Biological control and climate change: Insight from multi-level species interactions

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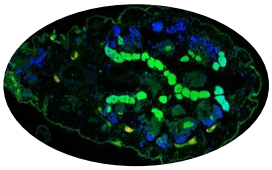
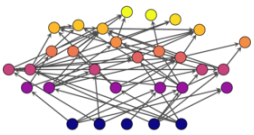
An overview of recent studies

Using the thermal biology of species to study changes in communities and biocontrol potential

Insect-bacteria symbioses



Host-parasitoid networks



Hyperparasitoids

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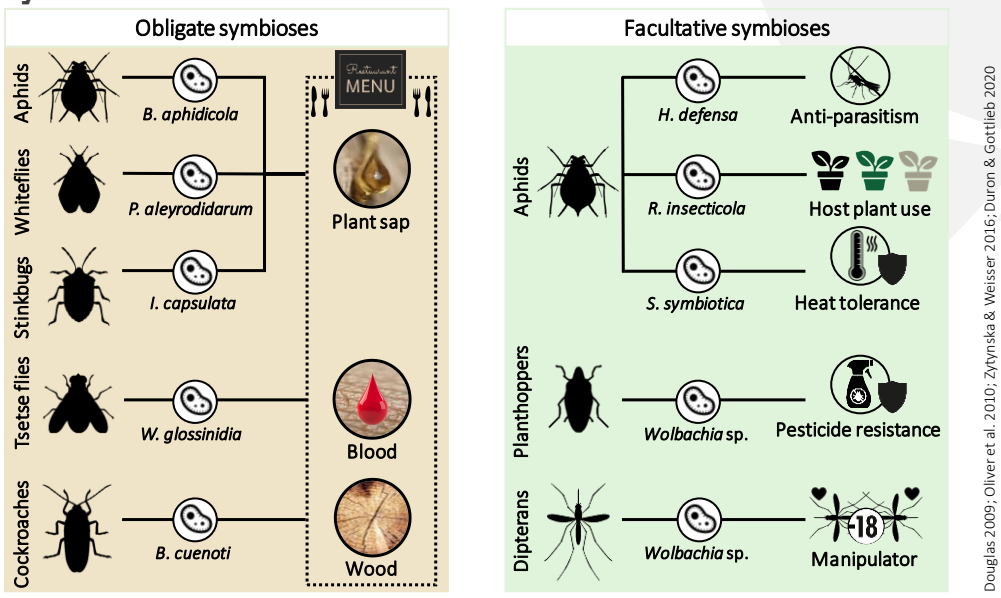
Effect of heat stress on the expression of aphid endosymbiont-modulated traits



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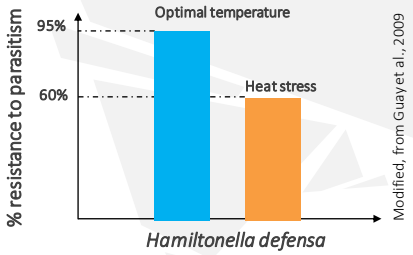
Effect of heat stress on the expression of aphid endosymbiont-modulated traits

- Temperature rapidly identified as a key environmental parameter, especially heat stress (Bensadia *et al.*, 2006)
- Modulates the outcome of host-symbiont interactions (Bougie *et al.*, 2021)
- Determines the net fitness consequences of carrying a particular symbiont genotype or species (Corbin *et al.*, 2017; Wernegreen *et al.*, 2012)



Empirical work has accumulated over the last two decades

Can we draw a general pattern on the effects of heat stress on symbiont-mediated trait expression in aphids?

What is the fate of insect-microbe mutualisms in a climate-change context?

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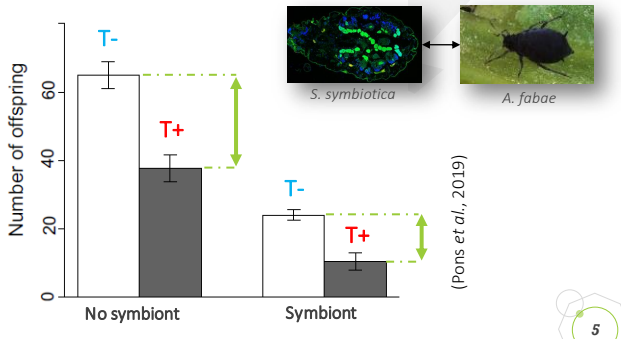
Effect of heat stress on the expression of aphid endosymbiont-modulated traits

Meta-analysis process

- **Standard bibliographic research between 1991 and 2020 using specific keywords**
- **Focus on aphids and their symbionts** (too few articles on temperature effects in other arthropod models)

- **We are interested in the "interaction effect":**
  - ❖ Effect of heat stress on aphid fitness components depending on the presence of a bacterial symbiont



(Tougeron & Iltis, 2022)

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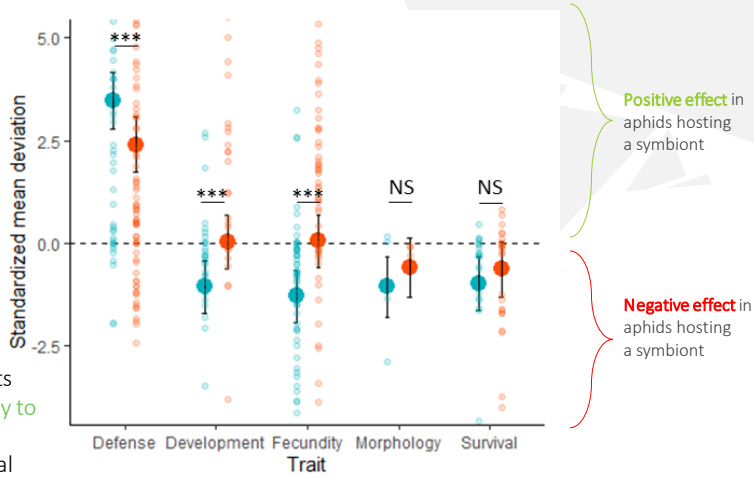
Effect of heat stress on the expression of aphid endosymbiont-modulated traits

- **Effect of the symbiotic infection is trait-dependent:**
  - ❖ Positive for defense
  - ❖ Negative for survival

- **Modulation effect of the temperature treatment on symbiont-mediated trait expression**
  - ❖ Defense: warming lowers the fitness benefits provided by the symbiont
  - ❖ Development and fecundity: warming shifts the effect of symbiotic infection from costly to neutral outcome
  - ❖ No modulation for morphology and survival



(Tougeron & Iltis, 2022)

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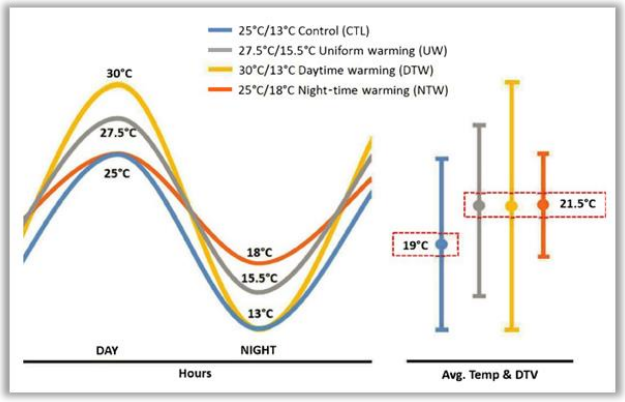
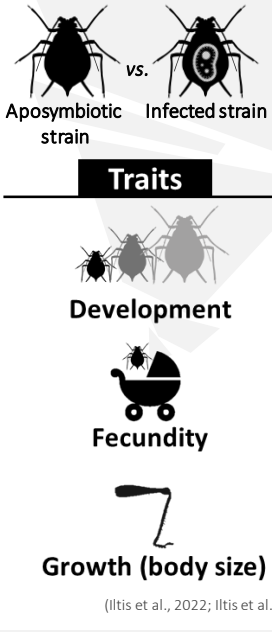
Effect of heat stress on the expression of aphid endosymbiont-modulated traits





But insects face more complex **temperature fluctuations** in nature… which effects are dependent on **symbiotic associations**

Affect a lot of traits and therefore **host-parasitoid interactions**, indirectly, and the potential for aphids to survive and thrive in various environments

(Iltis et al., 2022; Iltis et al., 2023)

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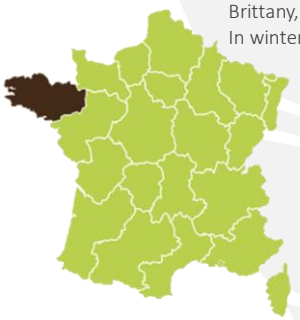
Change in aphid-parasitoid communities due to warmer winters

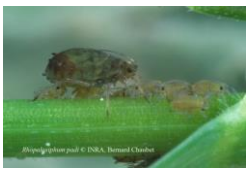
Western France, **mild winter climate** (+6°C average)
Aphids available **throughout the year**



Brittany, western France
In winter wheat fields

Aphidius matricariae

Aphidius rhopalosiphi



Bird cherry-oat aphid
Rhopalosiphum padi

English grain aphid
Sitobion avenae

Typical **winter community** since the 1980's (Krespi et al., 1990)
Relatively **stable** among years
All other parasitoid species were in diapause

(Tougeron et al., 2016)

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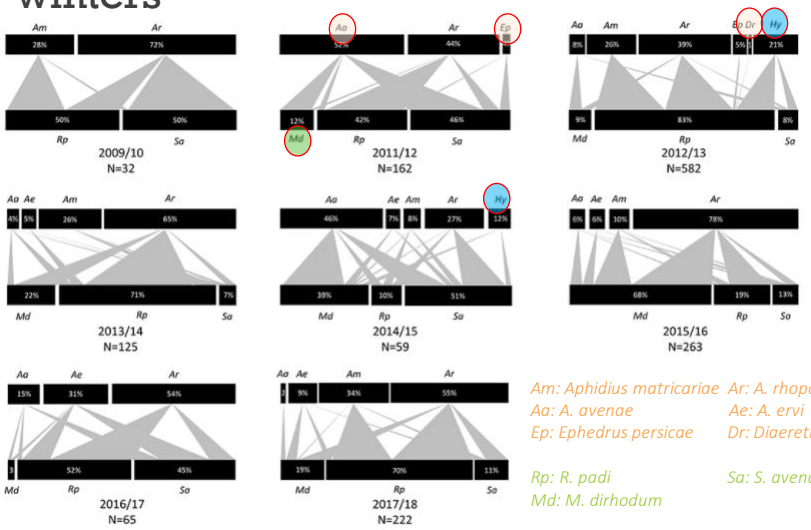
Change in aphid-parasitoid communities due to warmer winters



More **diverse** winter community (than before 2010)

Typical winter & spring species now **together during the winter**

Changes in **relative abundances** over time

Hyperparasitoids (1st time in winter 2012) present early (and earlier each year)

Am: Aphidius matricariae *Ar: A. rhopalosiphi*
Aa: A. avenae *Ae: A. ervi*
Ep: Ephedrus persicae *Dr: Diaeretiella rapae*

Rp: R. padi *Sa: S. avenae*
Md: M. dirhodum

Hy: Hyperparasitoids

One year missing due to low sample sizes

(Tougeron et al., 2016; 2018)

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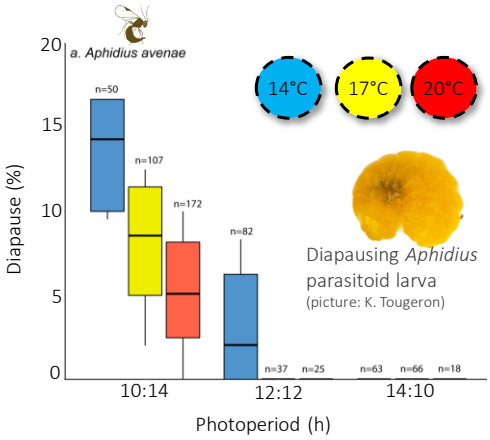
Change in aphid-parasitoid communities due to warmer winters

Two potential **mechanistic explanations**

1. Loss of winter diapause expression



2. Change in host quality and quantity

Sexual female morph

Asexual female morph

+20% parasitoid diapause incidence when developing in **sexual female aphids**

Sexual aphids are becoming very rare in the environment, because of warm winter temperatures

Parthenogenetic aphids are abundant throughout the winter in Brittany

(Tougeron et al., 2018; 2020)

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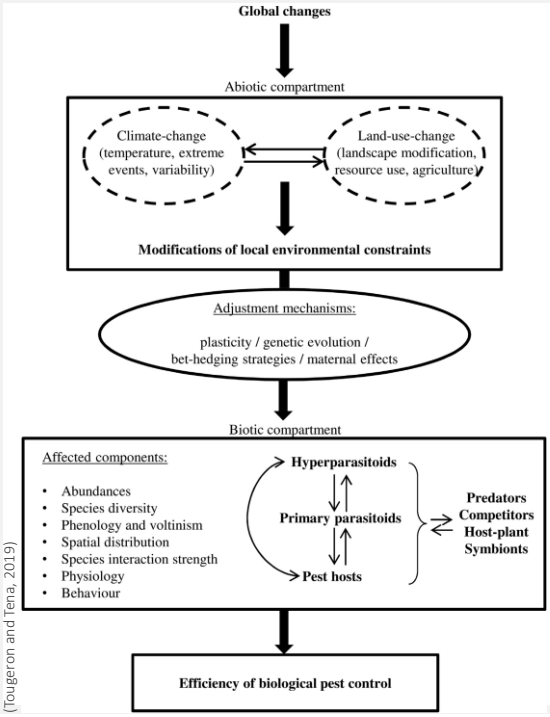

(Tougeron and Tena, 2019)

Hyperparasitoids as new biocontrol targets?

Hyperparasitoids act as biological control disruptors:
- Natural biological control
- Classical biological control
- Augmentative biological control
- Conservation biological control

Global change alter trophic interactions and phenology:
- Hyperparasitoids may benefit from global change, and especially from temperature increase

Considering hyperparasitoids as new biocontrol targets?
- Methods to buffer their negative impact on pest suppression
  - Use of chemical volatiles (Poelman and Kos, 2016)
  - Use of tertiary parasitoids (Harvey et al., 2009)
  - Manipulate symbiotic associations (Dicke et al., 2020)

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Take-home messages

Change in biological control potential of aphids, due to climate change

Arises from bottom-up and top-down effects, and from the action of microbial symbionts
Acts on pest populations, on natural enemies and on the whole interaction network

The question remains as to which of the pests or crop auxiliaries will benefit most from these changes, and how the various components of the complex system will respond to the changing climate

- **Quantitative studies confirm the net global increase in the adaptive value of symbiotic infection under heat stress for aphids**
  - ❖ Could symbionts facilitate their host adaptation to a warming world? (Renoz *et al.*, 2019; Perreau and Moran 2021)
  - ❖ Evaluating the cost-benefits balance for biological control, in various thermal contexts, including microclimates

- **Increase in minimal temperatures during winter = significant shifts in aphid-parasitoid food-webs, and allows early activity and higher abundance of hyperparasitoids**
  - ❖ Increased competition between primary parasitoids and negative effects of hyperparasitoids
  - ❖ Potential positive influence of hyperparasitoids on food-web stabilization

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Thanks for your attention!
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Thierry Hance, Alejandro Tena, Corentin Iltis (thank you!)
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