species are there in the tropics and where are they?

<table>
<thead>
<tr>
<th></th>
<th>Saturniidae</th>
<th>Sphingidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of records</td>
<td>93% (43333)</td>
<td>85% (22404)</td>
</tr>
<tr>
<td>Number of BINS</td>
<td>96% (3995)</td>
<td>94% (1829)</td>
</tr>
</tbody>
</table>

BIN = Barcode Index Number, as proxy for species

Observed richness at 200km cell-size
UNDERSTANDING PATTERNS

Estimating species richness in the tropics

<table>
<thead>
<tr>
<th>Cell size</th>
<th>Saturniidae (# Cells)</th>
<th>Sphingidae (# Cells)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tropics</td>
<td>With data</td>
</tr>
<tr>
<td>200</td>
<td>1272</td>
<td>702</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From these results, we fit multivariate models to identify the environmental predictors of species richness

Chao1 estimators at 200km cell-size
Used as response variable
**UNDERSTANDING PATTERNS**

Identified as drivers of richness

- **Altitudinal range:** Topographic heterogeneity
- **Annual mean Precipitation:** Precipitation variation
- **Annual mean temperature:** Temperature variation
- **Tree coverage (%):** Herbivores, insects
- **Biogeographical regions:** Regional and historical factors

**Log$_{10}$ S$_{\text{chao}}$**  
N= 236 cells. (Pseudo-$R^2 = 0.742$)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.053</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>0.058</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>0.091</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>0.019</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>0.491</td>
<td>0.127</td>
</tr>
<tr>
<td></td>
<td>0.619</td>
<td>0.165</td>
</tr>
<tr>
<td></td>
<td>0.850</td>
<td>0.122</td>
</tr>
<tr>
<td></td>
<td>0.282</td>
<td>0.120</td>
</tr>
</tbody>
</table>

**Log$_{10}$ S$_{\text{chao}}$**  
N= 147 cells. (Pseudo-$R^2 = 0.45$)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.367</td>
<td>17.947</td>
</tr>
<tr>
<td></td>
<td>0.047</td>
<td>1.905</td>
</tr>
<tr>
<td></td>
<td>0.059</td>
<td>2.286</td>
</tr>
<tr>
<td></td>
<td>0.014</td>
<td>0.615</td>
</tr>
<tr>
<td></td>
<td>0.249</td>
<td>2.427</td>
</tr>
<tr>
<td></td>
<td>0.084</td>
<td>0.532</td>
</tr>
<tr>
<td></td>
<td>0.281</td>
<td>2.865</td>
</tr>
<tr>
<td></td>
<td>0.249</td>
<td>2.634</td>
</tr>
</tbody>
</table>
Neotropics as the richest for the two families. Andean part in South America, Venezuelan Amazonia, Lowland of Peru.
In the Afrotropics: East arc Mountains, Highlands of Cameroon, Forest areas of Guinea and Sierra Leone, Madagascar.
In the Asian tropics: Indo-Burma Hotspot, Sumatra, Borneo, Papua and New Guinea.
UNDERSTANDING PATTERNS

Pearson’s r = 0.128 n= 450

Occurrence records. $S_{\text{chao}25}$. Pseudo-$R^2 = 0.145$ (n=146 cells)

Ballesteros-Mejia et al. (2013) Glob. Ecol. & Biogeography. 22
UNDERSTANDING PATTERNS
Macroecological analyses: distribution of species ranges (from BINs only)

Saturniids have smaller ranges than Sphingids
Species with narrow ranges often concentrated in biodiversity hotspot

Saturniids 2441 BINS
Sphingids 1245 BINS
Excluding singletons and doubletons
**AIM:** First and most complete phylogeny for a group of insects
Combination of: (1) 2000 sp./1380 UCE loci dataset with (2) 5000+sp./DNA barcode dataset

- Dated phylogeny
- Diversification analysis
- Historical biogeography

UNDERSTANDING PATTERNS

Role of traits

... on diversification dynamics

... on diversity patterns (richness, ranges, etc.)
Responses of sphingid and saturniid moths to environmental changes

UNDERSTANDING PATTERNS

Community analyses

Can...

... diversification rates accross lineages...

... inform how communities respond to environmental changes?

... and/or species traits...
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Take home messages

Fill up knowledge gaps at global scale for a group of insects

- Basic knowledge about insect diversity in space and time
- Understand, predict species responses to environmental changes
- Framework, workflow and tools made available for other groups

Perspectives

- Comparison to other groups (vertebrates, plants, etc.)
- Conservation biology:
  - highlight areas / taxa
  - evaluate current conservation framework
  - design new conservation strategies
ACKNOWLEDGEMENTS

All students (undergrads, master) and all contributors to the barcoding campaigns...

FUNDING AGENCIES