Article

Limited thermal tolerance in tropical insects and its genomic signature

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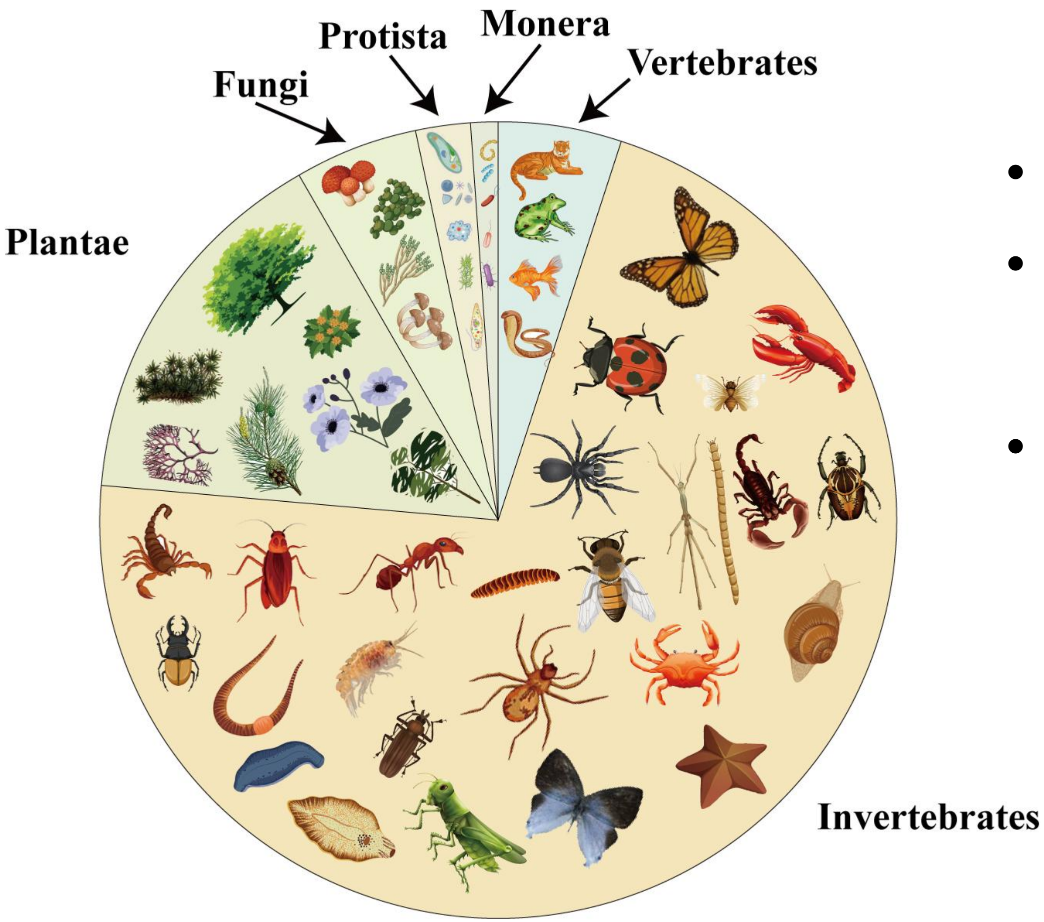
How physiology, phylogeny and proteins shape climate risk in tropical insects

Why this paper matters



- Tropical insects dominate animal diversity
- Thermal tolerance data remain sparse and taxonomically biased
- A key open question is whether tolerance can keep pace with warming

One question, five layers of evidence

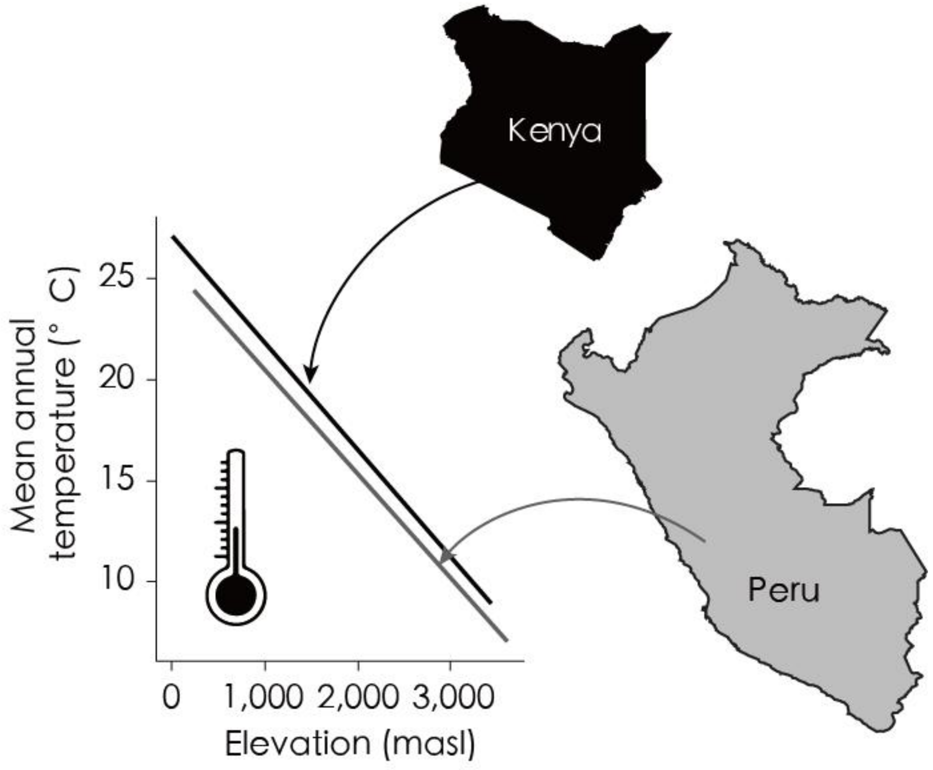
Core question: can tropical insects keep pace with warming?

Thermal limits → **Plasticity** → **Phylogeny** → **Proteins** → **Climate risk**

The paper moves from pattern to mechanism to consequence.

Step 1. Measuring thermal limits across tropical gradients

Location: Peru + Kenya mountains



CTmax (critical thermal maximum) dynamic ramp

1. Acclimation
28°C, 10 min

2. Dynamic ramp
+1°C every 2 min

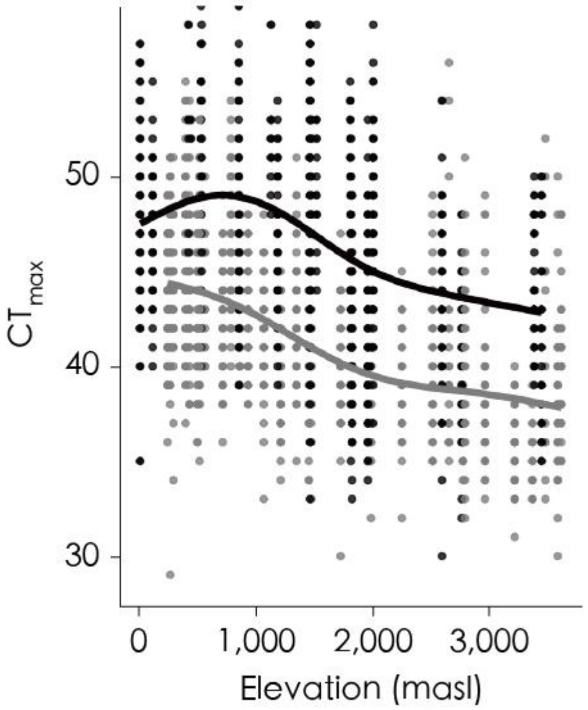
3. Endpoint scoring
Mobility checked after each step

4. Thermal limit
Loss of mobility= CTmax / CTmin

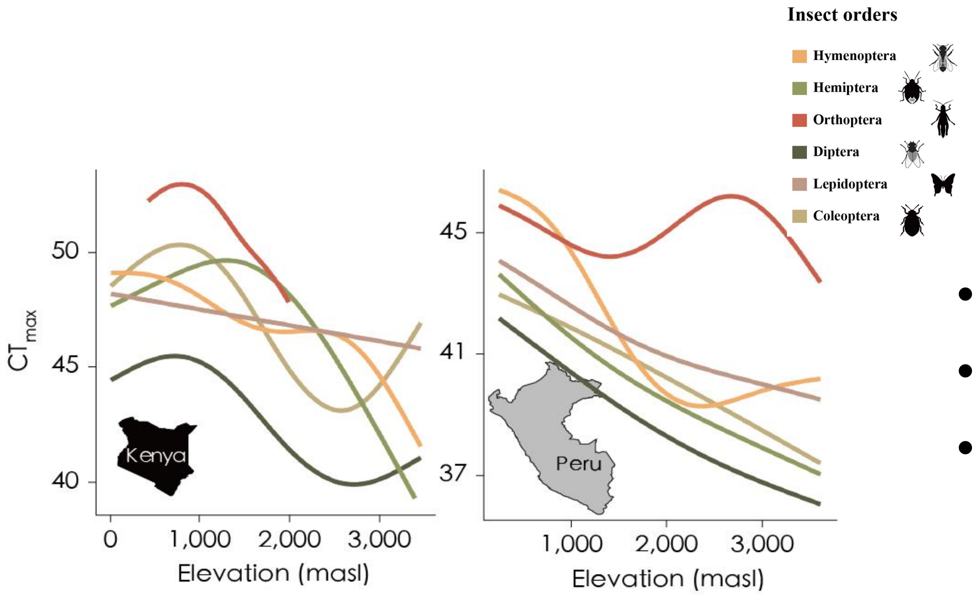
~8,000 individuals | ~2,300 species | dynamic assay 0.5°C min⁻¹

Evidence 1. Thermal limits lag behind warming

Individual-level measurements



Major-order elevational trends



- CTmax is higher in lowlands
- CTmax declines with elevation
- But CTmax rises much less than MAT

Neotropics: +0.41°C CTmax per +1°C MAT
Afrotropics: +0.31°C CTmax per +1°C MAT

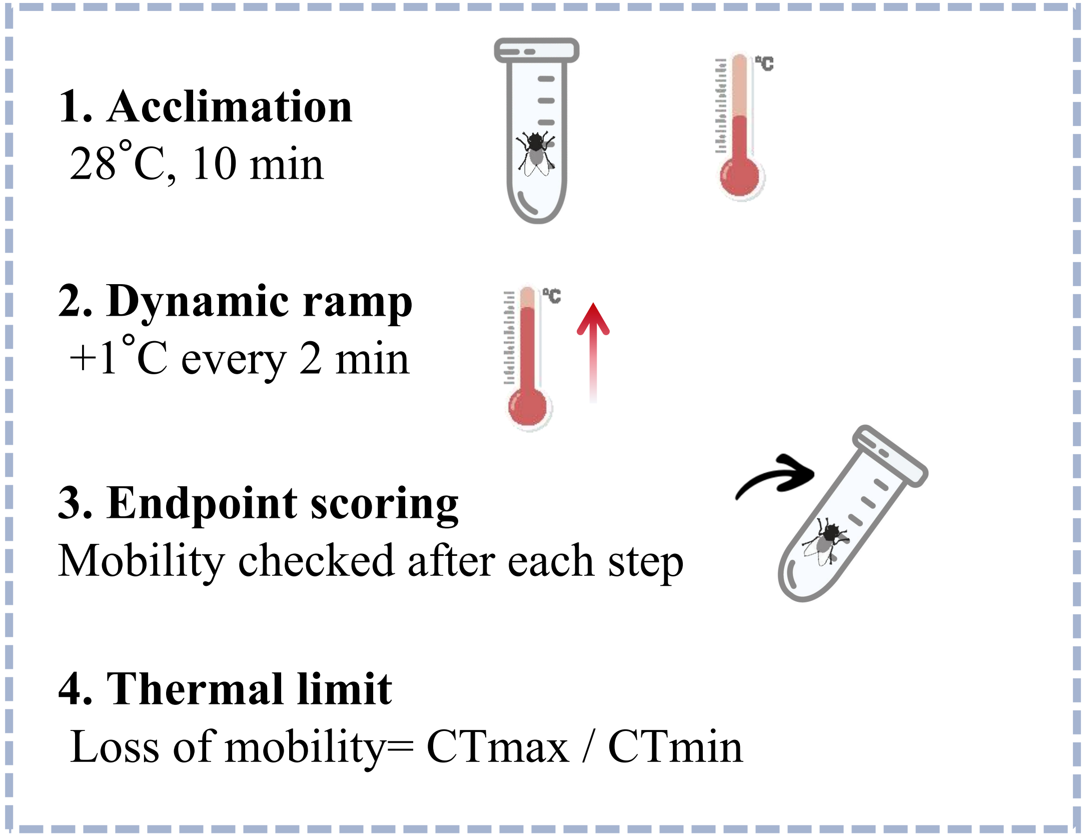
Tolerance shifts with environment, but not fast enough to keep pace with warming

Step 2. Short-term plasticity tests

Short-term buffering test

- Heat shock: 40°C for 10 min
- 35°C above 2700 m in Peru

CTmax dynamic ramp



1. Acclimation
28°C, 10 min

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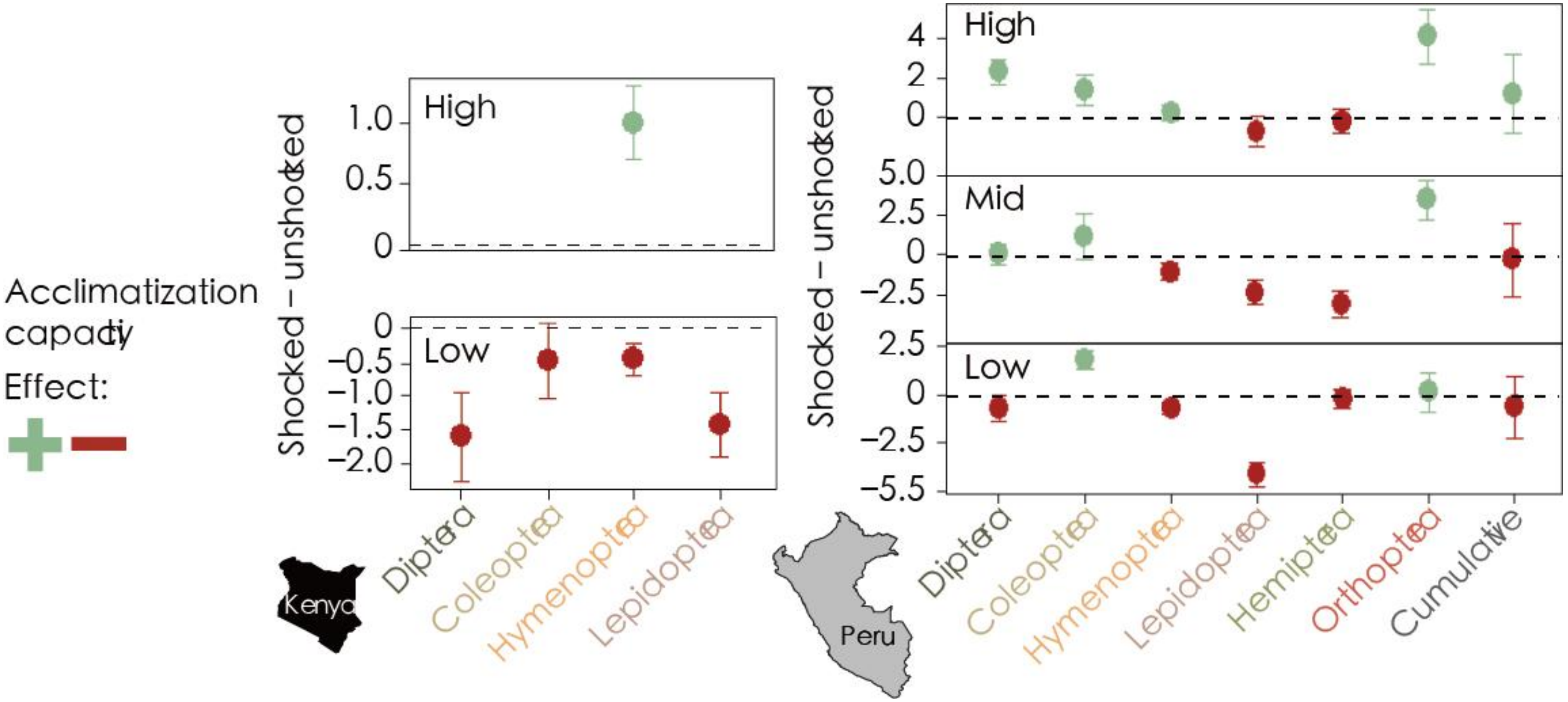
Evidence 2. Short-term plasticity is weakest where heat risk is highest



- Heat shock increased CTmax at high elevations
- In lowlands, shock often reduced heat tolerance
- Lowland species have little remaining short-term buffering capacity

Local environment matters—but it is not the whole story

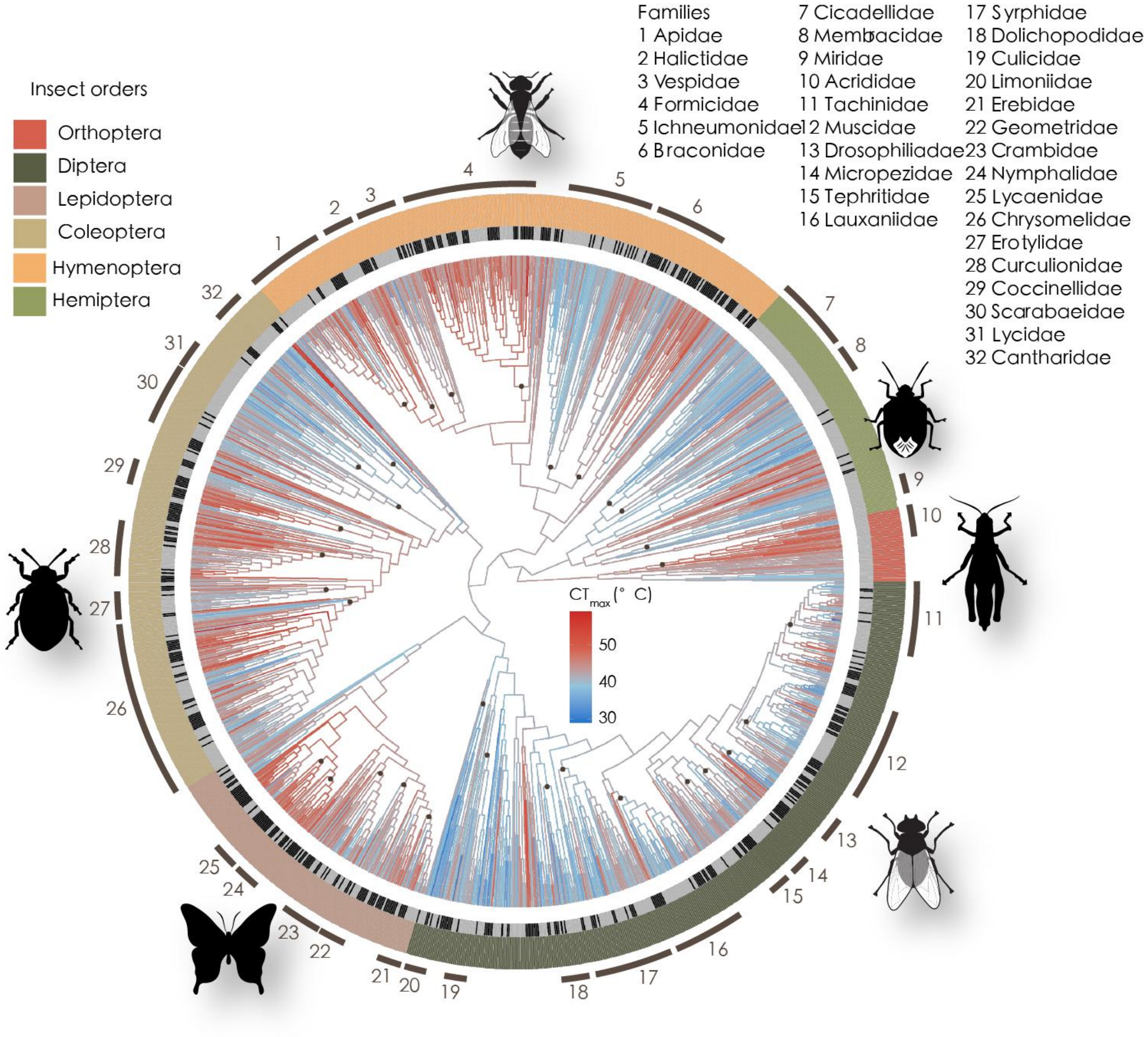
- CTmax varies with elevation
- Plasticity is limited in lowlands
- Is heat tolerance also evolutionarily constrained?

Step 3. Testing whether heat tolerance is evolutionarily constrained

COI barcoding → OTUs → supertree

2,246 OTUs with CTmax

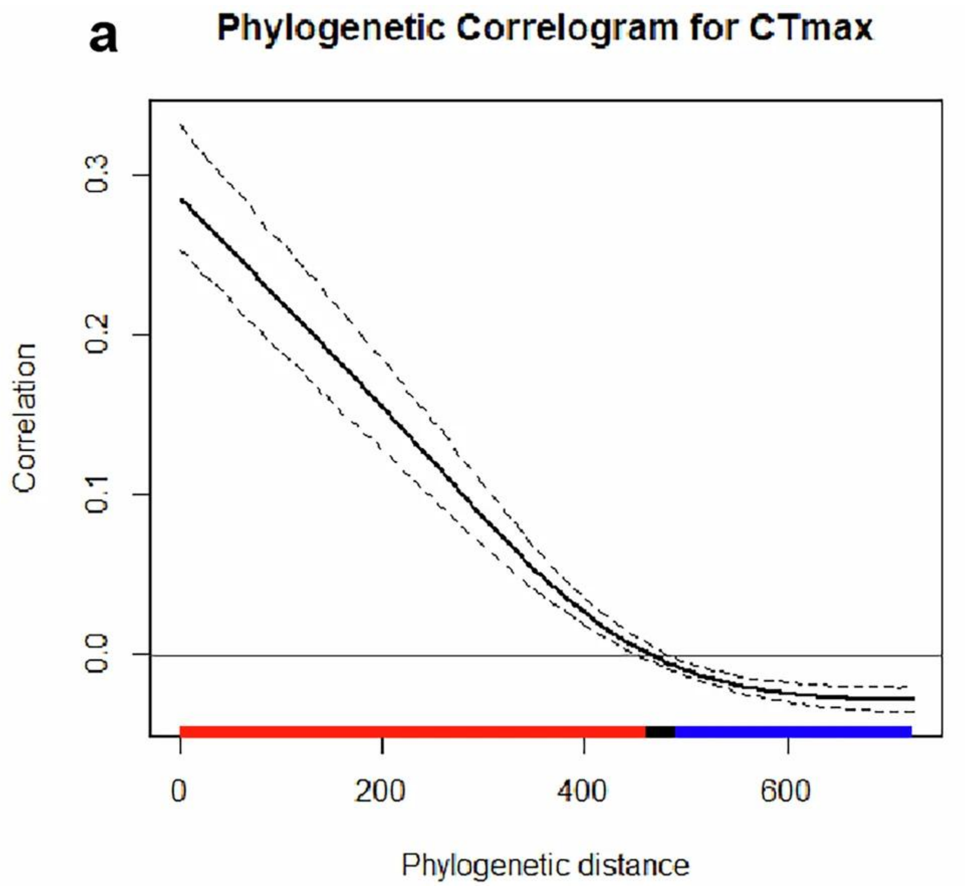
Ancestral reconstruction of CTmax



Thermal limits are not randomly distributed on the tree

Evidence 3a. CTmax shows significant phylogenetic signal

Formal phylogenetic correlogram



- Related lineages show positive similarity at short phylogenetic distances
- Similarity weakens as phylogenetic distance increases

CTmax is phylogenetically structured rather than randomly distributed across lineages

Evidence 3b. What would constrained evolution look like?

BM vs OU: two models for testing evolutionary constraint

Brownian motion (BM)

random walk

divergence accumulates through time

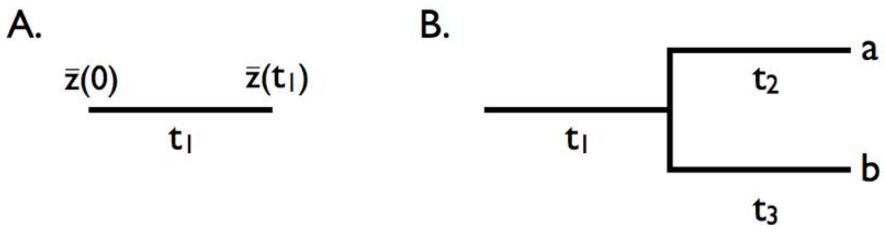
similarity reflects shared ancestry

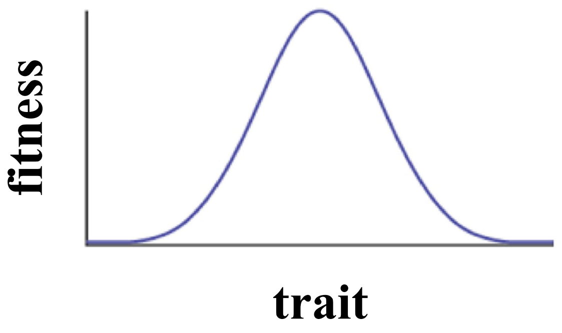
Ornstein–Uhlenbeck (OU)

divergence toward an optimum

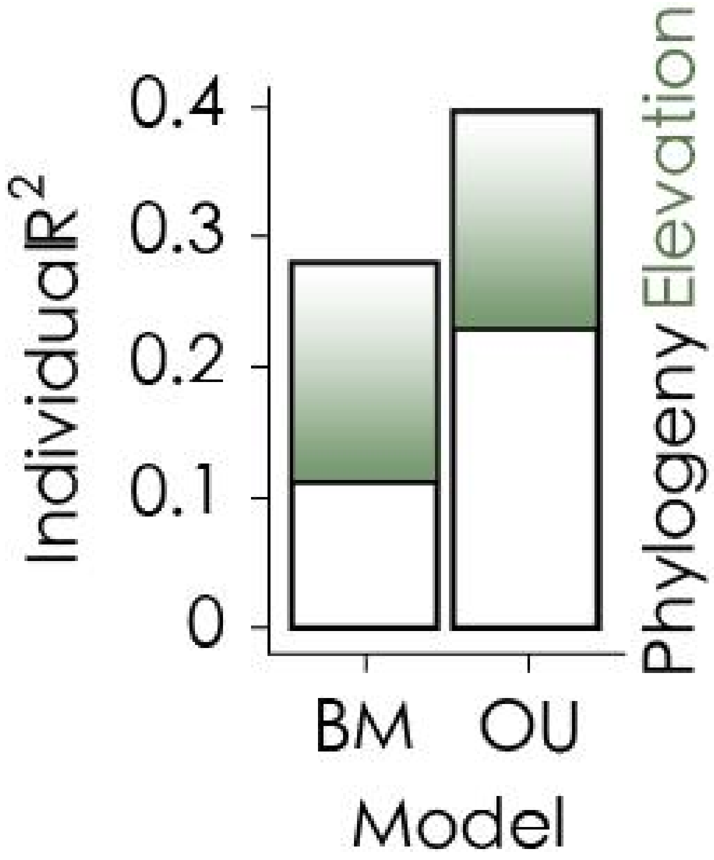
bounded rather than unlimited

more consistent with constrained evolution





Evidence 3c. Heat tolerance is better explained by constrained evolution



- OU fit better than BM by AIC
- Estimated optimum: θ = 42.2˚C
- Phylogeny explained slightly more variation than elevation
- partial r^2: phylogeny = 0.23; elevation = 0.17

Heat tolerance is not freely diverging; it is evolutionarily constrained

From phylogenetic pattern to molecular mechanism

CTmax is phylogenetically constrained

But phylogeny reveals pattern, not mechanism

What biological substrate might carry this constraint?

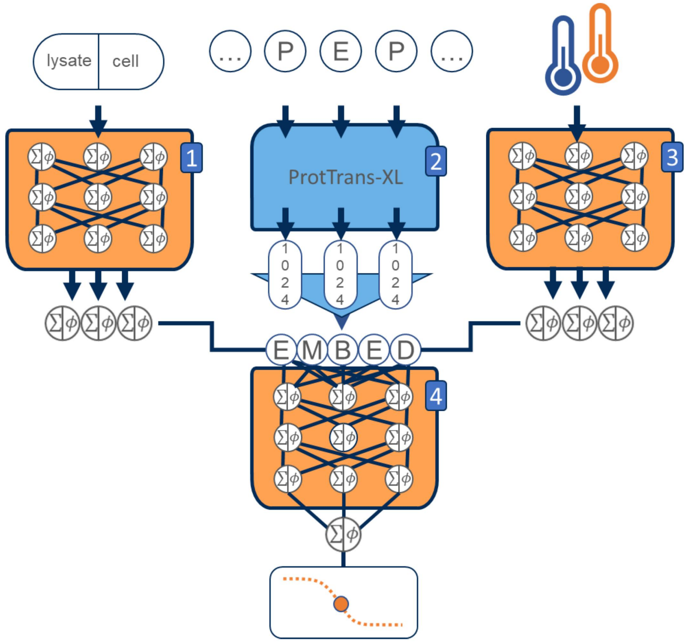
Phylogenetic constraint in CTmax → Proteome thermal stability (Tm)

Step 4. Testing molecular basis with predicted protein Tm

Question: does lineage's molecular stability track its heat tolerance?

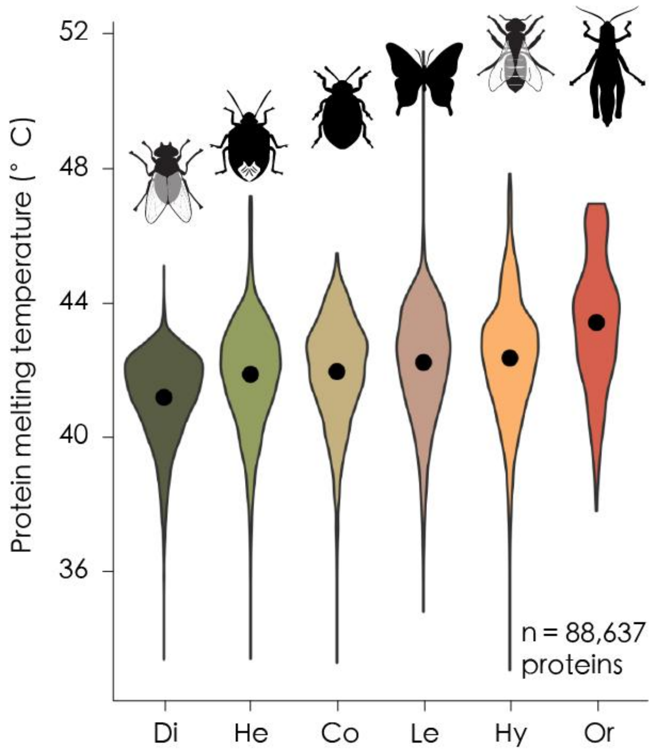
1. **677** insect genomes from InsectBase 2.0
2. **1,000** proteins sampled per species
3. **DeepSTABp** predicts protein melting temperature **(Tm)**
4. **Tm** is used here as a proxy for protein thermal stability
5. Compare family mean Tm with family mean CTmax

DeepSTABp

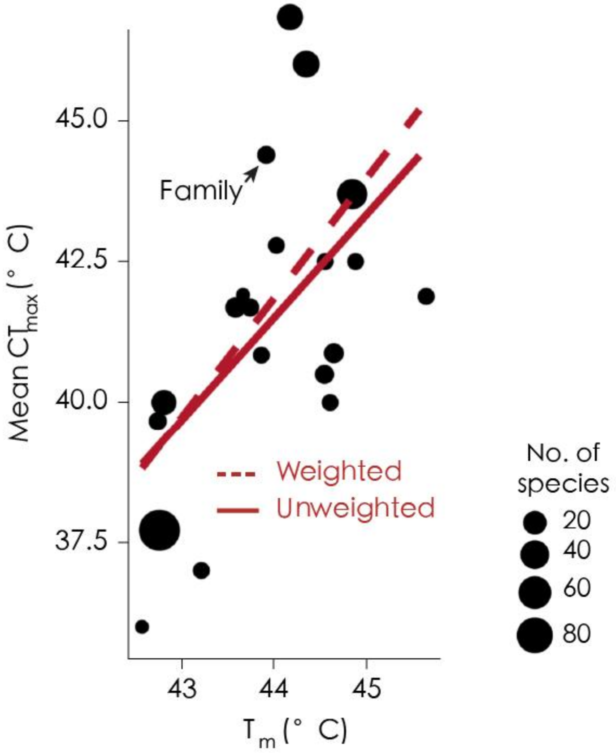


Jung et al. 2023

Evidence 4. Protein stability tracks heat tolerance



Predicted protein Tm varies across major insect lineages



Family-level Tm positively predicts family-level CTmax

Higher Tm

↓

More thermally stable proteomes

↓

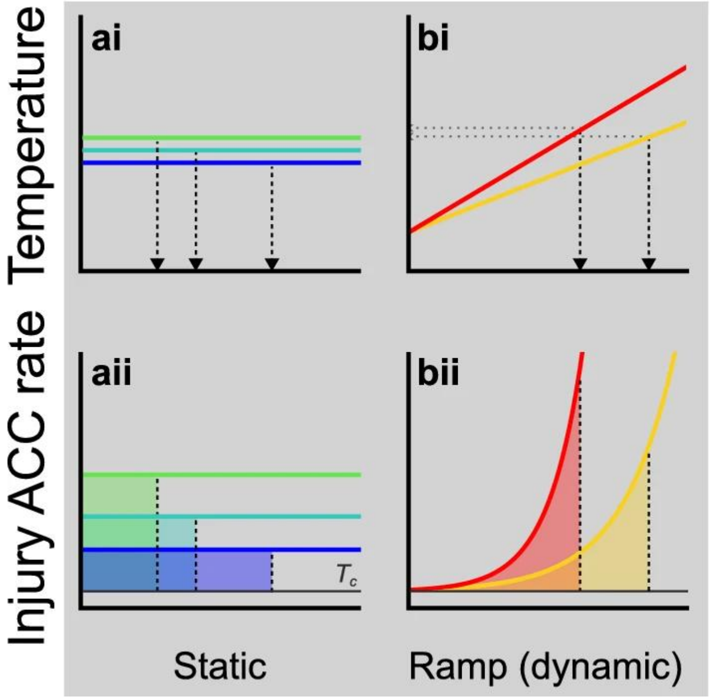
Higher CTmax

This suggests that conserved heat tolerance may be partly rooted in proteome-level biophysical stability

Step 5. Translating thermal limits into climate risk

Risk depends on both temperature and exposure time

tcoma = time to heat coma

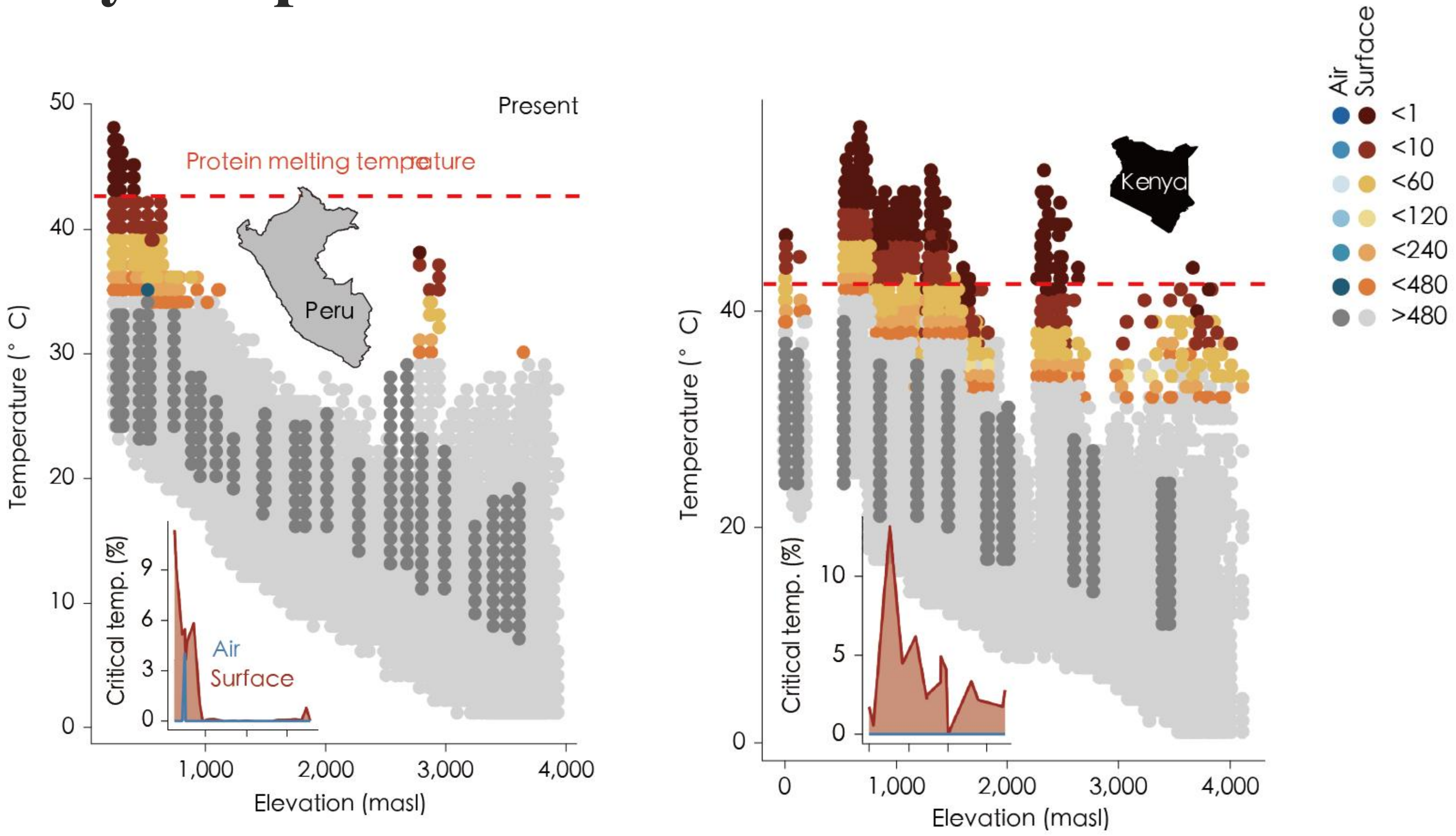


1. CTmax
2. Exposure-time model
3. Current/future temperatures
4. Tcoma
5. Critical temperatures

Temperatures causing heat coma within **8 h**

CTmax alone is not enough; risk depends on how long insects experience harmful temperatures

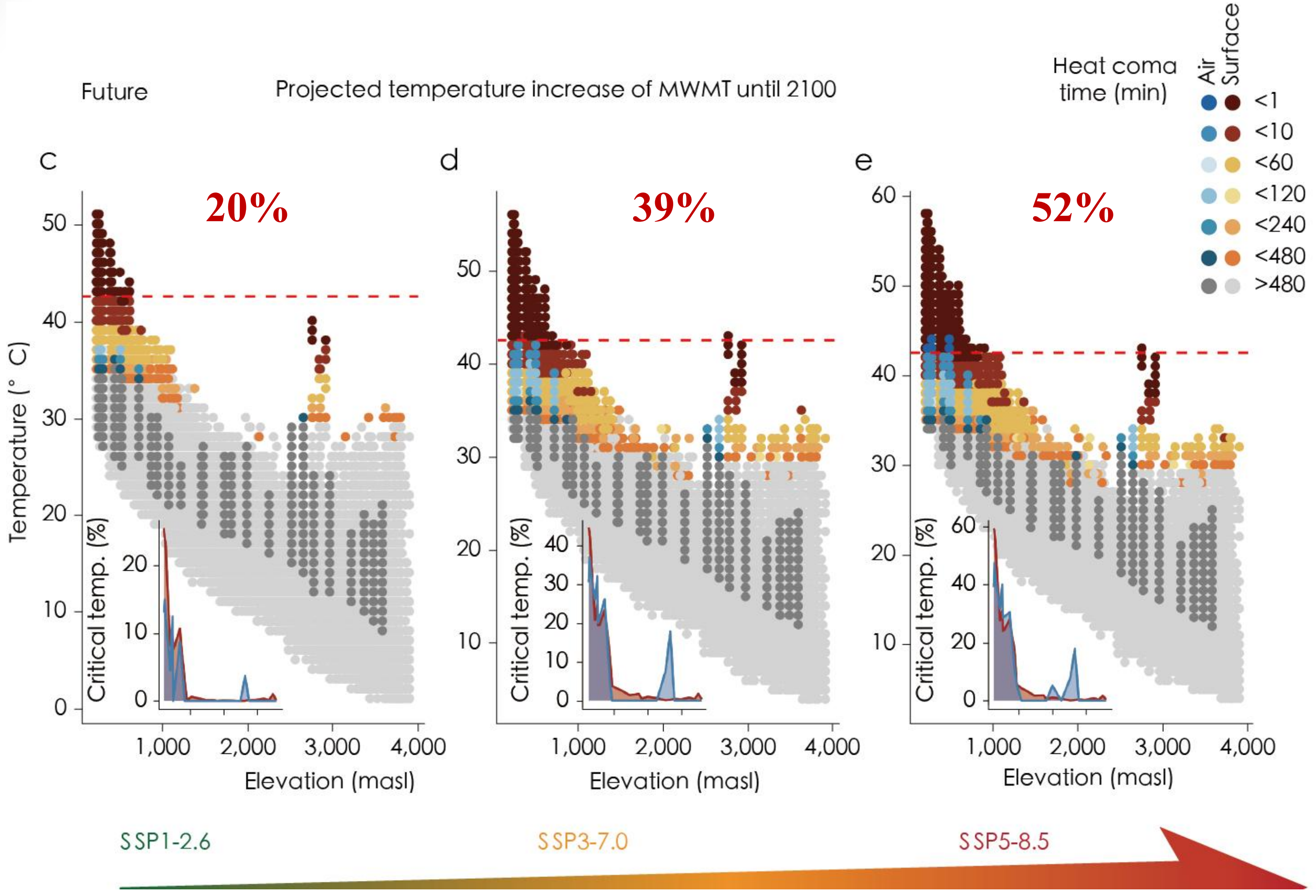
Evidence 5a. Present-day lowlands already experience risky temperatures



Risk is already present today, especially in hot lowland surface environments.

- Injury-causing temperatures already occur in lowland communities
- Surface temperatures are especially risky

Evidence 5b. Future warming sharply elevates lowland risk



Higher emissions

↓

Greater lowland risk

- Future risk rises across all scenarios
- Amazonian lowlands show the strongest increase in risk
- Projected lowland increase by 2100: **20%** → **39%** → **52%**

Synthesis

One question, five answers

1. Thermal limits rise toward warm lowlands, but too slowly
2. Short-term plasticity is weakest in lowlands
3. Heat tolerance is phylogenetically constrained
4. Protein stability provides a plausible molecular basis
5. Climate risk is already high and will intensify

Together, these results suggest that tropical insects may have limited capacity to keep pace with warming

Strengths, weakness, and take-home message

Strengths

Exceptionally broad tropical insect dataset

Integrates physiology, phylogeny, proteins, and climate risk

Moves beyond pattern description to mechanistic inference

Weakness

CTmax is a standardized proxy, not direct field mortality

Protein Tm is predicted rather than experimentally validated protein by protein

Micro refugia and behavior may still buffer realized exposure

Even with these weakness, the study provides an unusually integrative view of tropical insect thermal limits