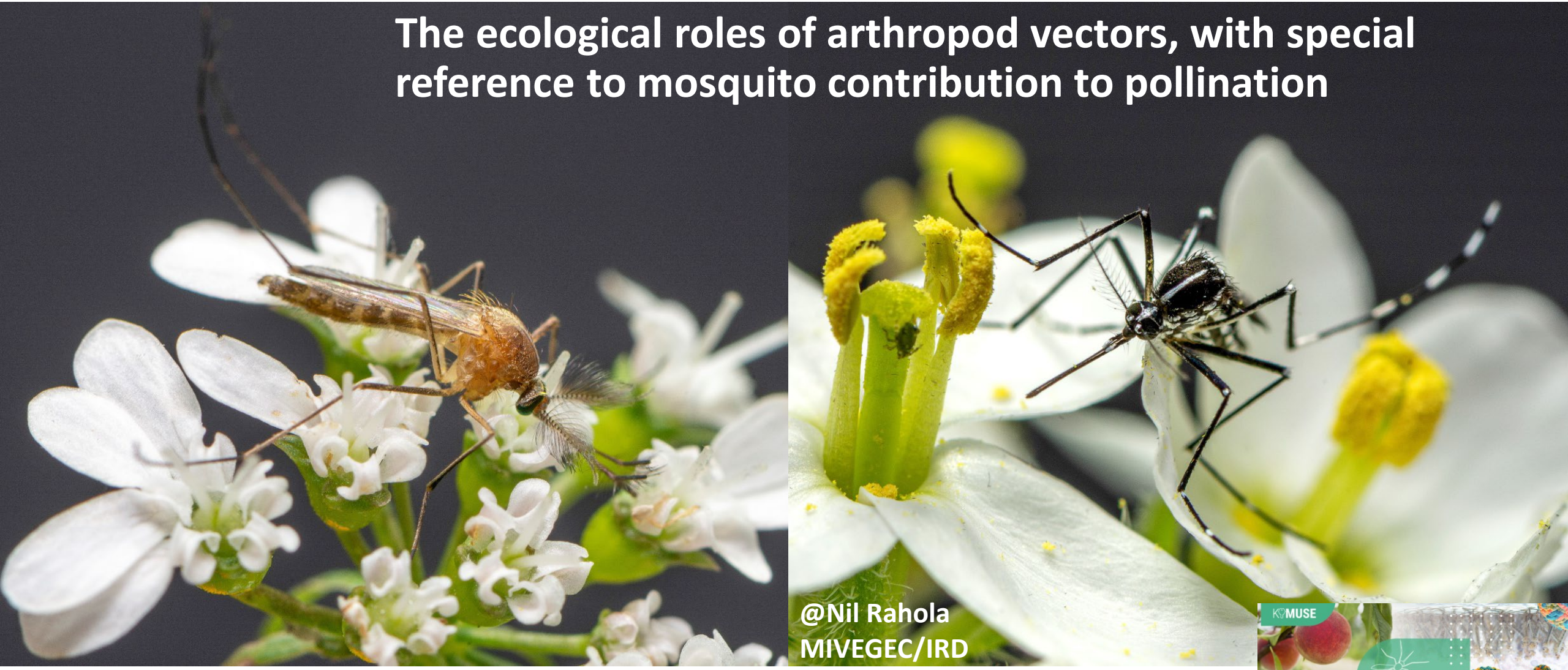
The ecological roles of arthropod vectors, with special reference to mosquito contribution to pollination



Colloque scientifique

9 et 10 novembre 2022

Agropolis - Montpellier

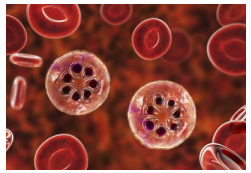
Thierry Lefèvre,
MIVEGEC lab, Univ. Montpellier, CNRS, IRD, Montpellier

KIM RIVE

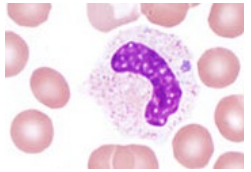
Vector control

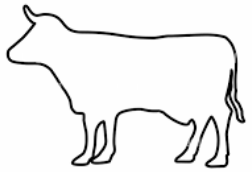
❖ Vectors of human, animal and plant pathogens

e.g. Malaria

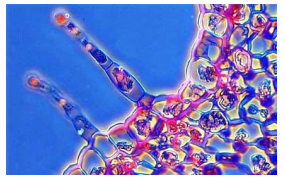


Anaplasmosis





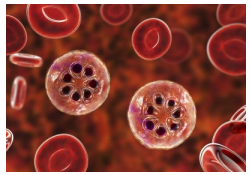
Mozaic viruses



Etc.

Vector control

e.g. Malaria



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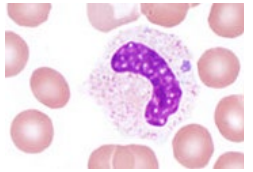

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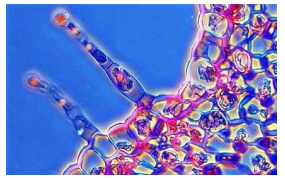


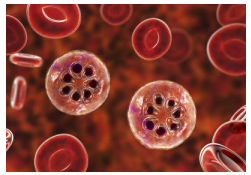
Etc.

- Vectors of human, animal and plant pathogens

79% of the 663 M averted malaria cases 2000 - 2015
Bhatt et al. 2015 Nature

Vector control

e.g. Malaria



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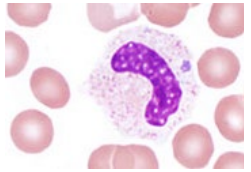

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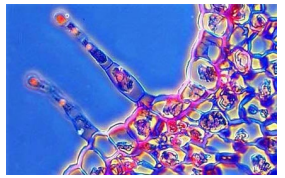

Etc.

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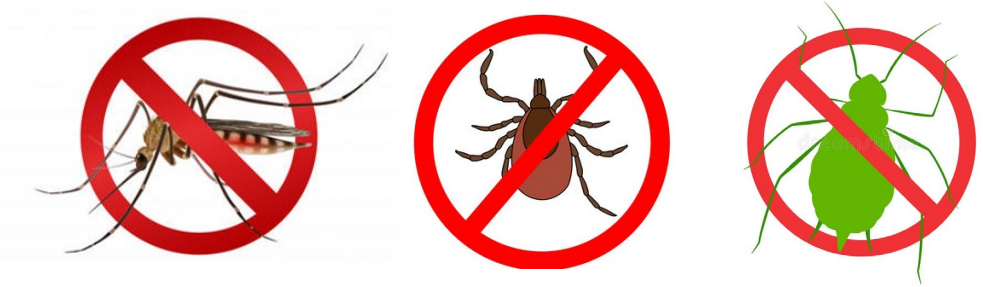
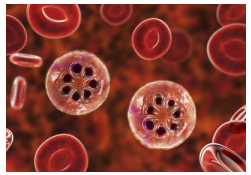


- Nuisance / direct detrimental impact on host populations

Vector control

e.g. Malaria



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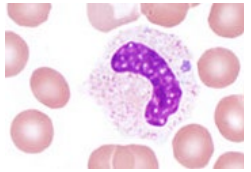

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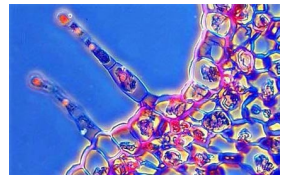

Etc.

- Vectors of human, animal and plant pathogens

79% of the 663 M averted malaria cases 2000 - 2015
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- Nuisance / direct detrimental impact on host populations

e.g. larvicidal *Bti* in wetlands

Environmental consequences of suppressing arthropod vectors ?

Environmental consequences of suppressing arthropod vectors ?

Ecology

Environmental consequences of suppressing arthropod vectors ?

Some basic aspects of vector ecology still unknown

e.g. What do vectors eat
and what feed on vectors?

e.g. What is the intensity of intra-
and inter-specific competition?

e.g. Do vectors provide pollination
services?

Environmental consequences of suppressing arthropod vectors ?

Ecole d'été RIVE « Biodiversité & Vecteurs »

1ère édition: Septembre 2021

2nde édition: Septembre 2022

KEY INITIATIVE MUSE RISKS & VECTORS (KIM RIVE)

Tour du Valat

Elodie Suttling, Didier Fontenille, Marion Vittecoq, Florence Fournet, Haoues Alout, Thierry Boulinier, Aurélie Binot, Catherine Cetre Sossah, Nicolas Sauvion, Claire Loiseau, Maryline Uzest…

Environmental consequences of suppressing arthropod vectors ?

KEY INITIATIVE MUSE RISKS & VECTORS (KIM RIVE)

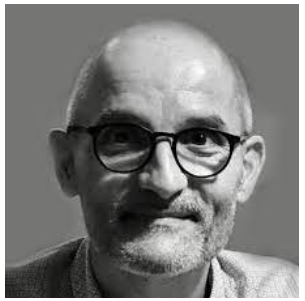
CellPress

Trends in Parasitology

Review

The ecological significance of arthropod vectors of plant, animal, and human pathogens

Thierry Lefèvre [1,2,3,*] Nicolas Sauvion [4] Rodrigo P.P. Almeida [5] Florence Fournet [1,2] and Haoues Alout [3,6]



N. Sauvion

R. Almeida

Vectors of plant pathogens

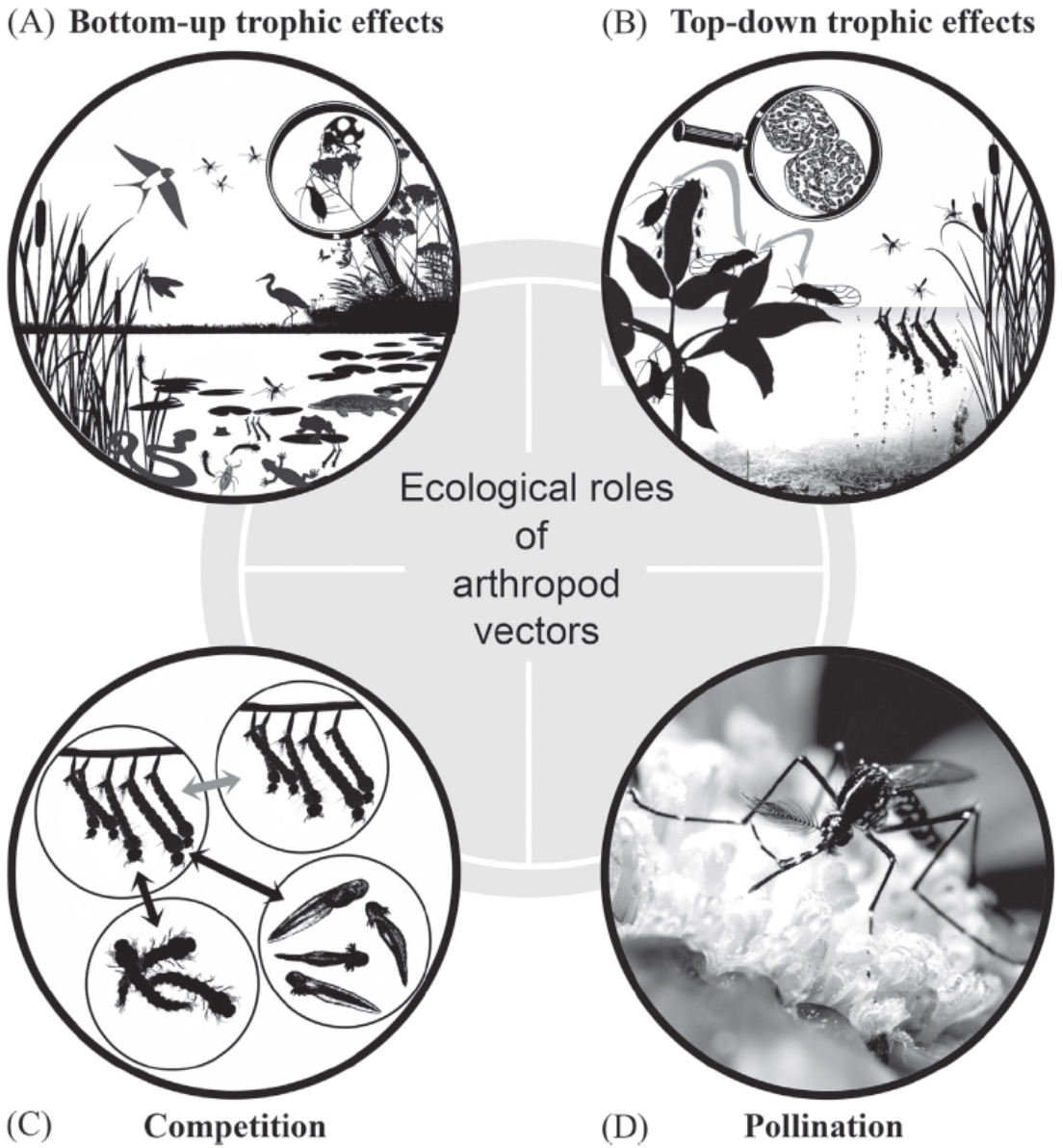
F. Fournet

H. Alout

Vectors of human and animal pathogens

Environmental consequences of suppressing arthropod vectors ?

1. **Effects on predators ?**



2. **Effects on prey populations, (decomposition and water purification) ?**

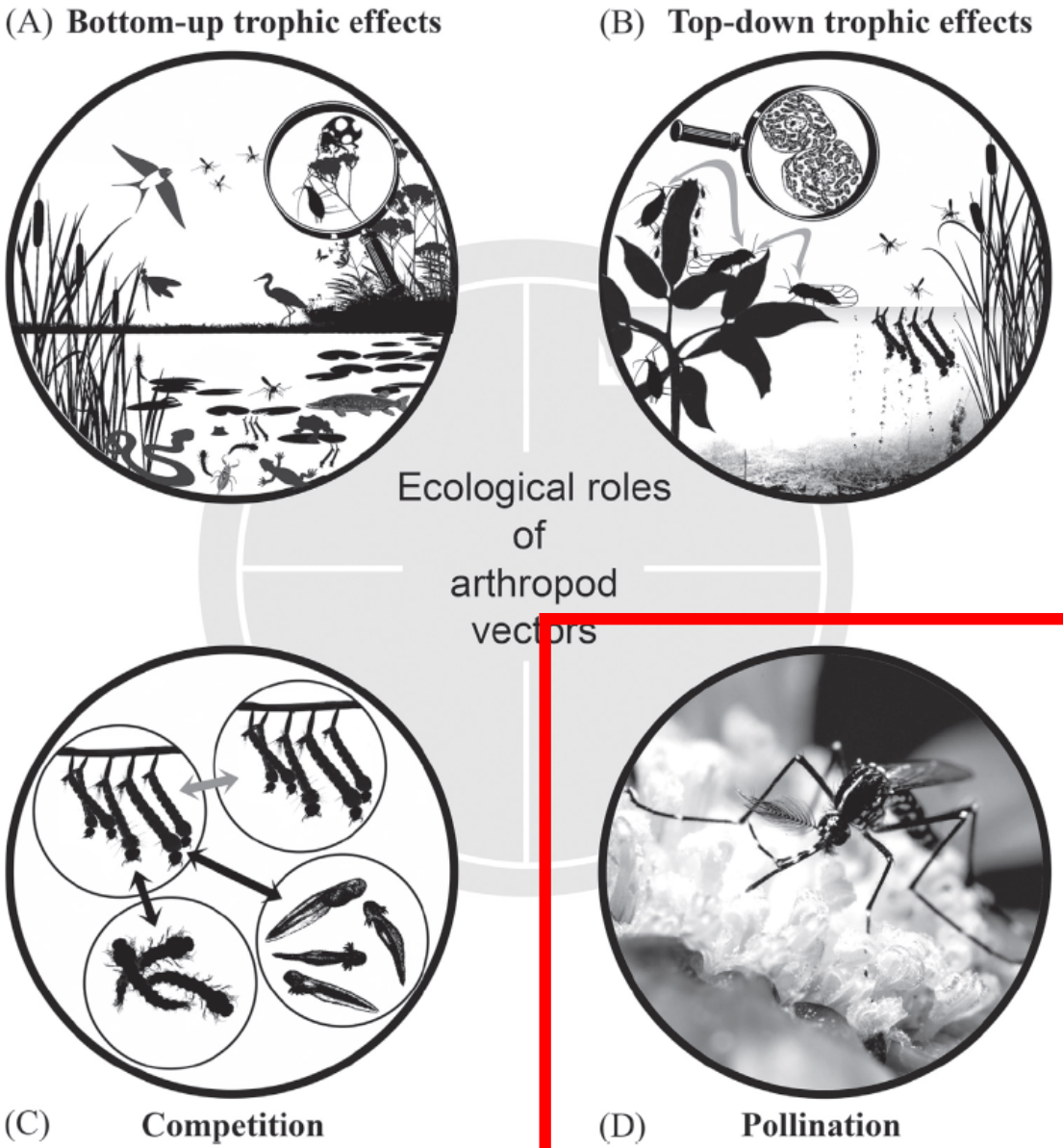
3. **Effects on inter- and intra-specific competition?**

4. **Effects on plant reproduction?**

Lefèvre, Sauvion, Almeida, Fournet, Alout. 2022 Trends in Parasitology

Environmental consequences of suppressing arthropod vectors ?

1. **Effects on predators ?**



2. **Effects on prey populations, (decomposition and water purification) ?**

3. **Effects on inter- and intra-specific competition?**

4. **Effects on plant reproduction?**

Lefèvre, Sauvion, Almeida, Fournet, Alout. 2022 Trends in Parasitology

Plant-derived sugars are important for the nutritional ecology of mosquitoes

♂

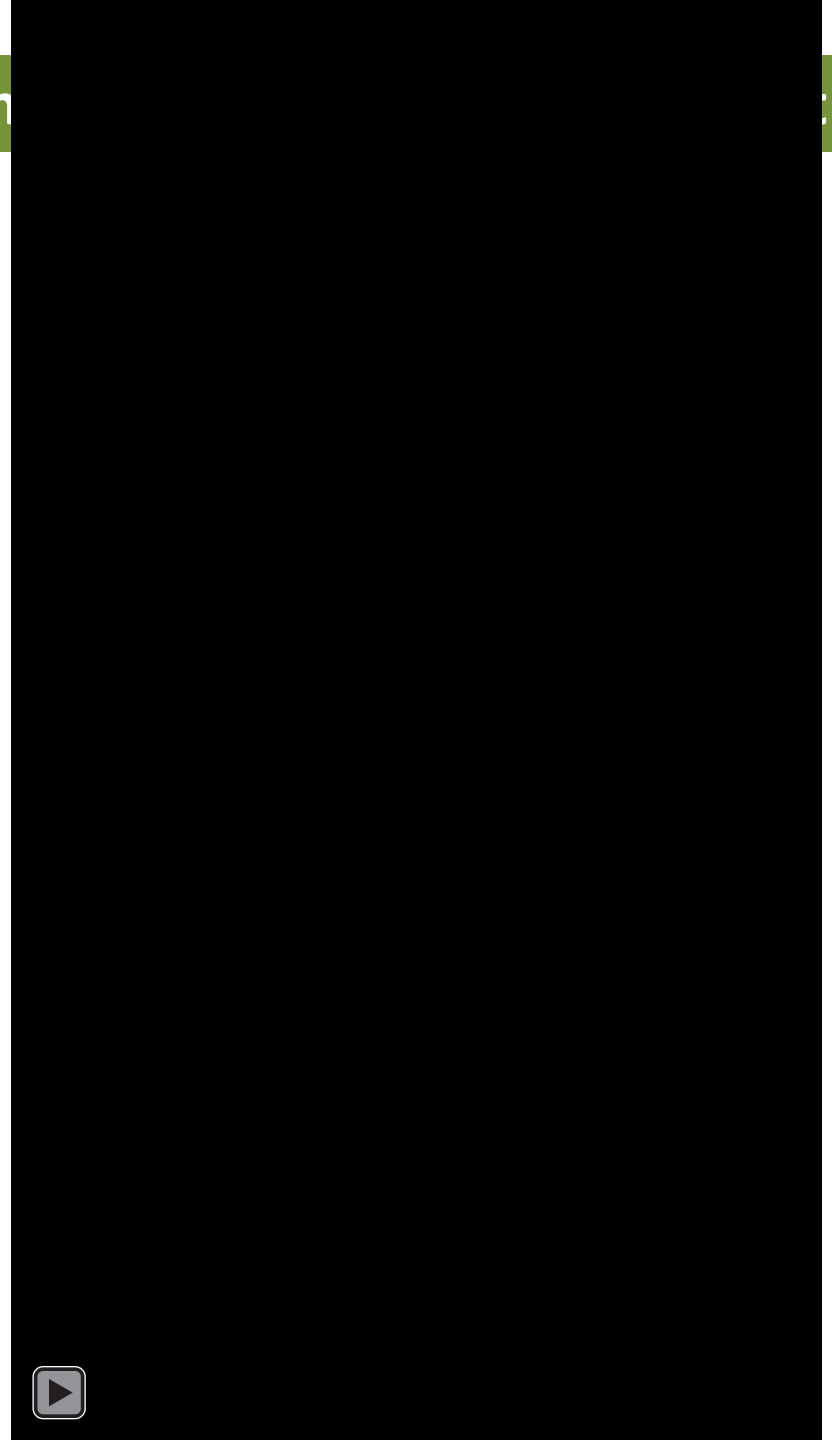
Males exclusive phytophageous

♀

Besides feeding on blood, females readily feed on plant sugars

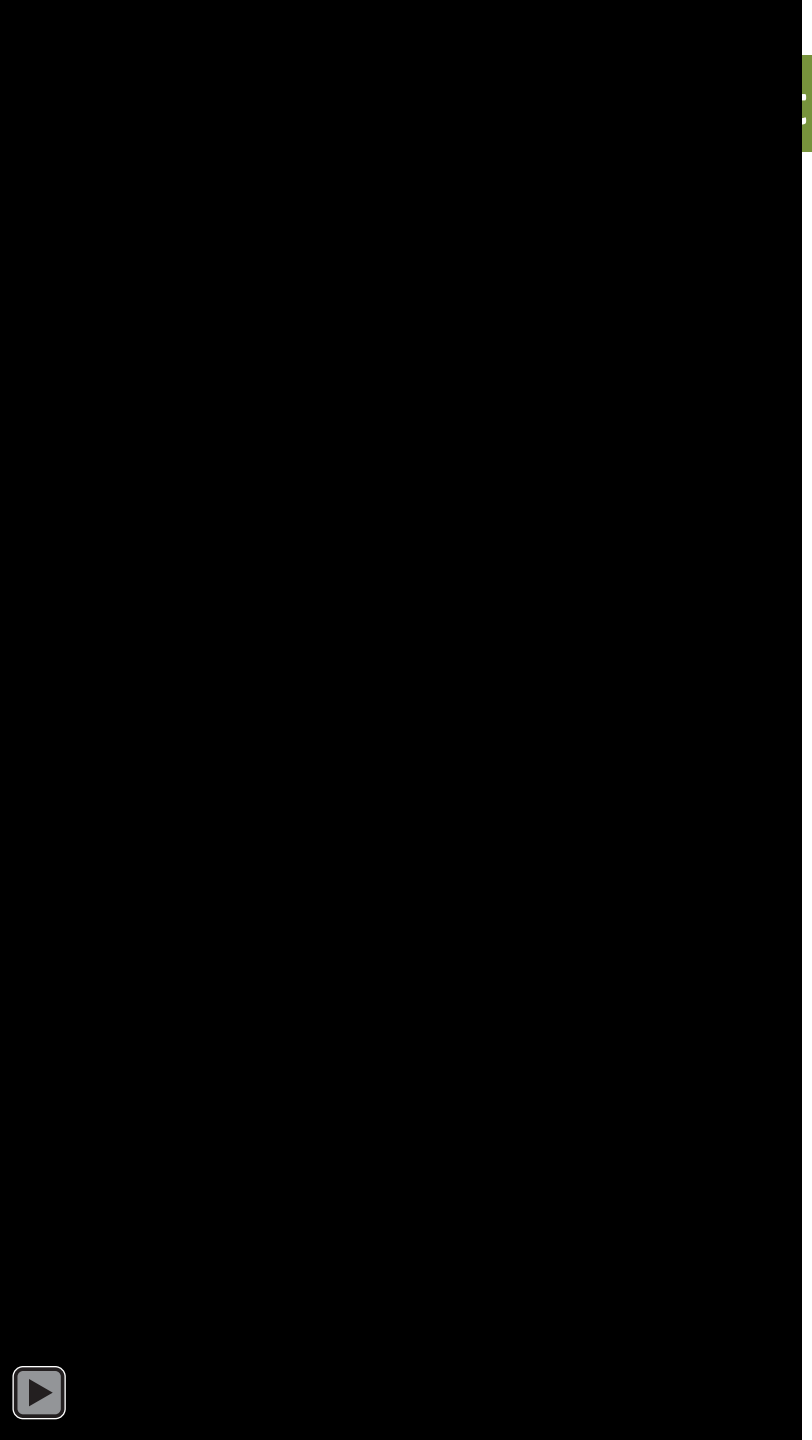
Foster 1995 Annu. Rev. Entomol.

Plan for the nutritional ecology of mosquitoes



Aedes albopictus males and females feeding on nectar from mint flowers (*Mentha spicata*) in my backyard in July 2022

Plan for the nutritional ecology of mosquitoes



Aedes albopictus males and females feeding on nectar from mint flowers (*Mentha spicata*) in my backyard in July 2022

Ok! they do feed on plant nectar but …
are they effective pollinators ?

Mosquito contribution to pollination

The olfactory basis of orchid pollination by mosquitoes

Chloé Lahondère[a,1], Clément Vinauger[a,1], Ryo P. Okubo[a], Gabriella H. Wolff[a], Jeremy K. Chan[a], Omar S. Akbari[b], and Jeffrey A. Riffell[a,2]

The orchid's odour mediates a unique mutualism between *Aedes* mosquitoes and *Platanthera obtusata* orchids

Aedes spp. - Platanthera obtusata

Lahondère et al. 2020 PNAS

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Lahondère 2020 PNAS

Nectar thieves or invited pollinators? A case study of tansy flowers and common house mosquitoes

Daniel A. H. Peach[1] · Gerhard Gries[1]

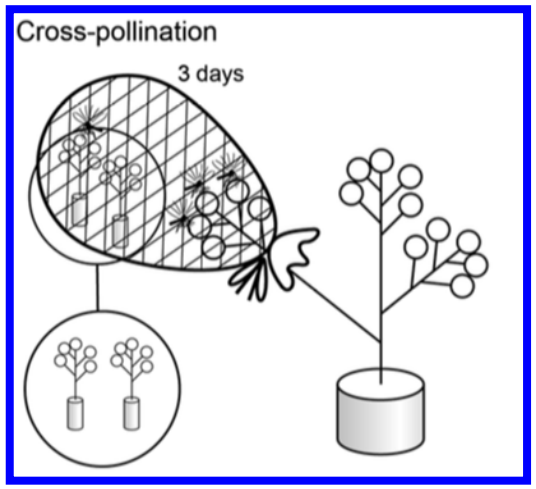
Culex pipiens – Tanacetum vulgare

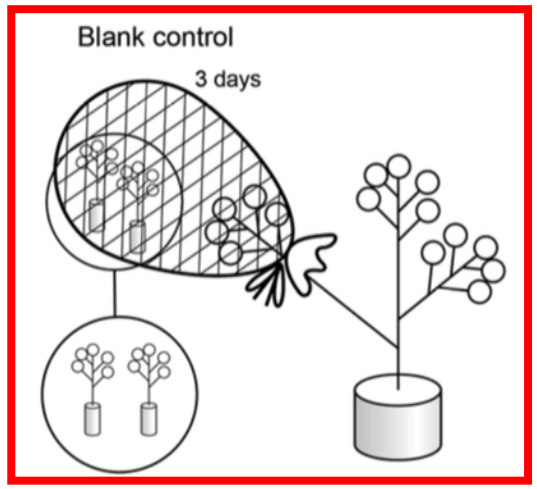
Peach and Gries 2016
Arthropod Plant Interact.

Mosquito contribution to pollination

Nectar thieves or invited pollinators? A case study of tansy flowers and common house mosquitoes

Daniel A. H. Peach[1] · Gerhard Gries[1]





60 mosquitoes kept for 3 days in a bag enclosing:

The flowers of a living potted tansy and

+

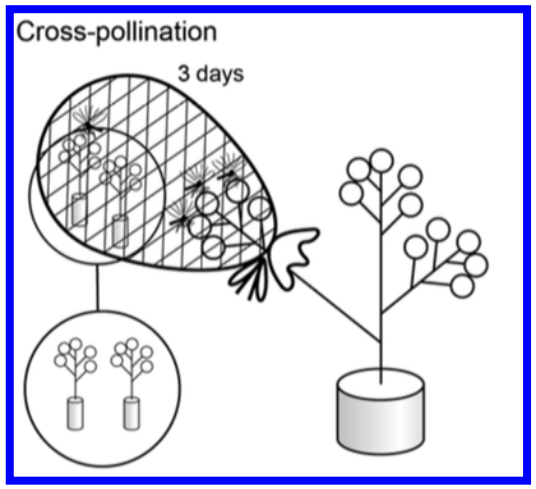
2 excised flowers of another tansy kept in water-filled vials.

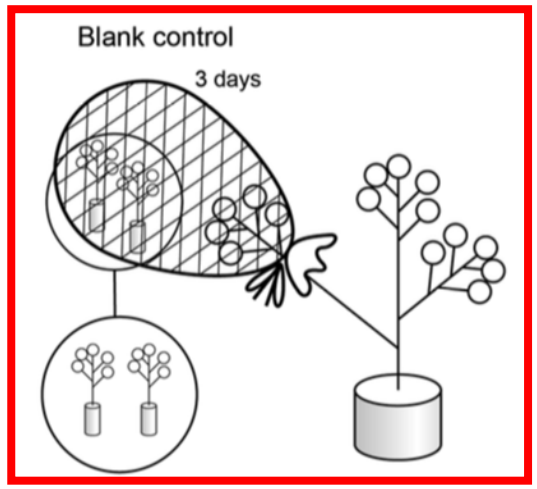
The control treatment was identical except that mosquitoes were absent

Mosquito contribution to pollination

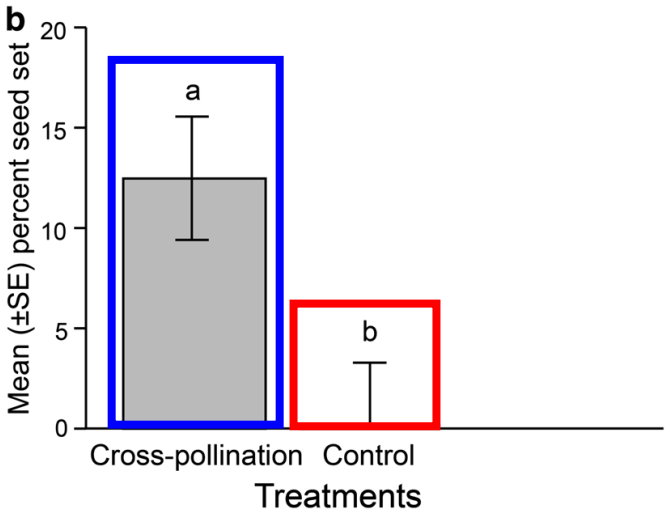
Nectar thieves or invited pollinators? A case study of tansy flowers and common house mosquitoes

Daniel A. H. Peach[1] · Gerhard Gries[1]





Culex pipiens effectively transferred pollen between inflorescences, resulting in seed set



Mosquito contribution to pollination

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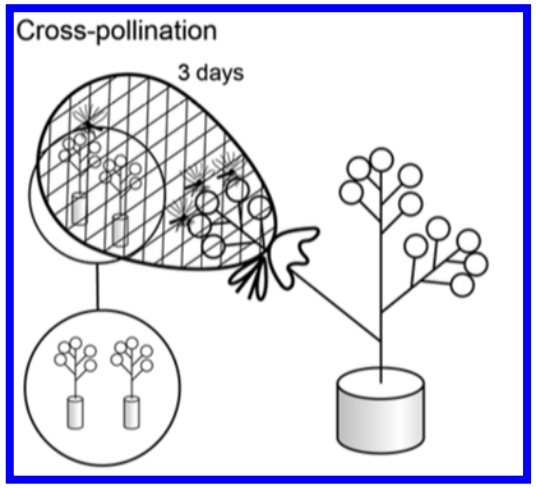
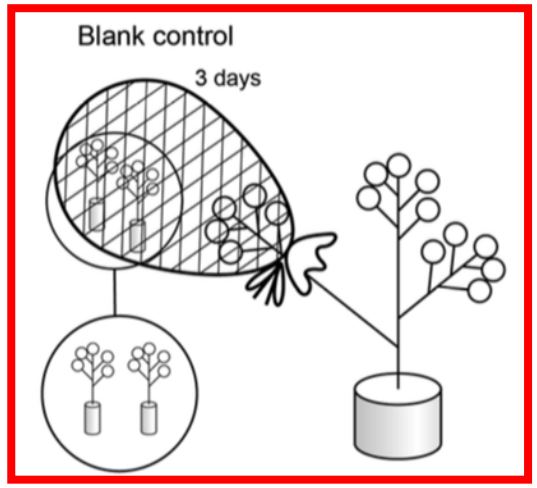
Daniel A. H. Peach[1] · Gerhard Gries[1]





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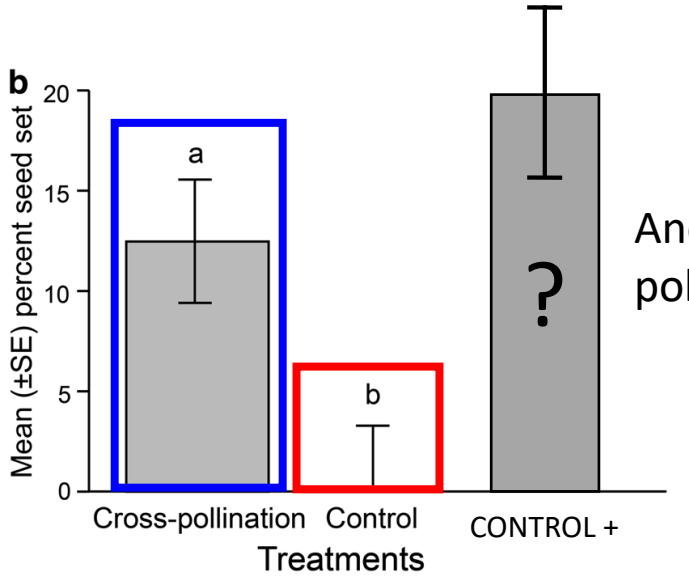

Another generalist pollinators

Materials and Methods

Fly vs. mosquito pollination

Tanacetum vulgare

Culex pipiens molestus

vs.

Protophormia terraenovae

Materials and Methods

Fly vs. mosquito pollination

Tanacetum vulgare

Culex pipiens molestus

vs.

Protophormia terraenovae

Brassica rapa

Cx pipiens molestus

vs.

P. terraenovae

Ae. albopictus

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Culex: sewage ponds, north of Montpellier

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Plants: Greenhouses to prevent pollination

Materials and Methods

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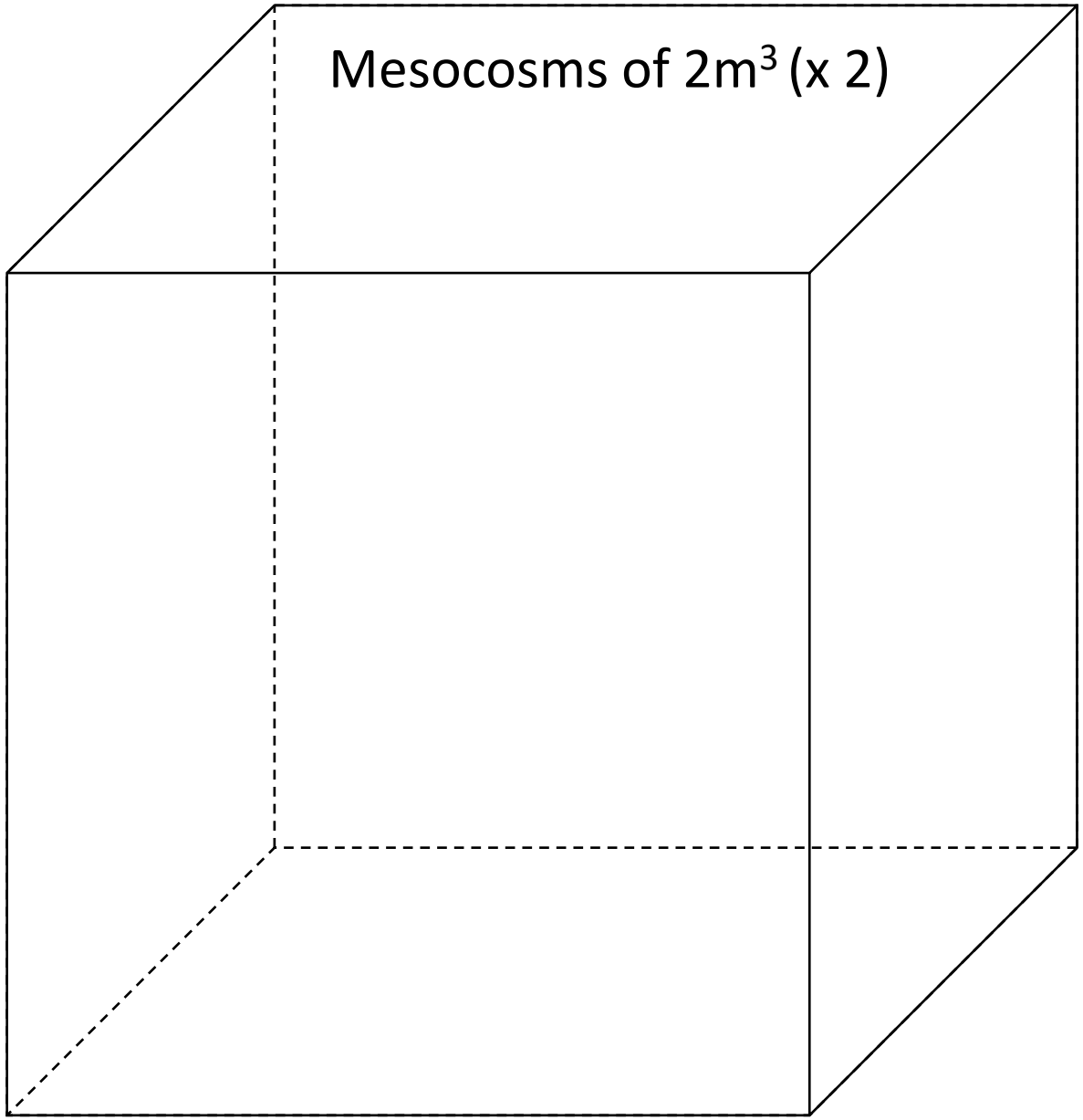

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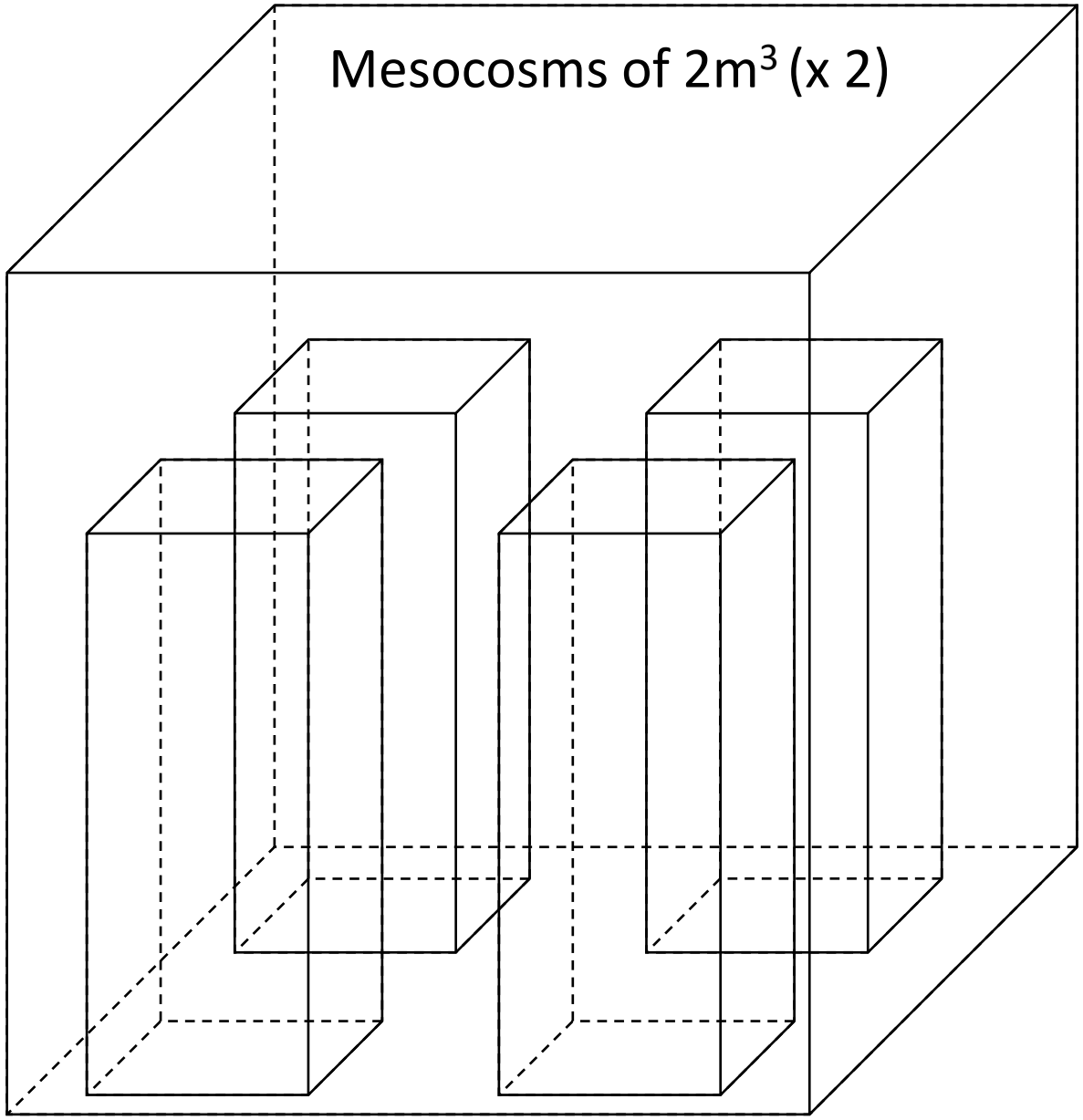

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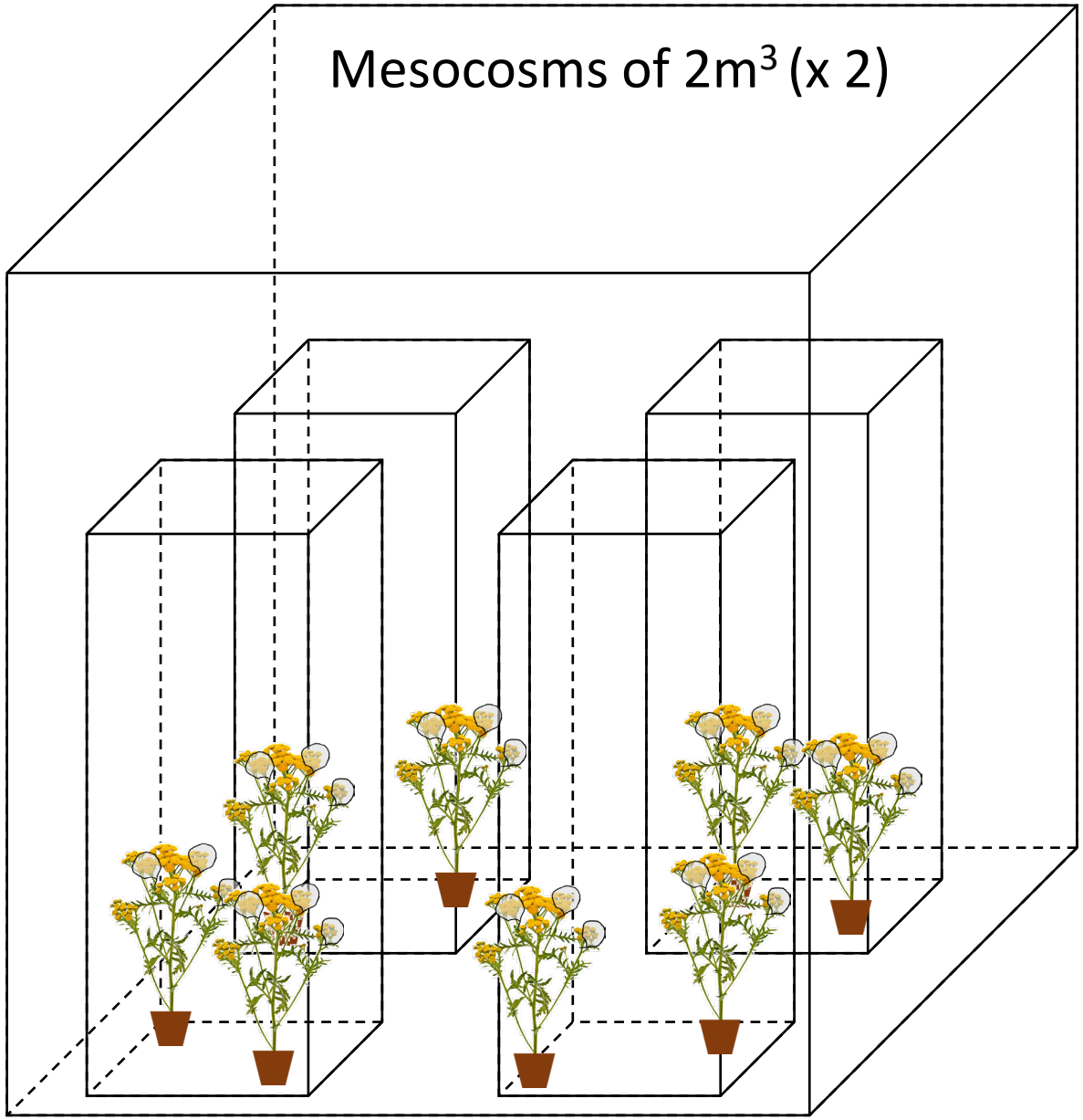

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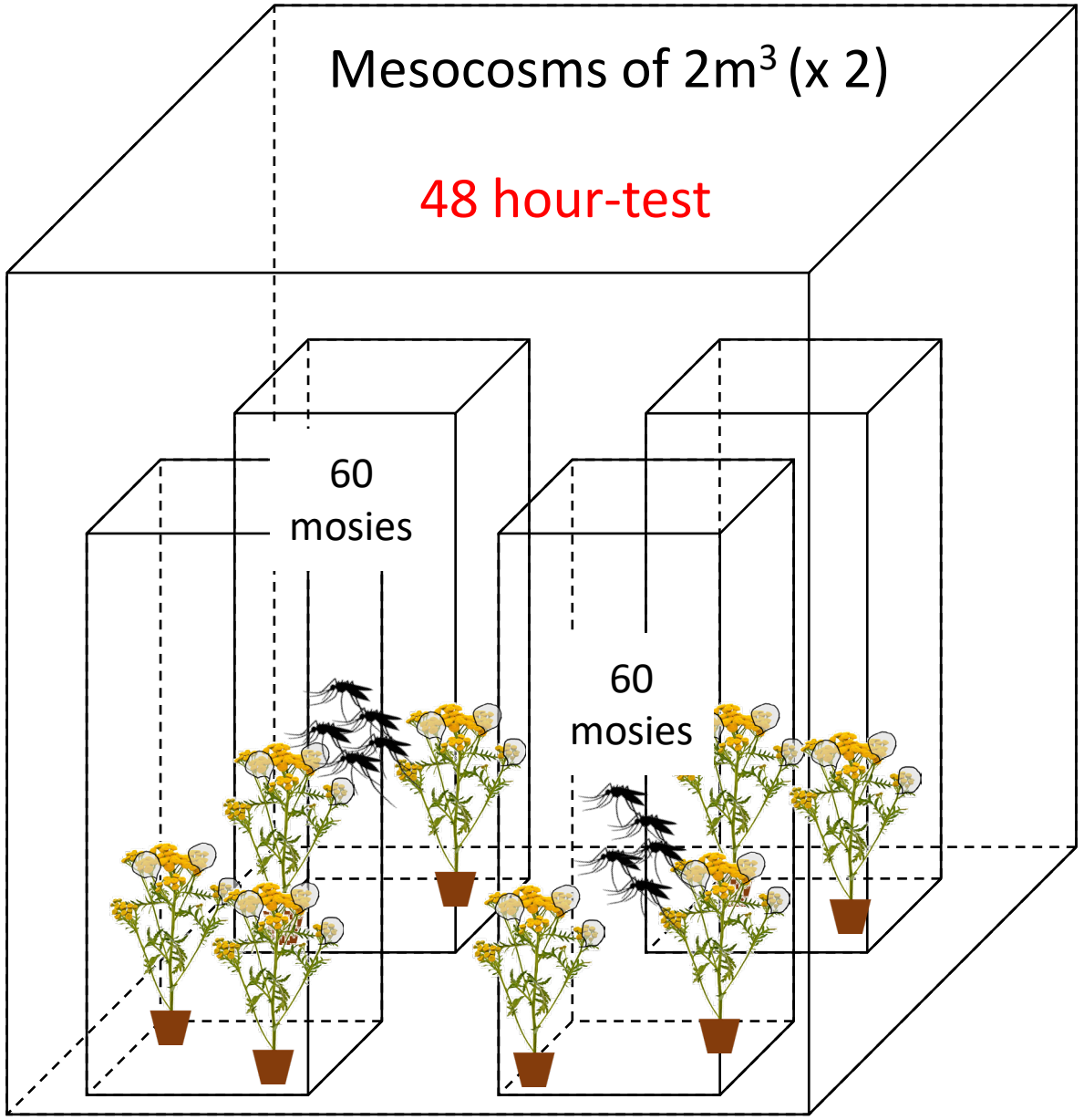

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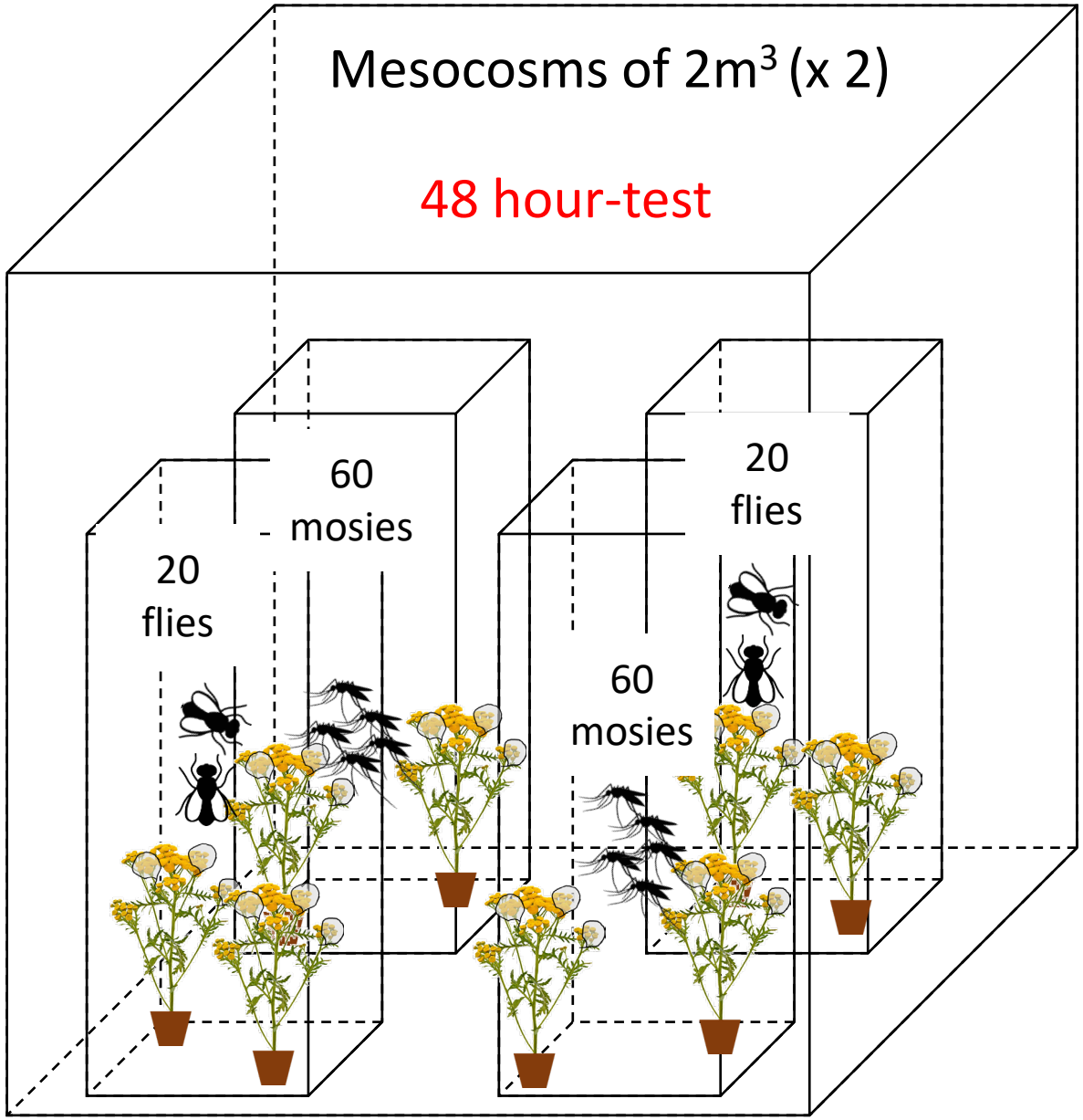

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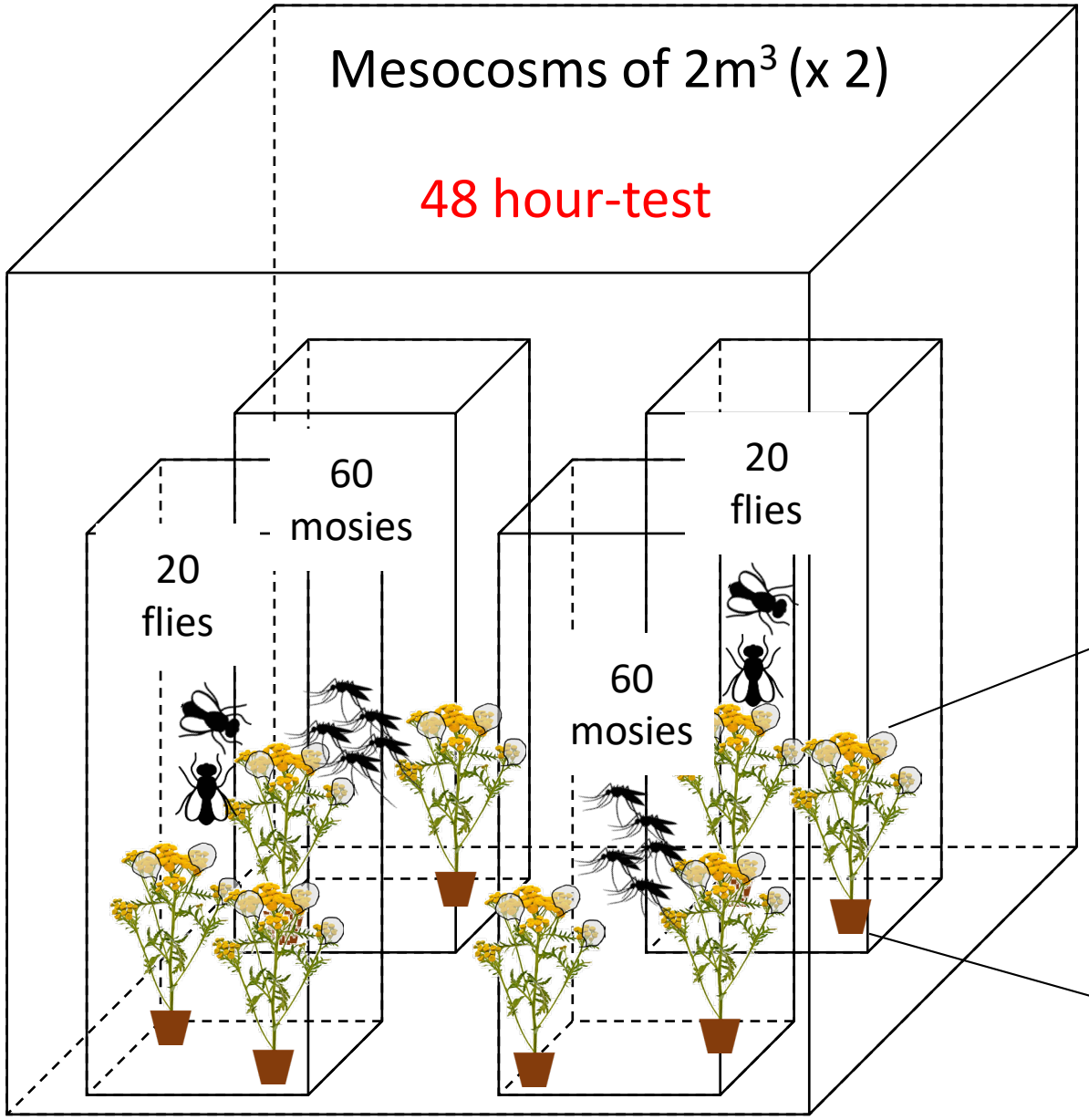
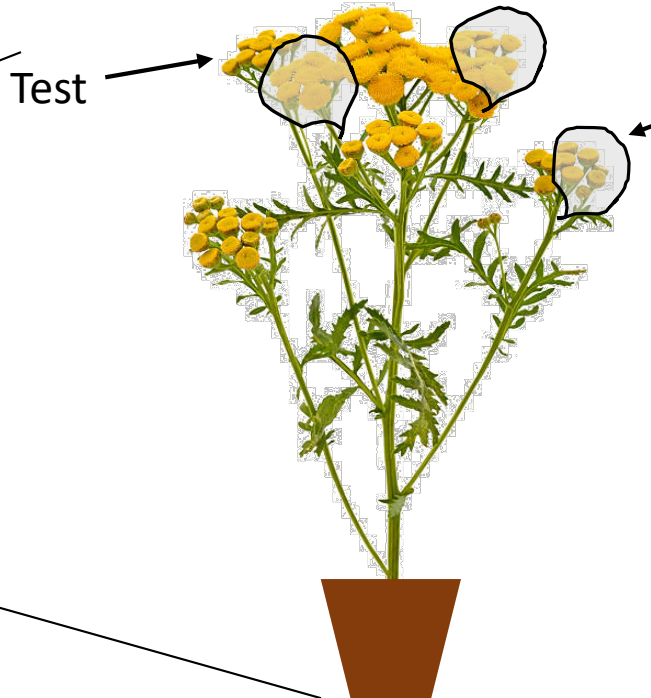




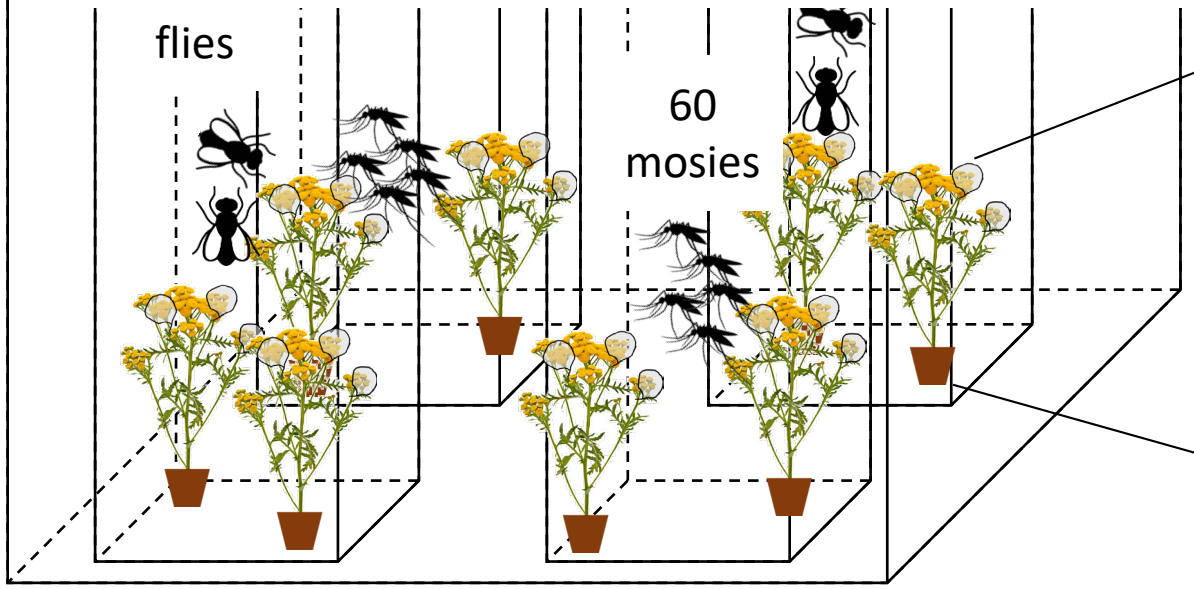
Materials and Methods

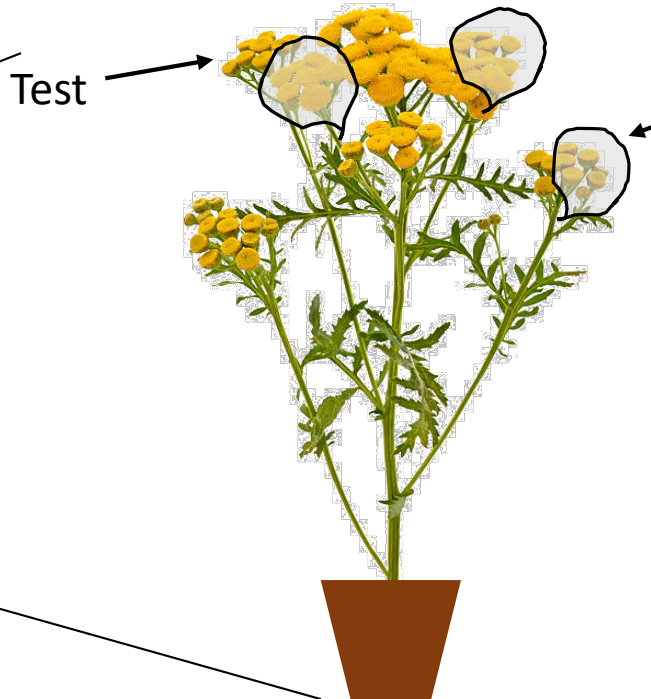
Fly vs. mosquito pollination

Mesocosms of $2m^3$ (x 2)

48 hour-test

This 2-day assay, with 2 mesocosms (8 cages), was repeated 4 times at different periods (N = 64 individual plants)





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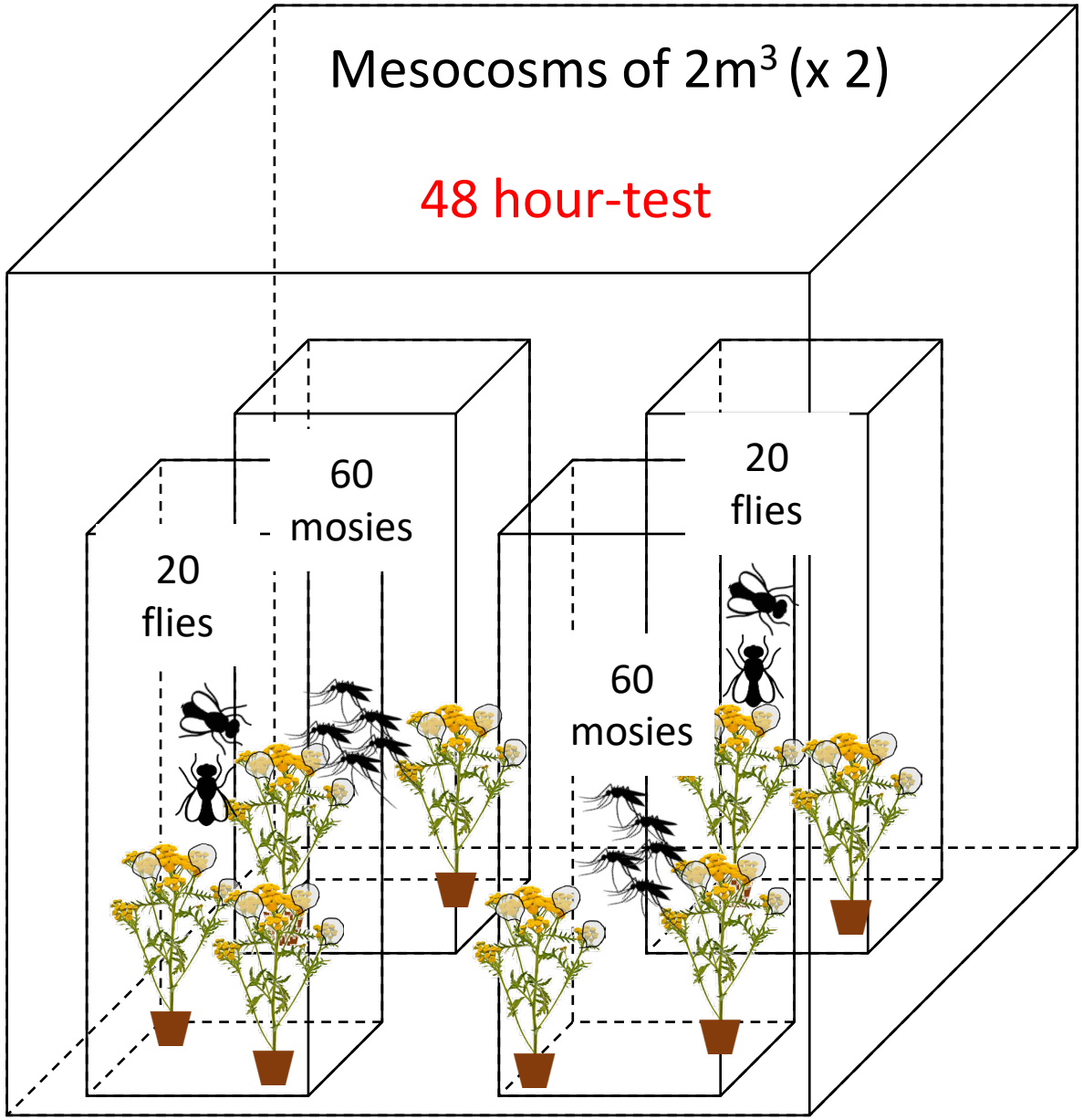
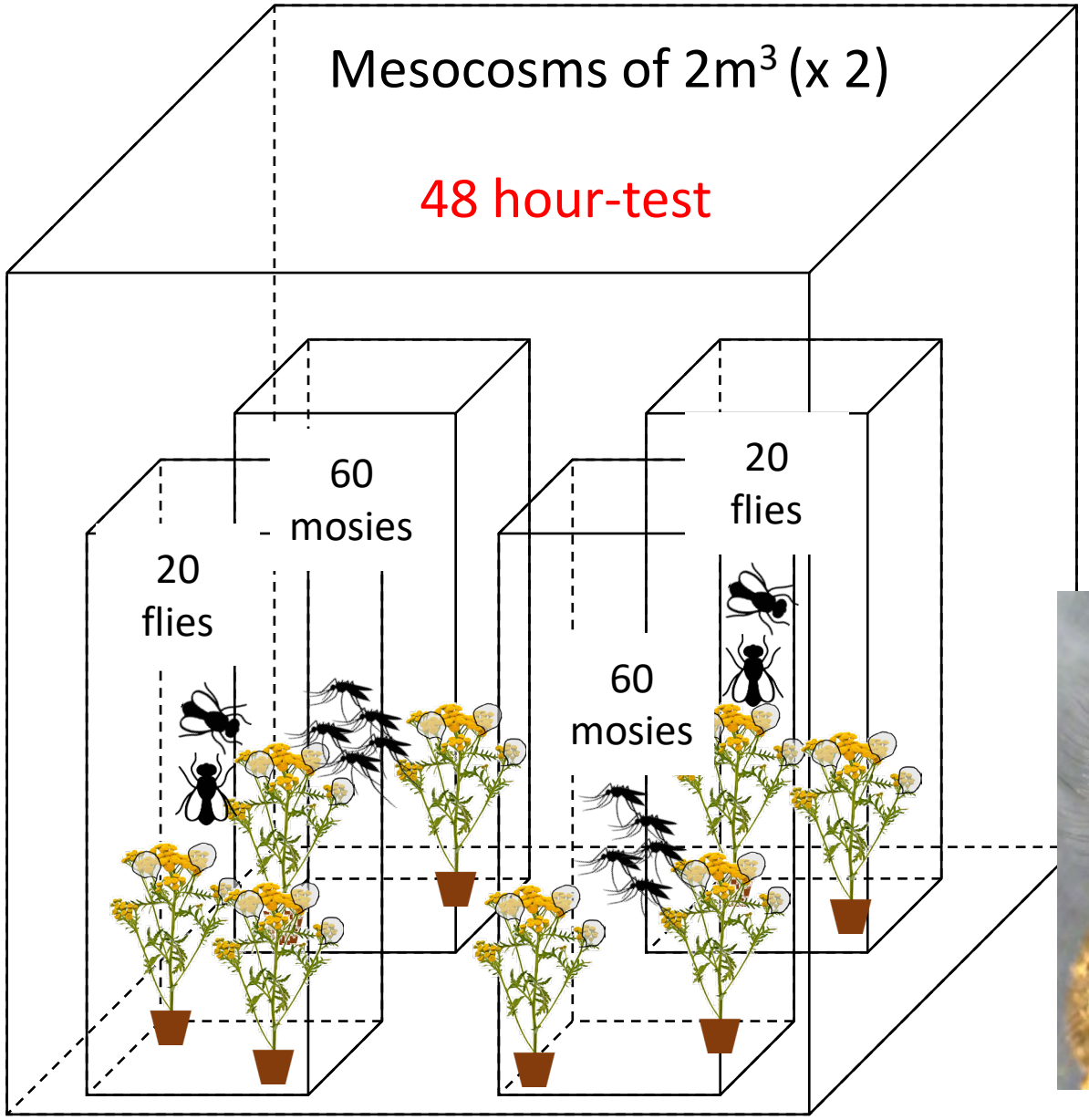


At the end of the two-day assay:

- Insect survival

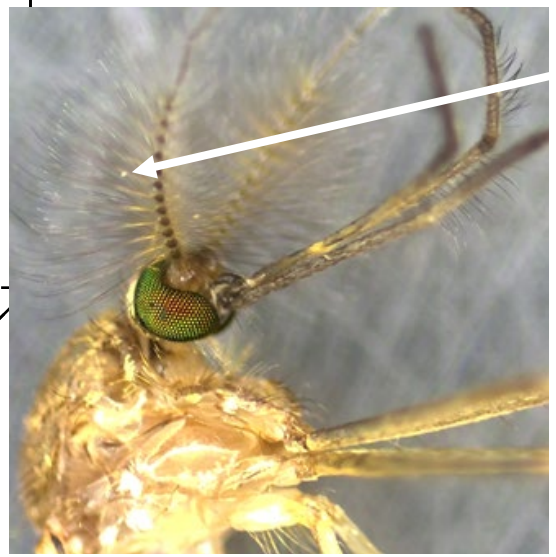
Materials and Methods

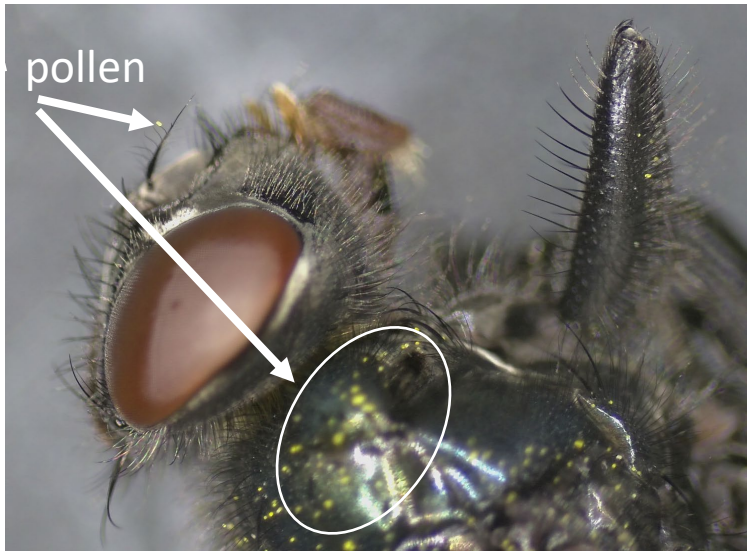
Fly vs. mosquito pollination



At the end of the two-day assay:

- Insect survival
- Pollen distribution on insect body parts from ten randomly selected individuals from each cage (5 males and 5 females)





Materials and Methods

Fly vs. mosquito pollination

At the end of the two-day assay:

- Insect survival

- Pollen distribution on insect body parts from ten randomly selected individuals from each cage (5 males and 5 females)

- Exposed flowers (tests) were enclosed with mesh bags to prevent contact with other potential pollinators, and placed in the field for several weeks until fruit maturation.

Fly vs. mosquito pollination

Following maturation, seedset was derived from semi-automatic counting from pictures:

- 3 control fruits from each individual plant
  (N_C= 3 control x 64 plants = 192)
- 5 test fruits from each plant
  (N_T= 5 test x 64 plants = 320)

Fly vs. mosquito pollination

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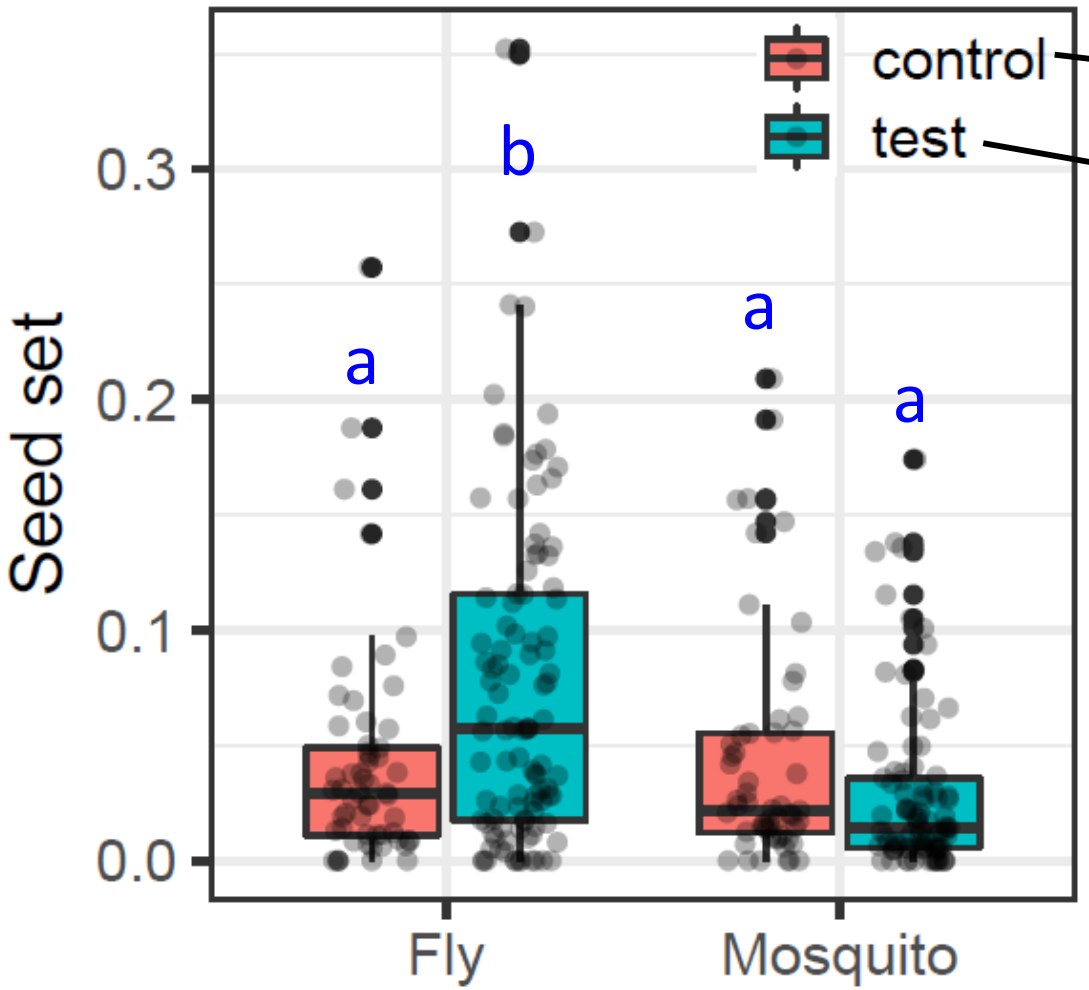
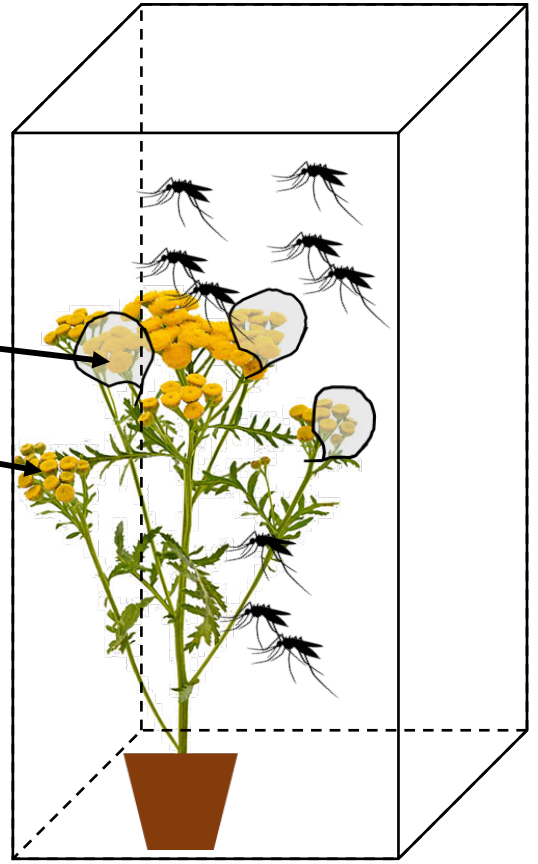
  (N_C= 3 control x 64 plants = 192)
- 5 test fruits from each plant
  (N_T= 5 test x 64 plants = 320)

$$\text{seedset} = \frac{\text{Fertilized ovules (seed)}}{\text{fertilized + unfertilized ovules}}$$

Tansy pollination: fly vs. *Culex pipiens*

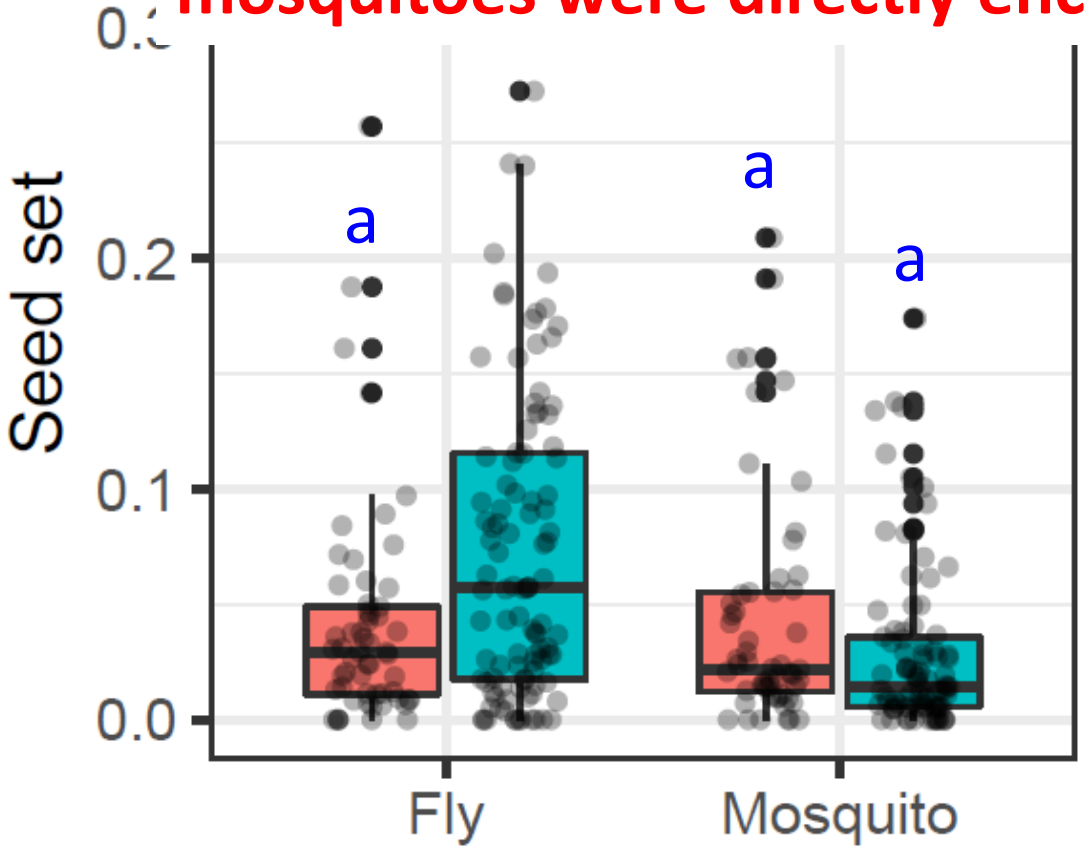




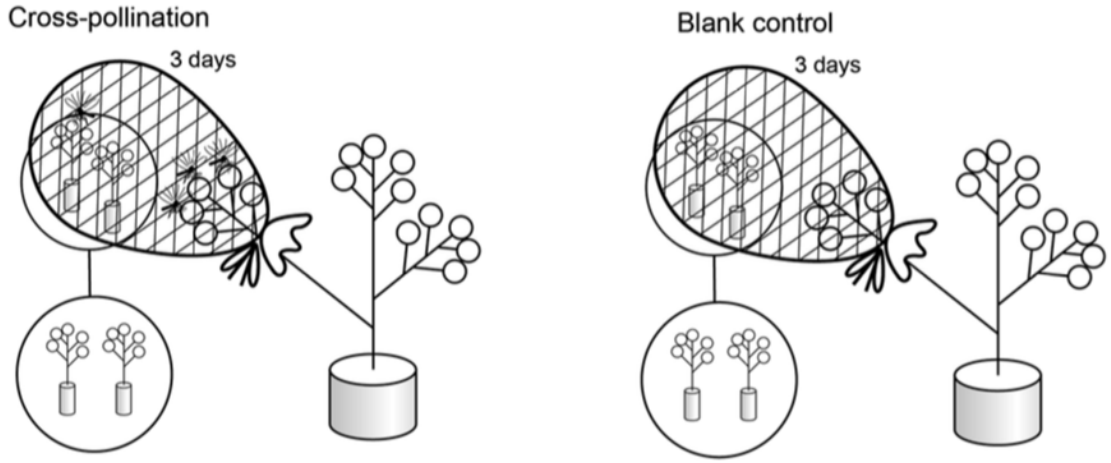
Compared to controls, pollination (seed production) increased following exposure to flies but not to mosquitoes

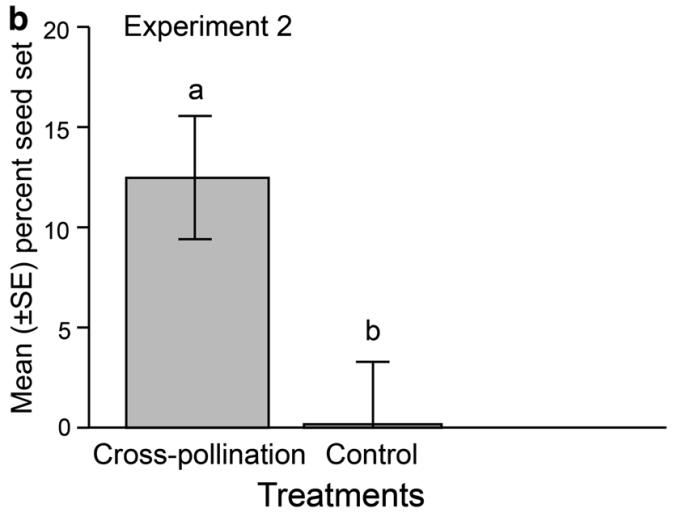
Tansy pollination: fly vs. *Culex pipiens*

Our results do not confirm previous findings obtained when mosquitoes were directly enclosed in bags

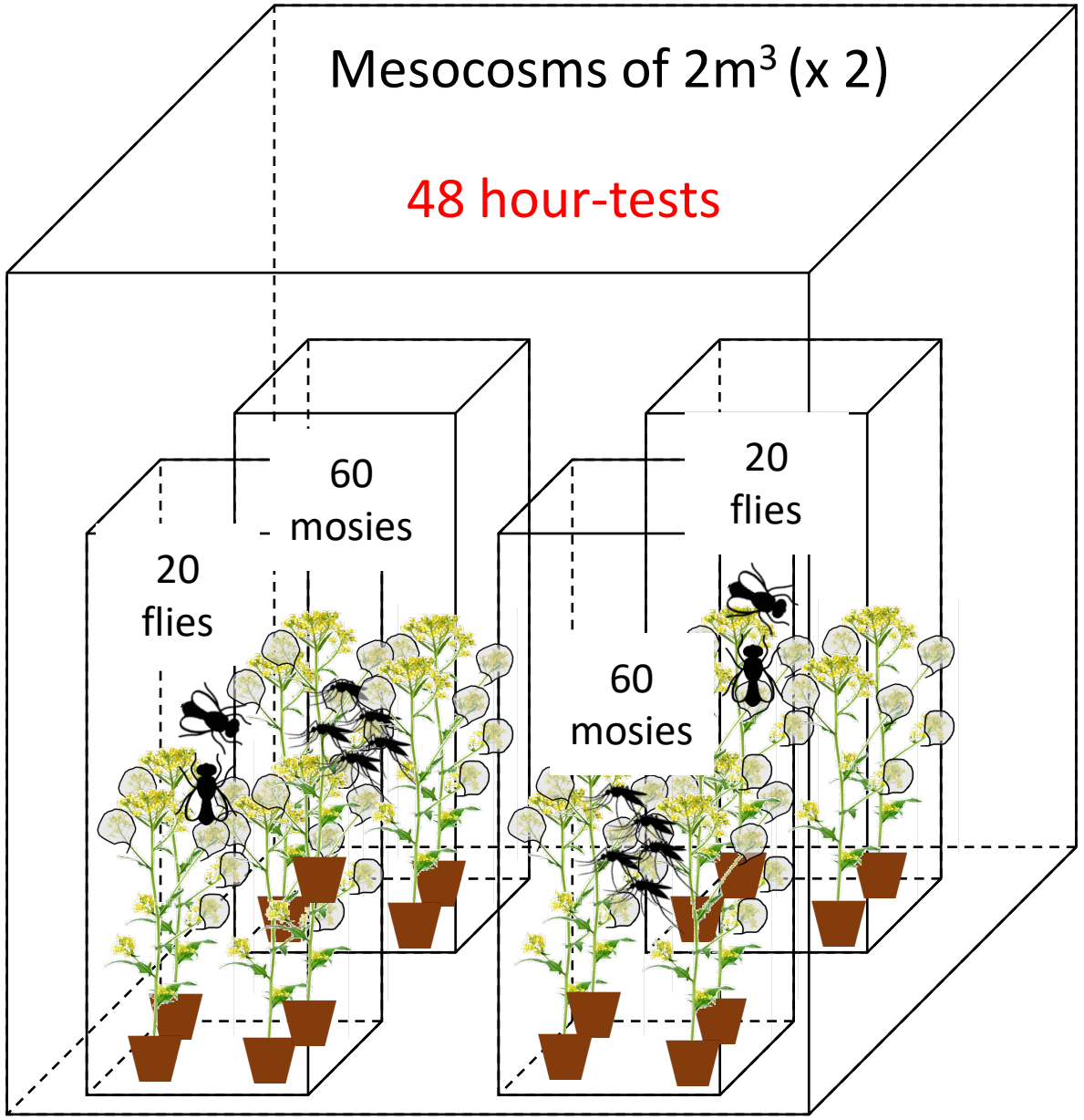


≠





Brassica pollination



Brassica rapa

Cx pipiens molestus

vs.

P. terraenovae

Ae. albopictus

vs.

P. terraenovae

Exact same experiment… with Brassica

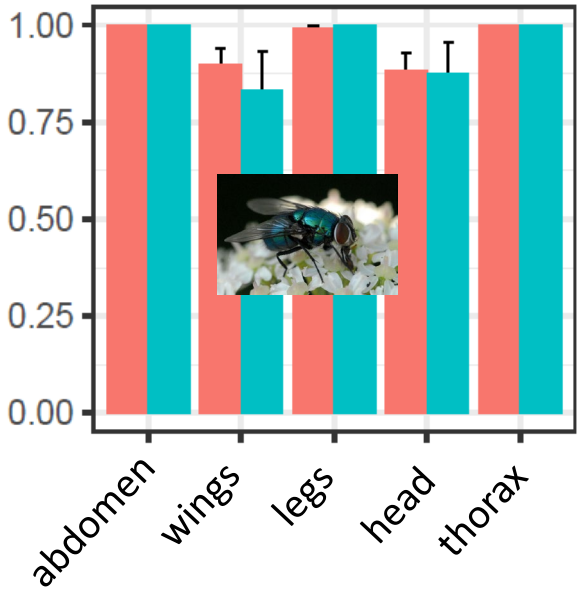
+

a combination of *Ae. albopictus* vs. fly

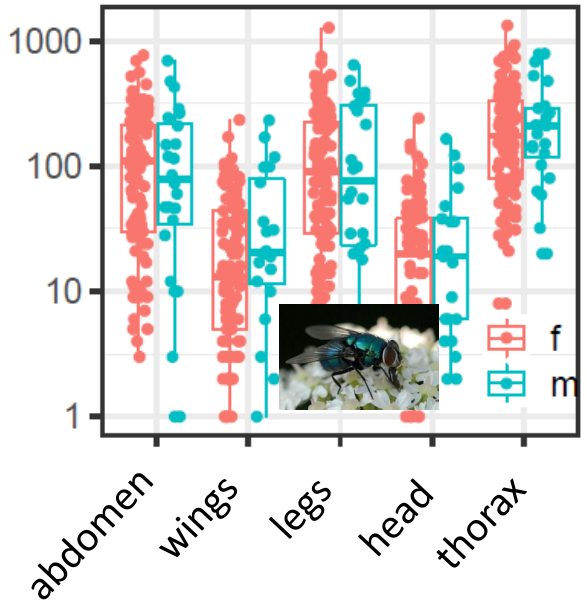
Results

Brassica pollination: fly vs. *Culex pipiens*

Pollen carriage fly



Pollen abundance fly

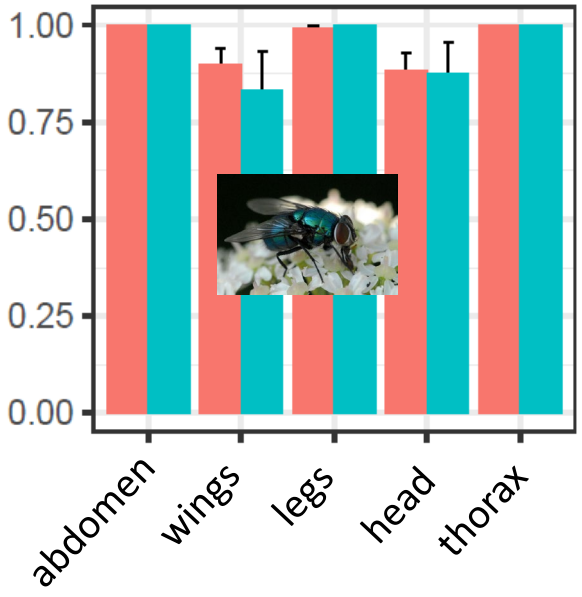


Flies were always loaded with pollen especially on the abdomen, legs and thorax

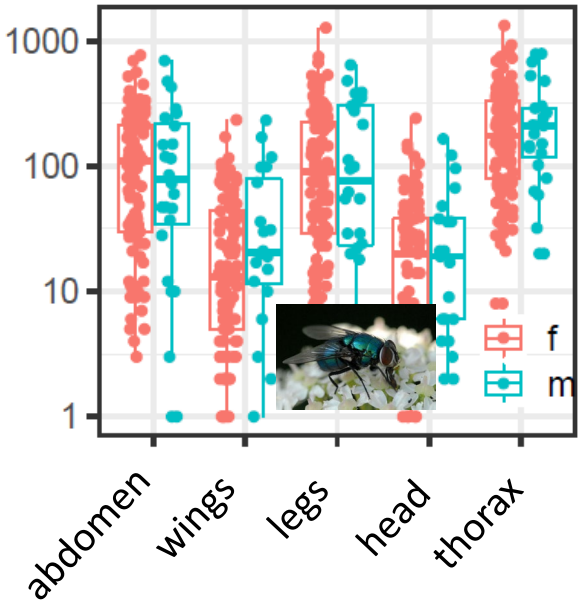
Results

Brassica pollination: fly vs. *Culex pipiens*

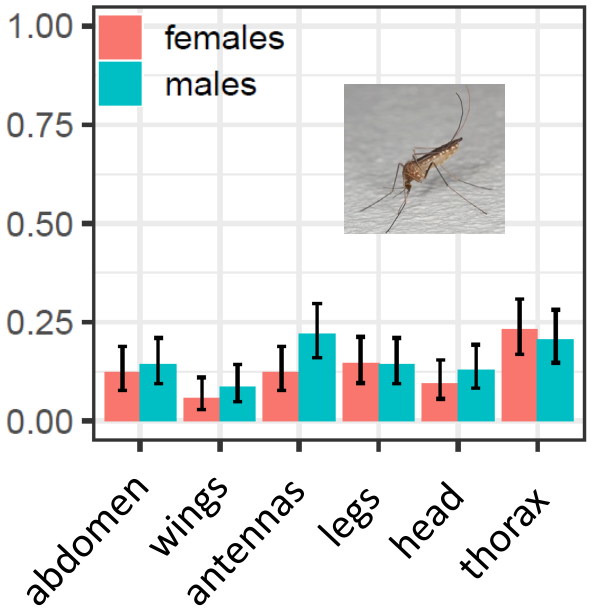
Pollen carriage fly



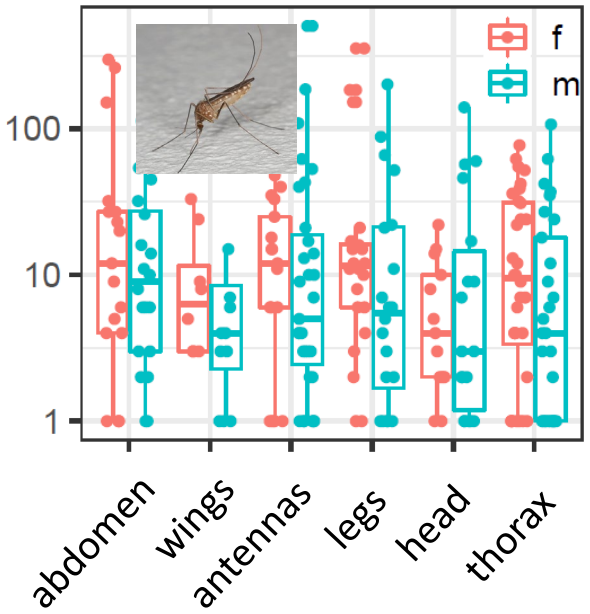
Pollen abundance fly



Pollen carriage *Culex*



Pollen abundance *Culex*



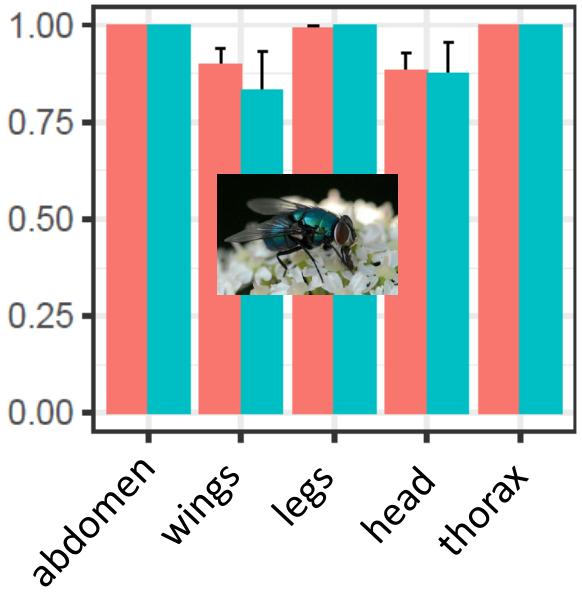
Flies were always loaded with pollen especially on the abdomen, legs and thorax

About 20% of *Culex* carried pollen with an average load of 10 grains

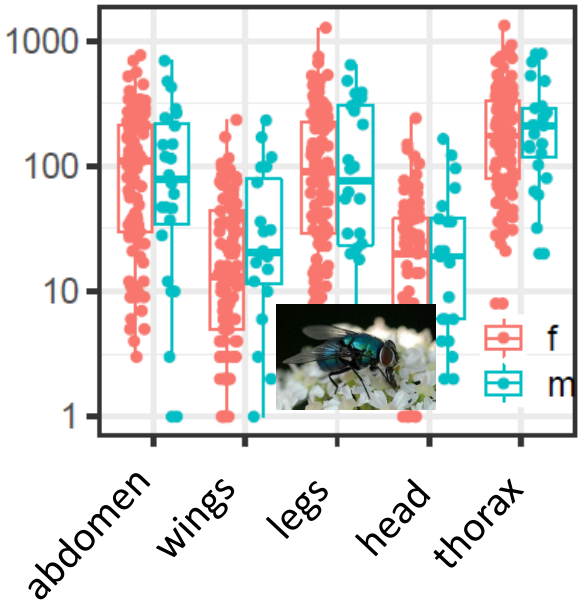
Results

Brassica pollination: fly vs. *Culex pipiens*

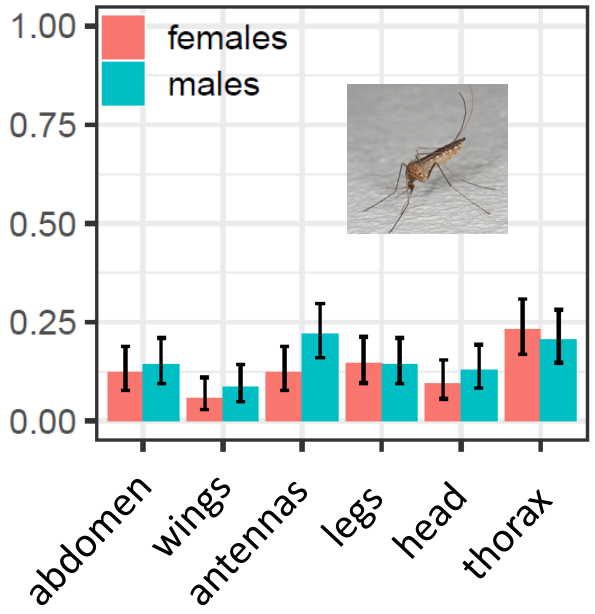
Pollen carriage fly



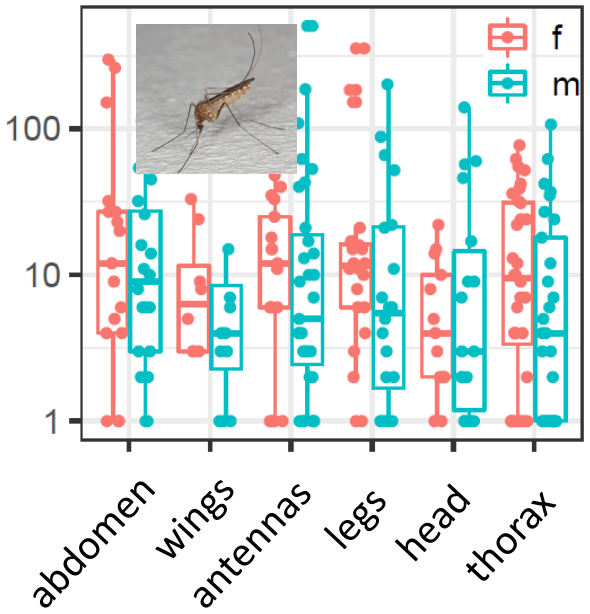
Pollen abundance fly



Pollen carriage *Culex*



Pollen abundance *Culex*



Flies were always loaded with pollen especially on the abdomen, legs and thorax

About 20% of *Culex* carried pollen with an average load of 10 grains

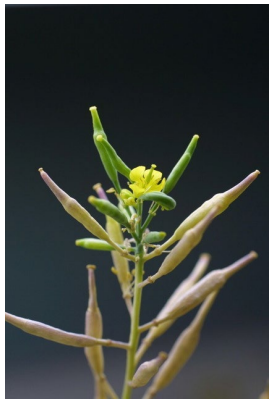
No effect of insect sex

Brassica pollination: fly vs. *Culex pipiens*

Fruit set

=

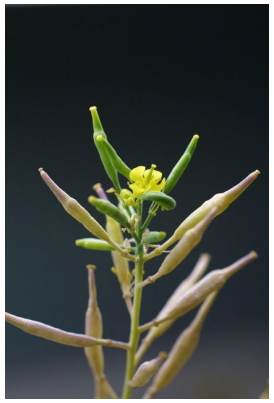
$$\frac{\text{Fruit number}}{\text{Flower number}}$$

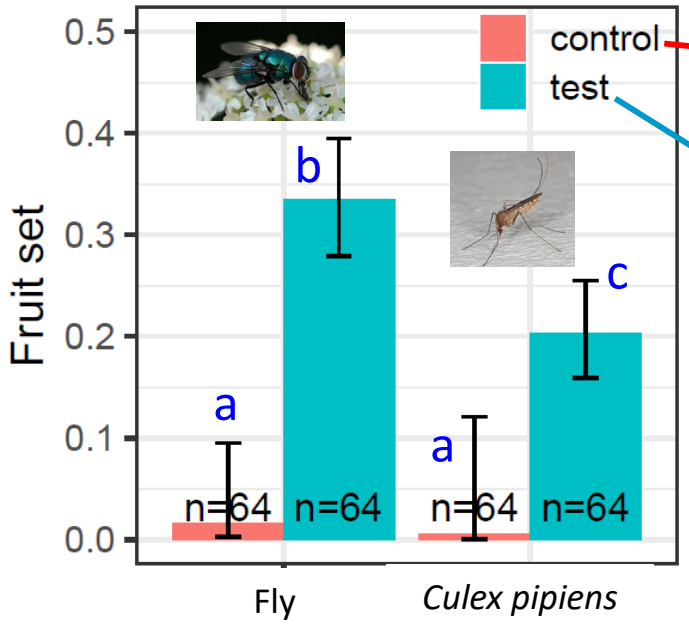


Results

Brassica pollination: fly vs. *Culex pipiens*

Fruit set
=
Fruit number
—————
Flower number

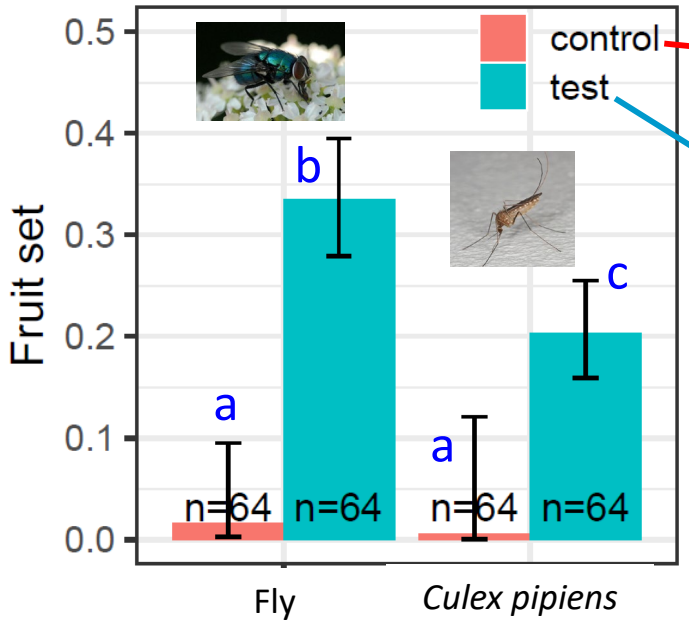


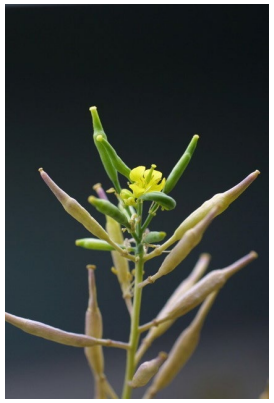


Results

Brassica pollination: fly vs. *Culex pipiens*

Fruit set
=
Fruit number
—————
Flower number



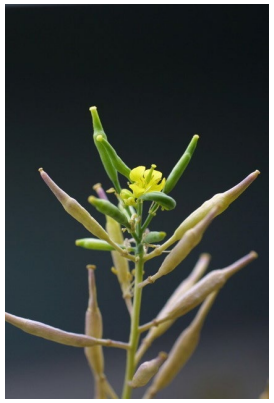


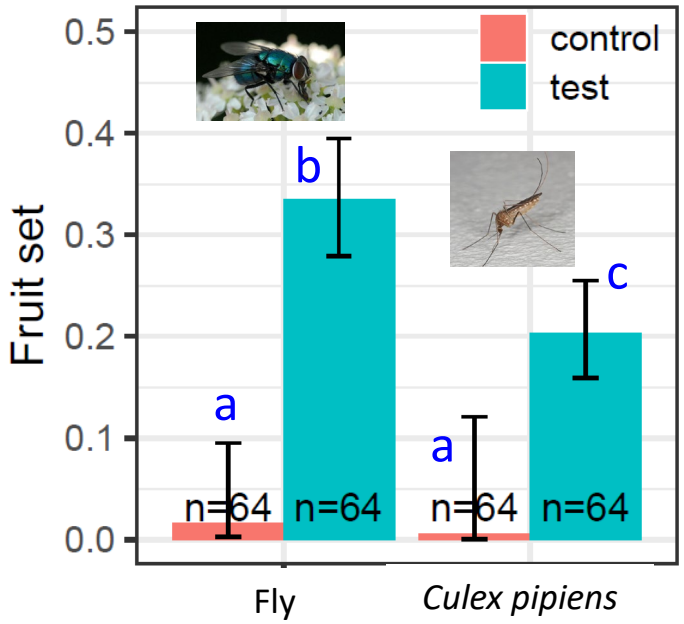
- Controls (flowers covered up = red bars) worked properly and fruit sets were much higher in the tests (blue bars)
- Fruitset resulting from exposure to fly (33%) was higher than that from culex (20%).

Results

Brassica pollination: fly vs. *Culex pipiens*

Fruit set
=
Fruit number
—————
Flower number



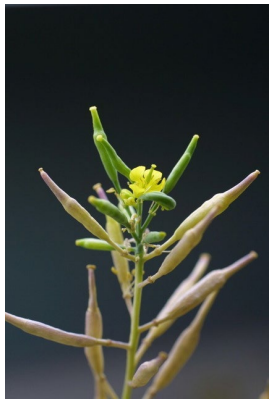


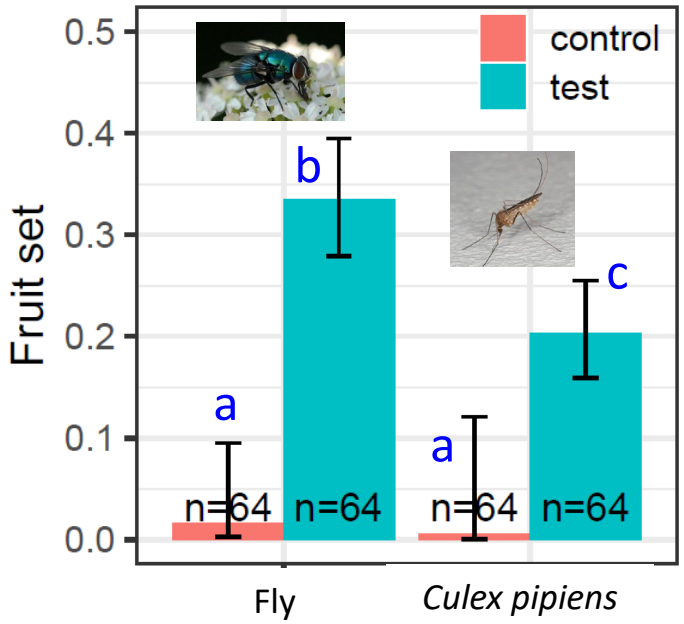
Seed set
=
Seed number
—————
Ovule number

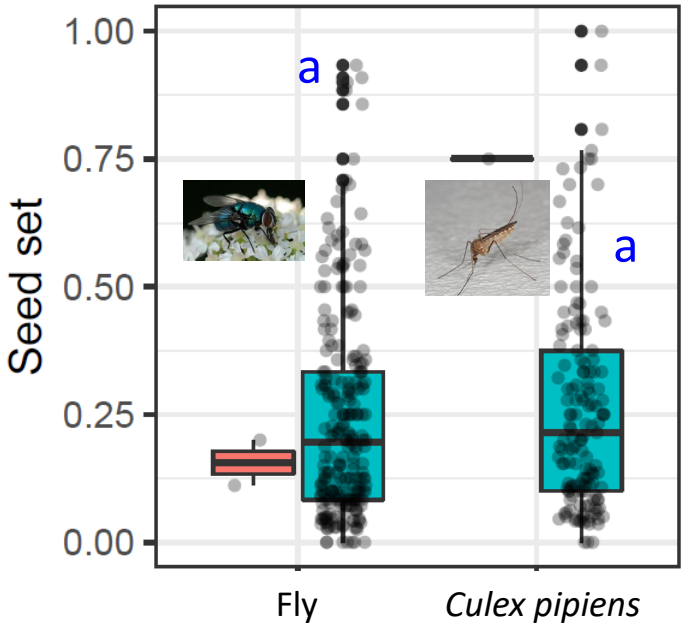
Results

Brassica pollination: fly vs. *Culex pipiens*

Fruit set
=
Fruit number
—————
Flower number





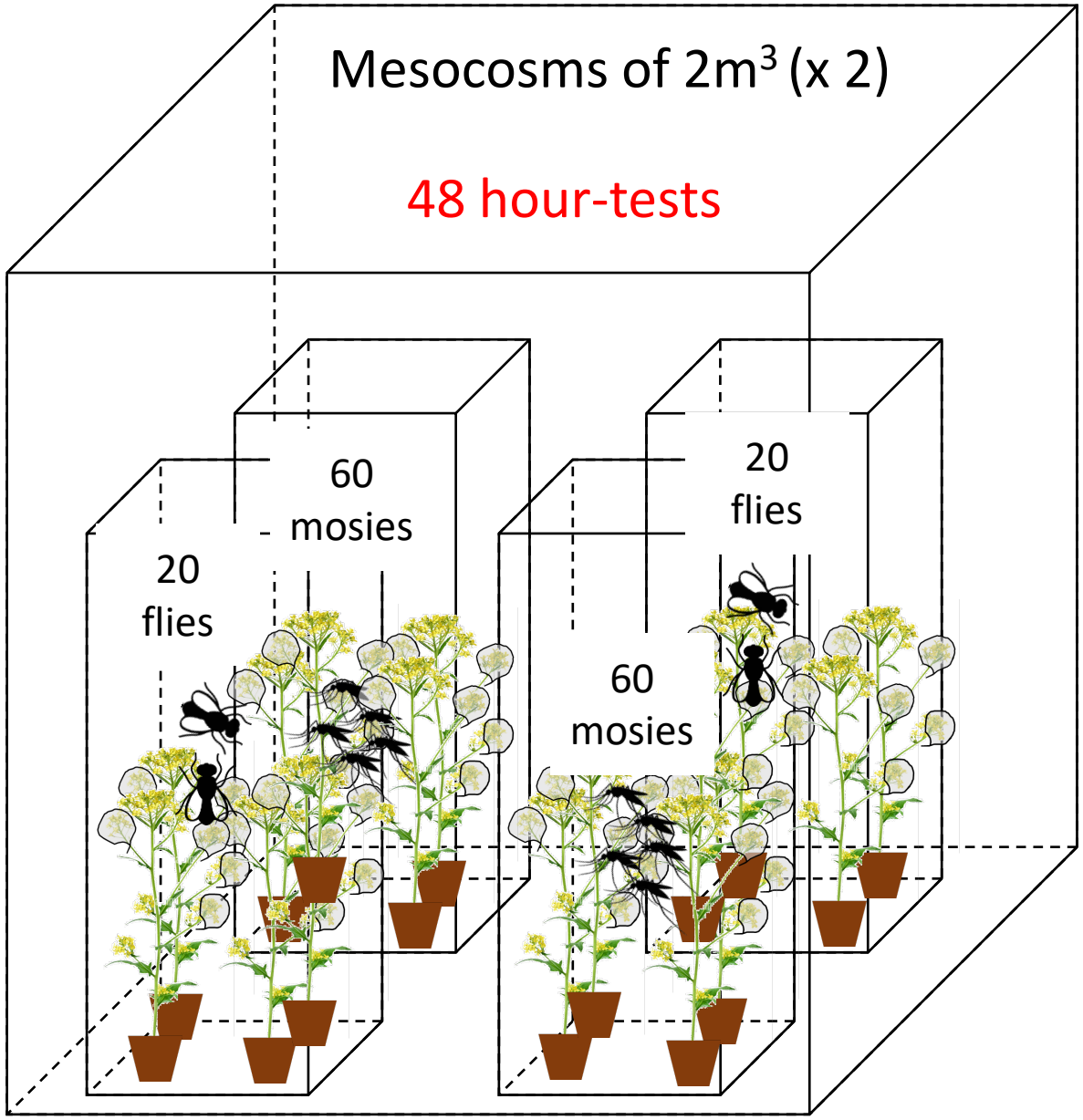


Seed set
=
Seed number
—————
Ovule number

Similar average seedset of 25% in flies and *Culex*

Results

Brassica pollination: fly vs. *Aedes albopictus*



Brassica rapa

Cx pipiens molestus

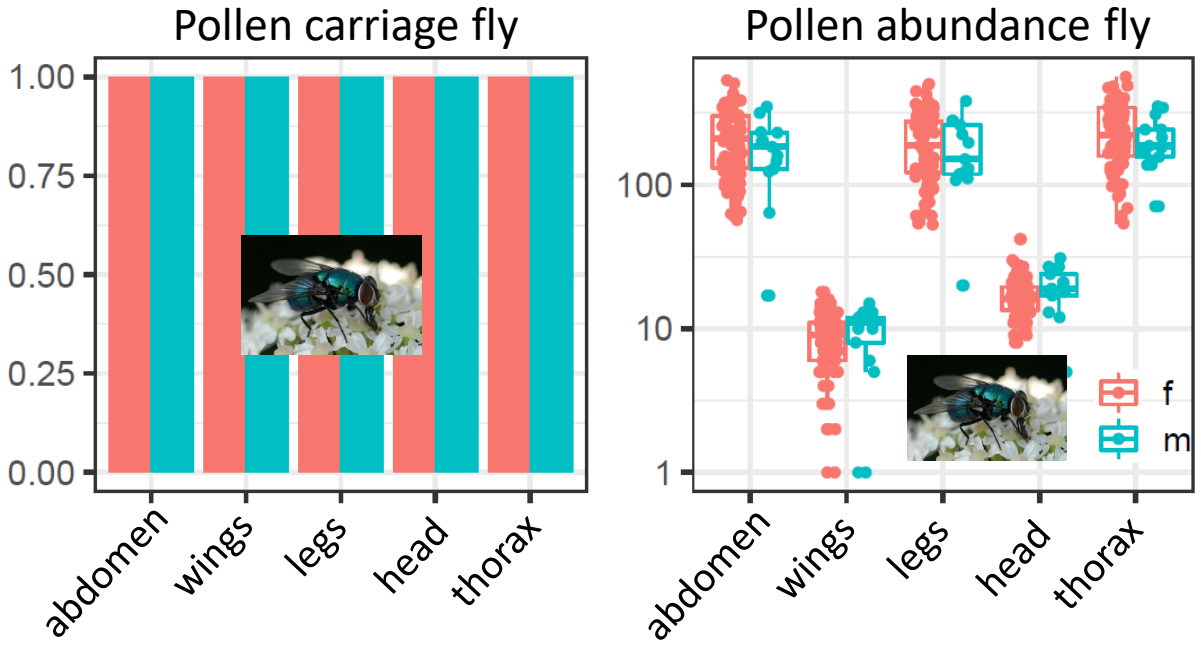
vs.

P. terraenovae

vs.

Ae. albopictus *P. terraenovae*

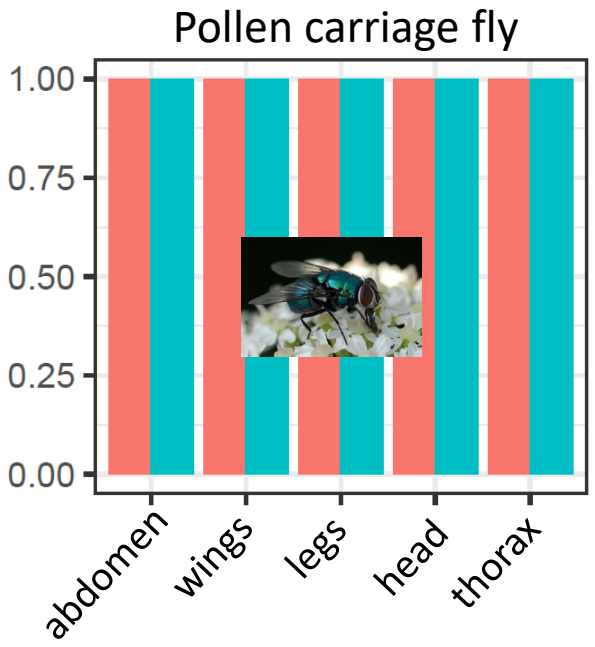
Brassica pollination: fly vs. *Aedes albopictus*

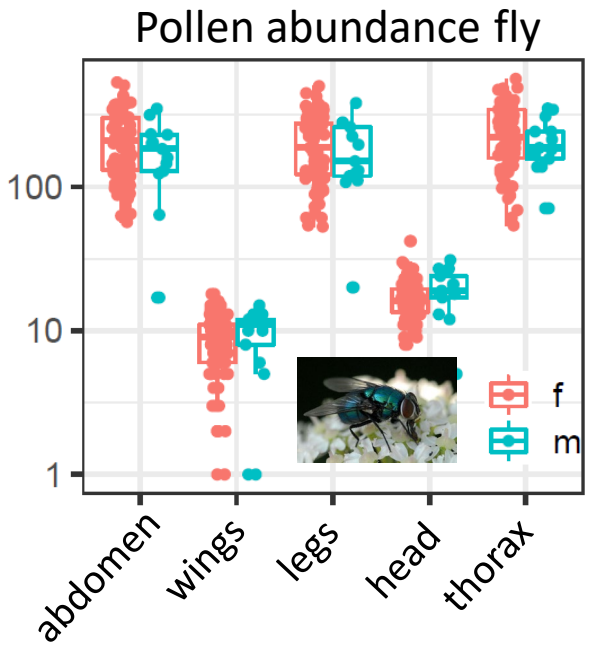


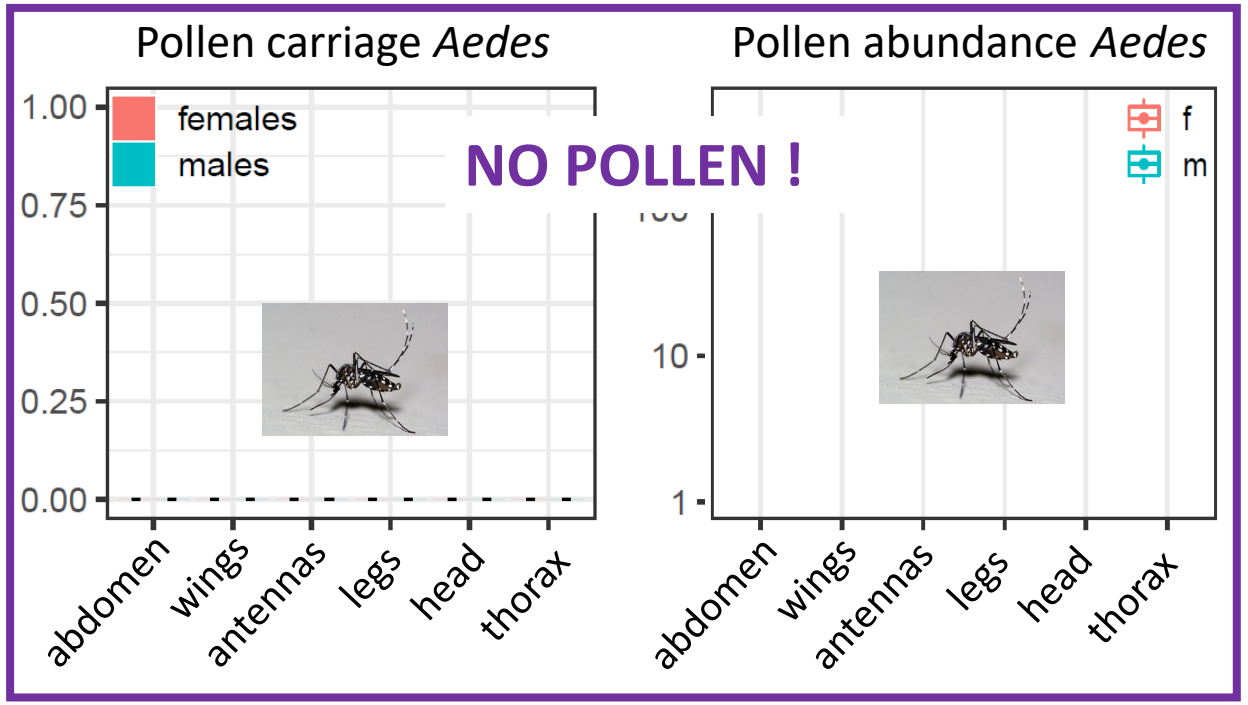
Similar to the brassica « fly vs Culex » combination, 100% of flies were again loaded with pollen especially on the abdomen, legs and thorax

Results

Brassica pollination: fly vs. *Aedes albopictus*





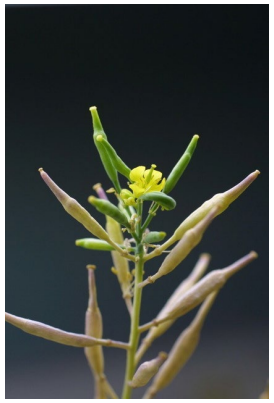


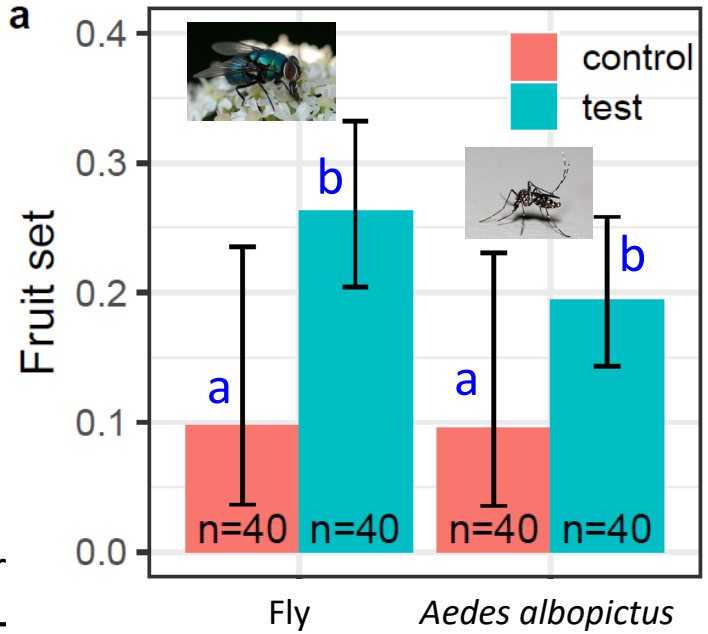
Similar to Tansy flowers, and the brassica fly vs Culex combination, 100% of flies were again loaded with pollen especially on the abdomen, legs and thorax

Surprisingly, not a single pollen grain on *Aedes albopictus*

Brassica pollination: fly vs. *Aedes albopictus*

Fruit set
=
Fruit number
———————
Flower number



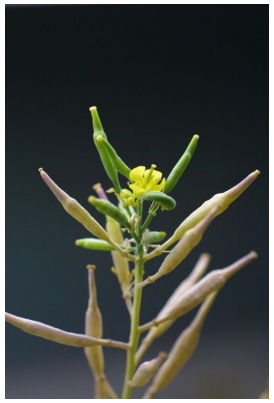


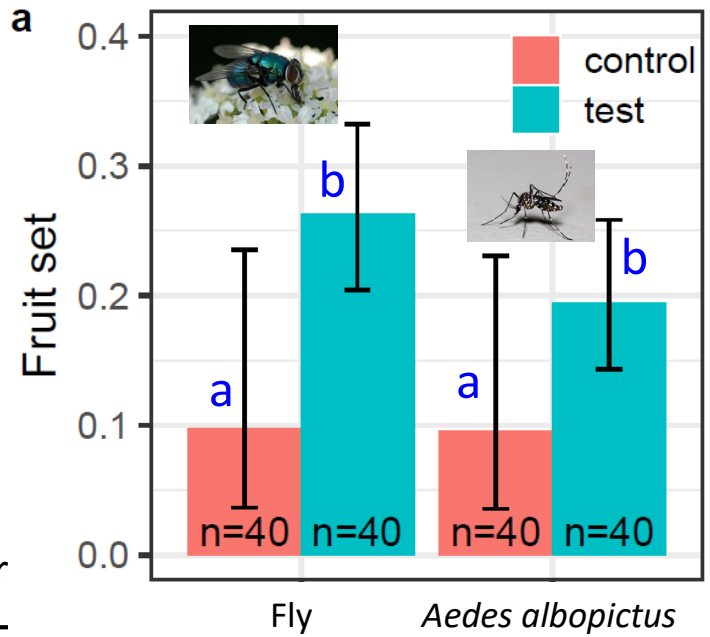
- Fruitsets resulting from exposure to flies (26%) and *Aedes* (20%) were higher than that from controls (10%).

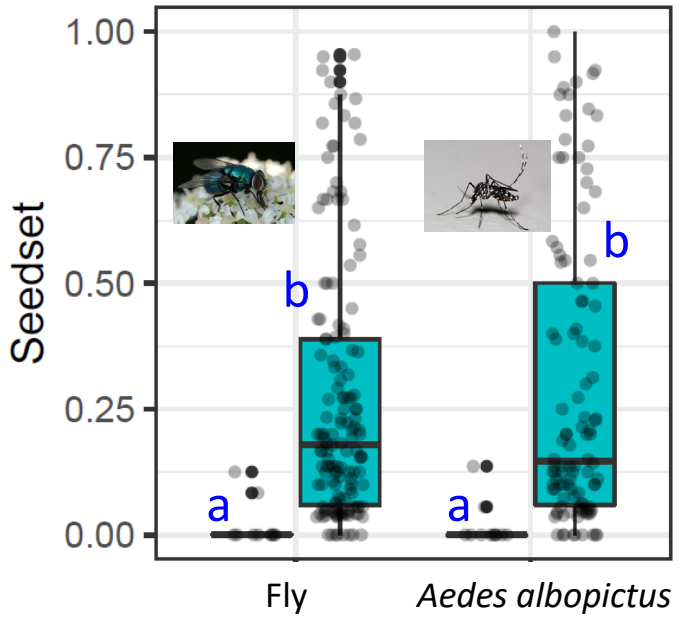
Results

Brassica pollination: fly vs. *Aedes albopictus*

Fruit set
=
Fruit number
—————
Flower number







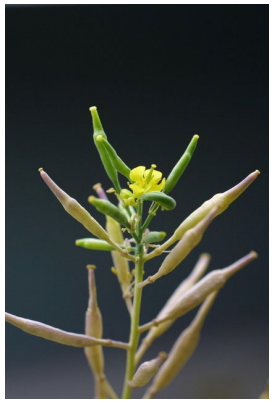
Seed set
=
Seed number
—————
Ovule number

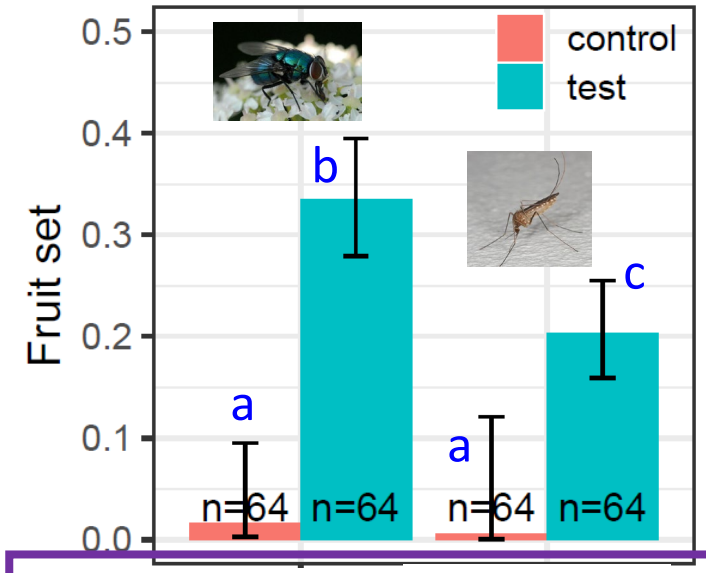
Similar average seedset of 25% in flies and culex and much higher than controls

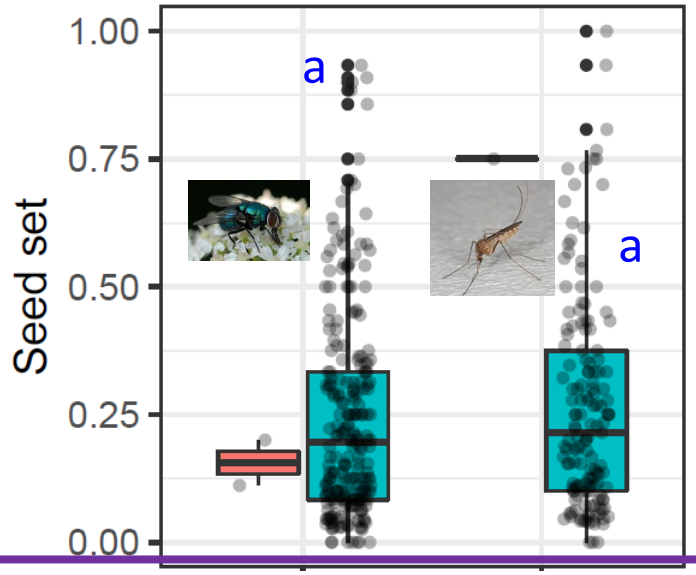
Results

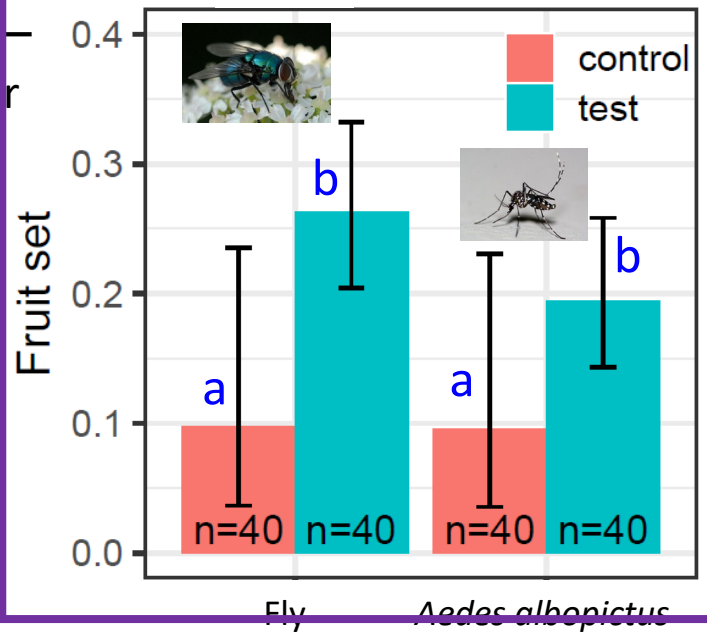
Brassica pollination

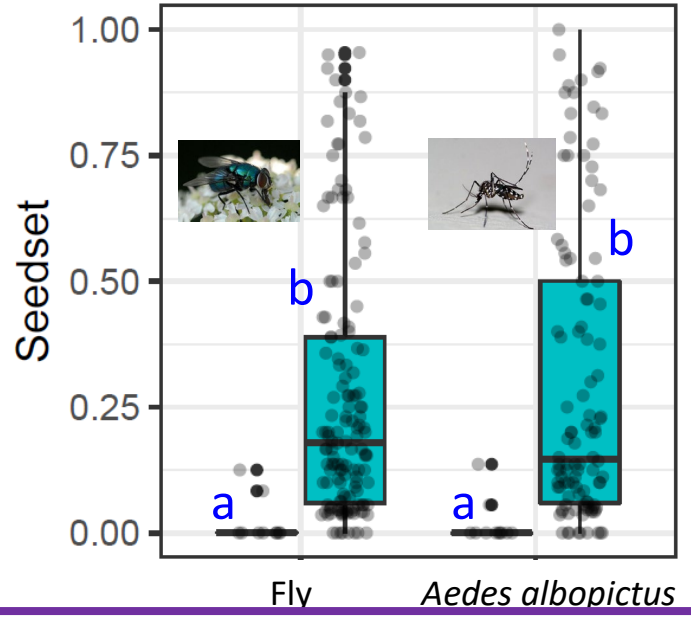
Fruit set
=
Fruit number
—————
Flower number











Seed set
=
Seed number
—————
Ovule number

In spite of the absence of pollen on their body, *Ae. albopictus* does cause fruit and seed production

Mosquito vs. Fly pollination

Tanacetum vulgare

Culex pipiens molestus

vs.

Protophormia terraenovae

Brassica rapa

Cx pipiens molestus

vs.

P. terraenovae

Ae. albopictus

vs.

P. terraenovae

- **Together our results suggest that mosquitoes are poor pollinators of tansy flowers compared to flies, but that they pollinate *Brassica* equally well**

conclusion

Mosquito vs. Fly pollination

Tanacetum vulgare

Culex pipiens molestus

vs.

Protophormia terraenovae

Brassica rapa

Cx pipiens molestus

vs.

P. terraenovae

Ae. albopictus

vs.

P. terraenovae

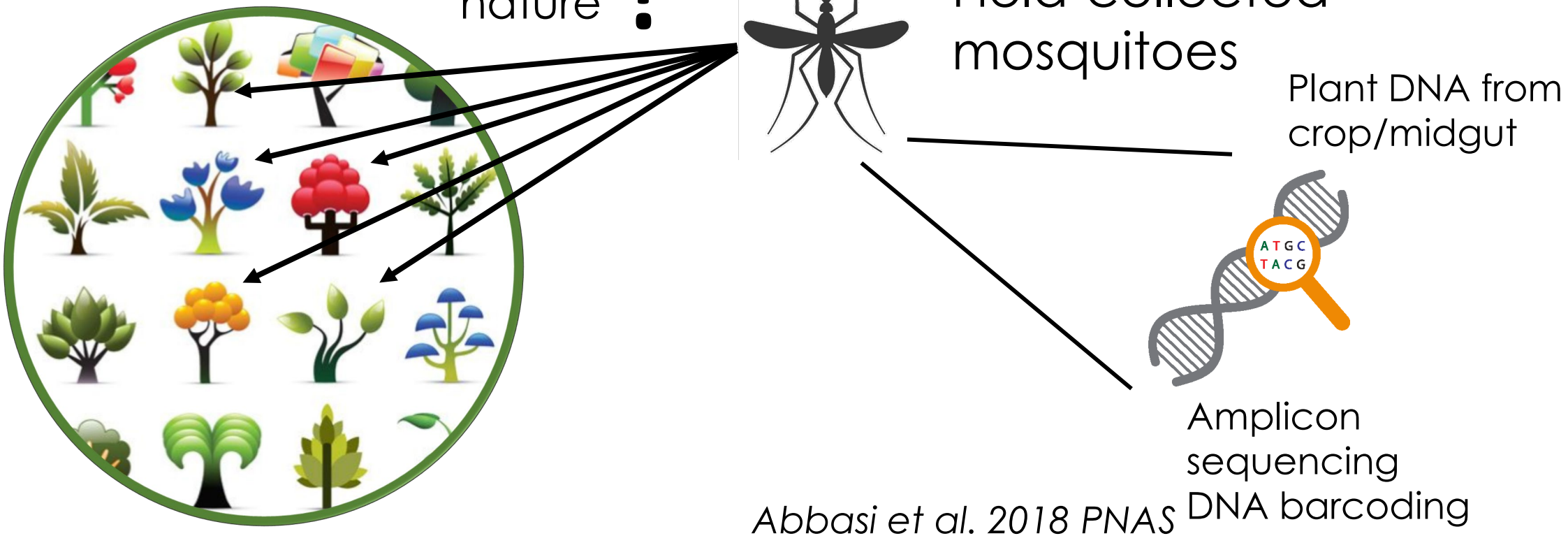
- Together our results suggest that mosquitoes are poor pollinators of tansy flowers compared to flies, but that they pollinate *Brassica* equally well
- **Although we did not find any pollen grains on *Ae. albopictus*, fruit- and seed-sets were equivalent to that of flies (hygienic behavior? Poor attachment?)**

Untangle mosquito-plant interactions

Proof of principle OK… but we somehow approached the question the wrong way

DNA barcoding to untangle mosquito-plant interactions

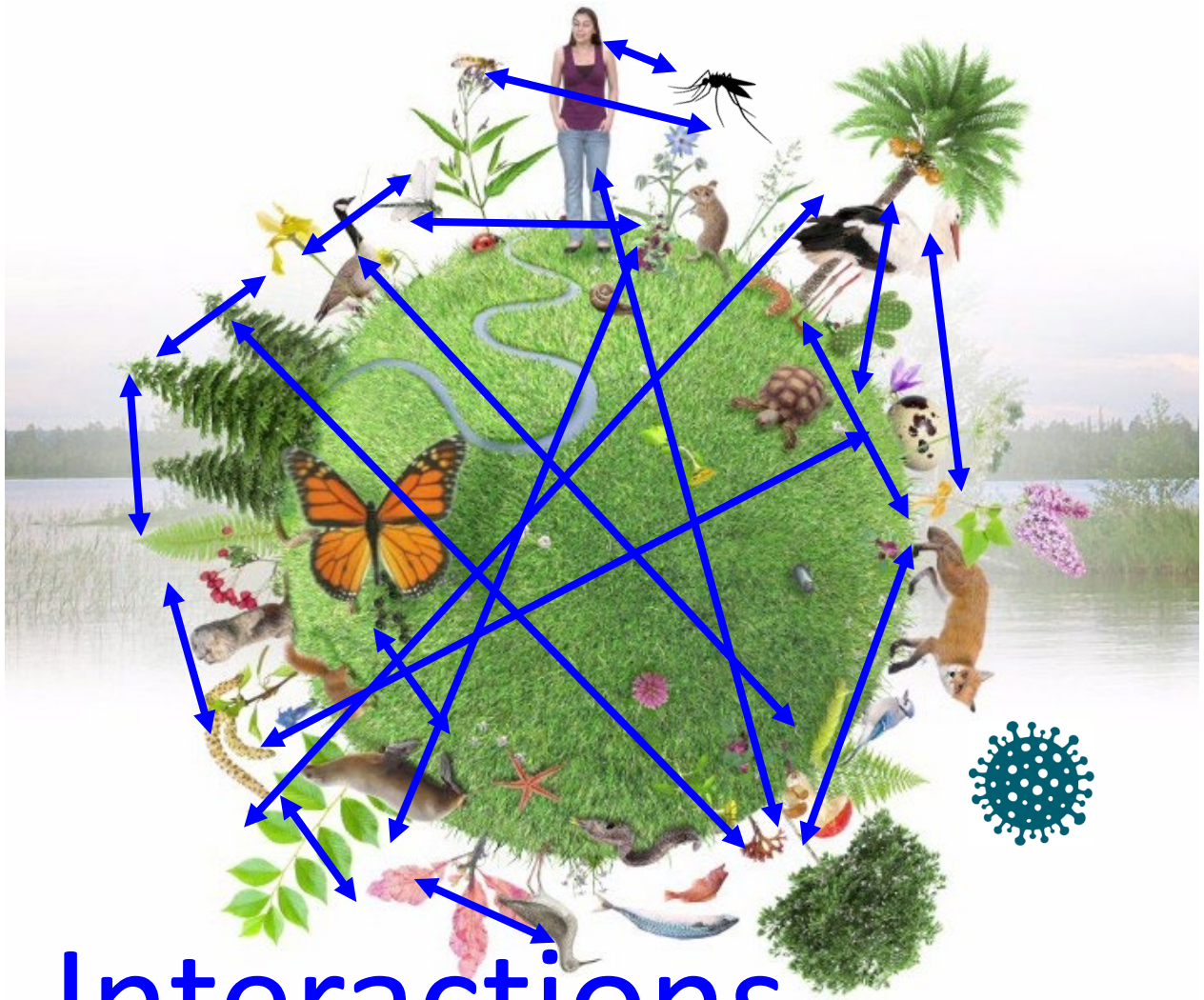
Proof of principle OK… but we somehow approached the question the wrong way



conclusion

Biodiversity

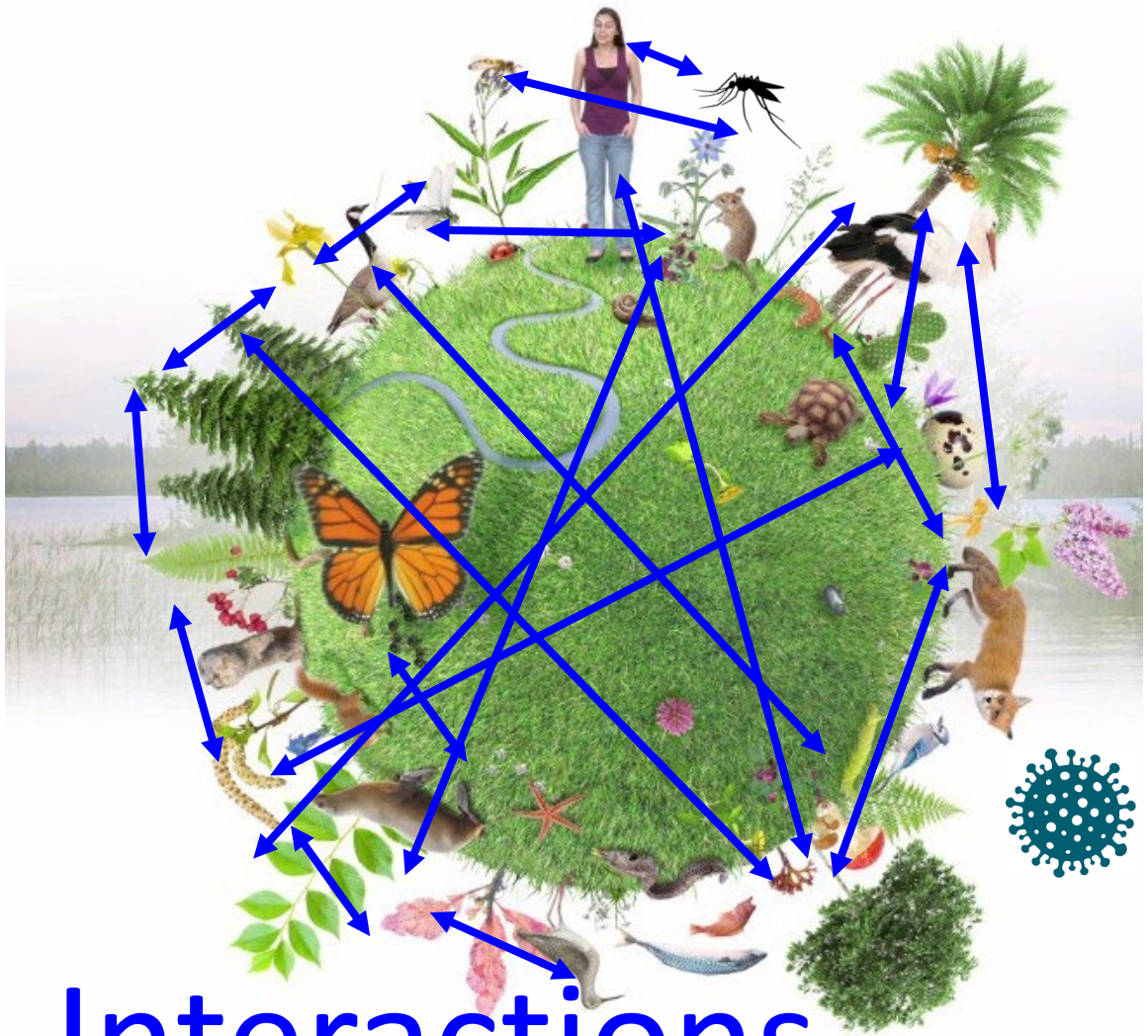
Network of



Interactions

Biodiversity

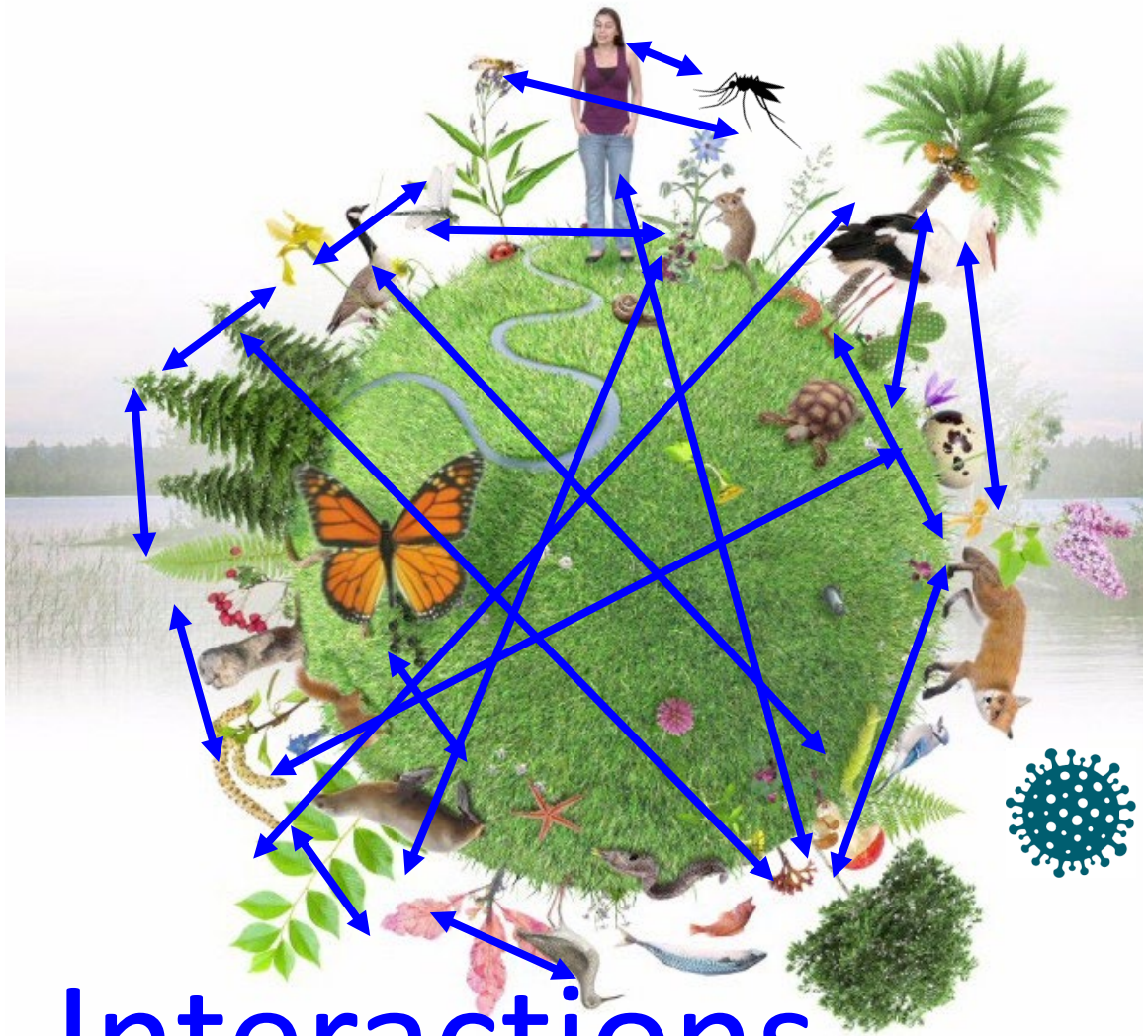
Network of Interactions



- Arthropod vectors have weak links with other community members : they are neither the only resource for their predators nor the only consumer of their prey

Biodiversity

Network of Interactions

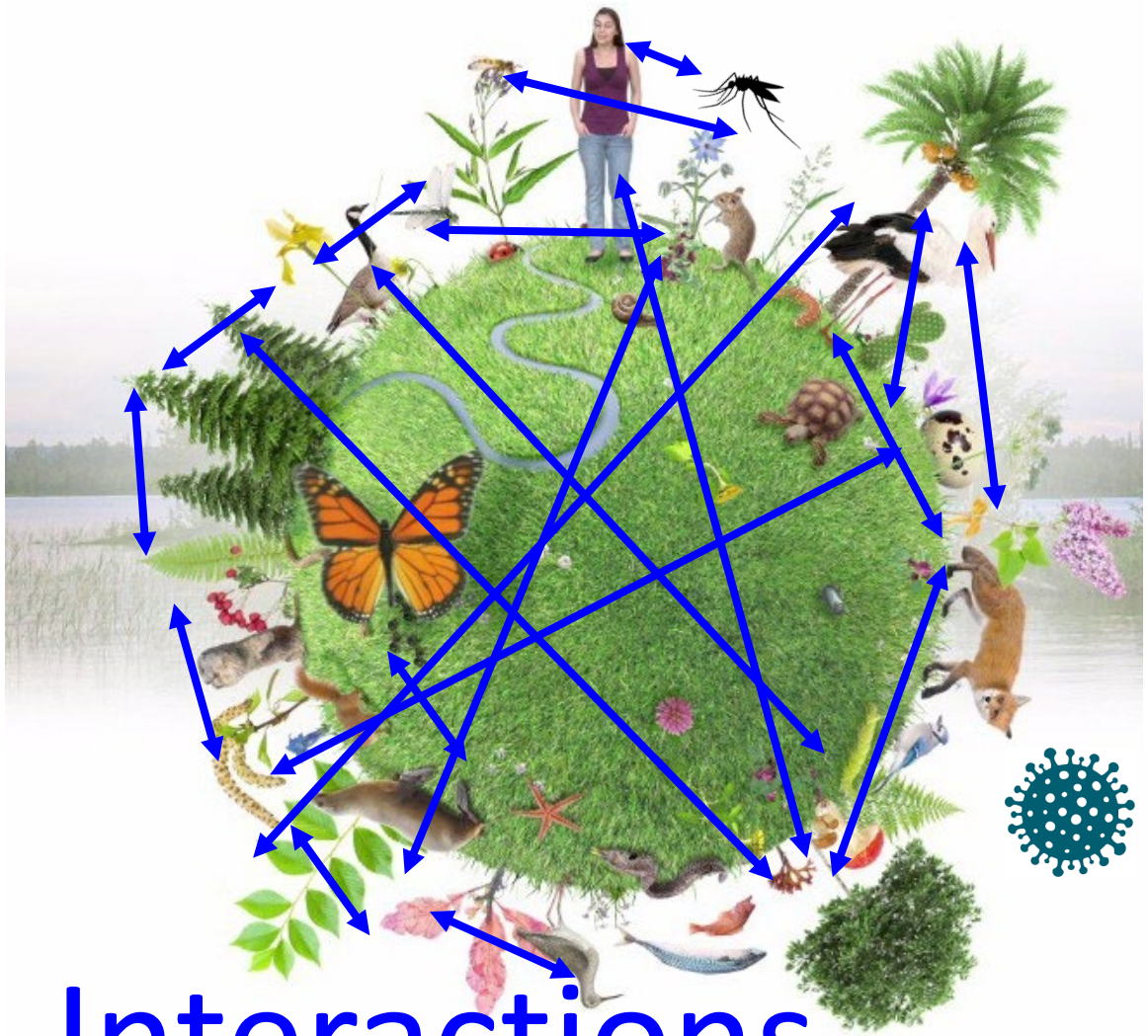


- Arthropod vectors have weak links with other community members : they are neither the only resource for their predators nor the only consumer of their prey

- Similar **functional redundancy** likely characterize the role of mosquitoes as pollinators?

Biodiversity

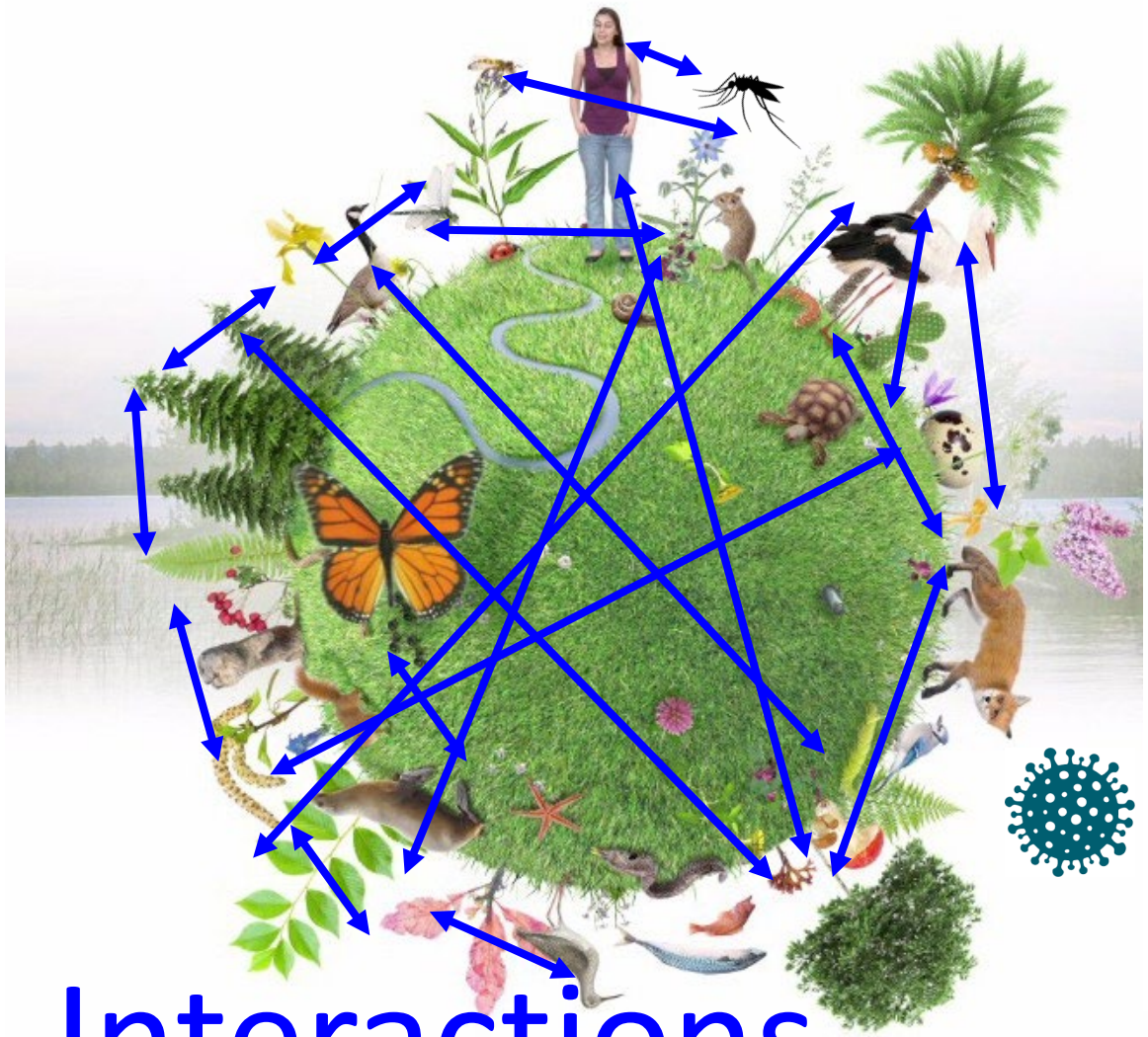
Network of Interactions



- Arthropod vectors have weak links with other community members : they are neither the only resource for their predators nor the only consumer of their prey
- Similar **functional redundancy** likely characterize the role of mosquitoes as pollinators?
- **As such, if the ecological roles of vectors are redundant with other organisms, then there might be a legitimate ecological argument supporting their suppression or elimination, especially if they are invasive alien species**

Biodiversity

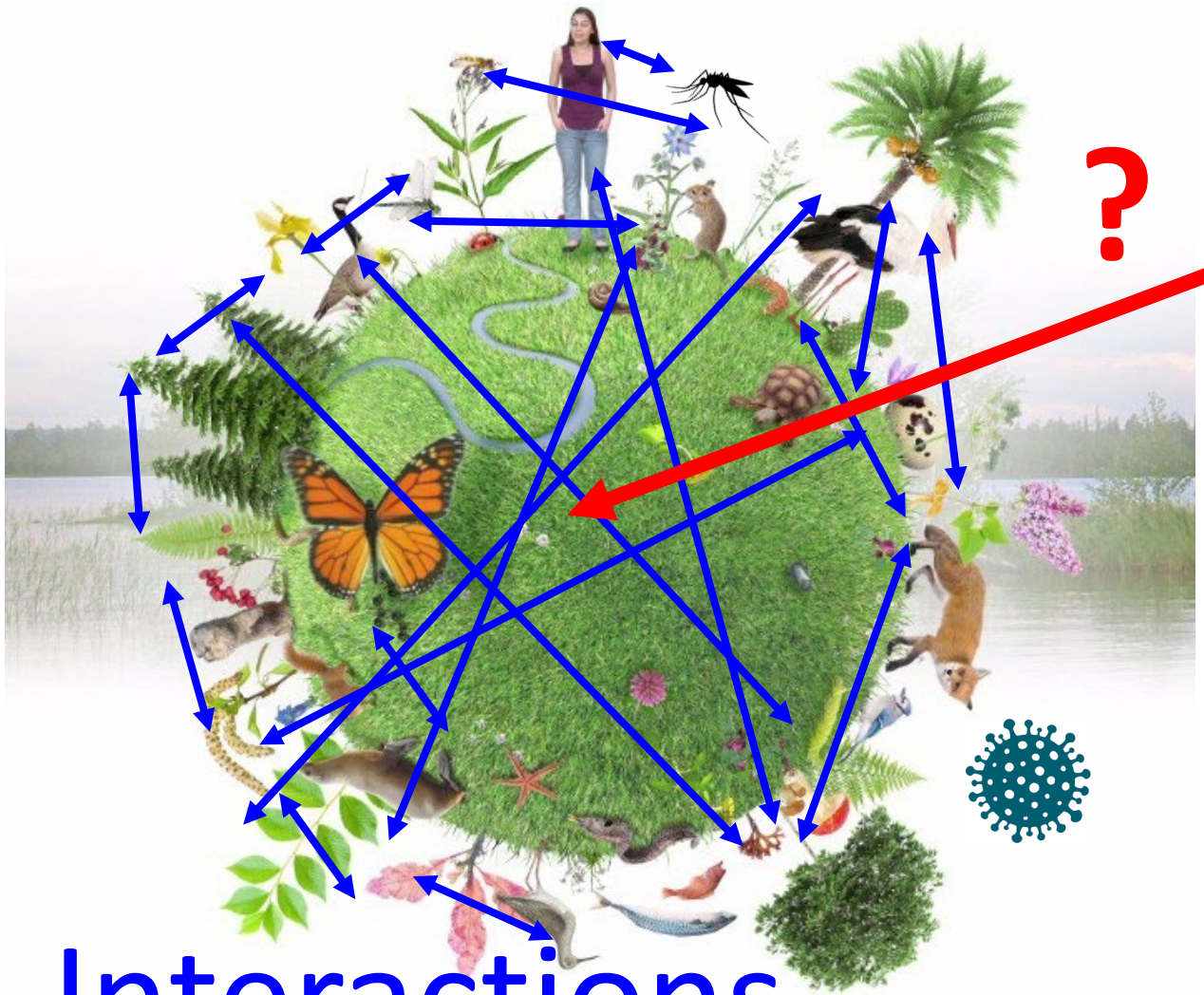
Network of Interactions



- Arthropod vectors have weak links with other community members : they are neither the only resource for their predators nor the only consumer of their prey
- Similar **functional redundancy** might characterize the role of mosquitoes as pollinators?
- As such, if the ecological roles of vectors are redundant with other organisms, then there might be a legitimate ecological argument supporting their suppression or elimination, especially if they are invasive alien species.
- However, recent theoretical works suggest that even the elimination of weak nodes in an ecological network can result in collapse and biodiversity loss.

Dale & Fortin (2021) Quantitative Analysis of Ecological Networks. Cambridge Univ. Press

Network of Interactions



?

Vector control

Compared with the efforts devoted to evaluating the efficacy of vector control tools, there are still very few environmental impact assessments

Even if vectors are not keystone species we should better quantify their ecological roles

Thank you

KEY INITIATIVE MUSE RISKS & VECTORS
(KIM RIVE)

MiVEGEC

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Marie Rossignol
Pauline Fournier
Gabriel Johnson
Emilie Balthazar
Paul Taconet
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Erygeron

Culex pipiens vs. Protophormia terraenovae

Tanaisie

Cx. pipiens vs. P. terraenovae

Brassica rapa

Cx. pipiens vs. P. terraenovae

Aedes albopictus vs. P. terraenovae

ECOTRON

TE (FIELD)

CENTRE D'ECOLOGIE FONCTIONNELLE & EVOLUTIVE

Scabieuses

Cx. pipiens vs. autres

The width of the space between the eyes, the frons:

M♂

F♀

Tansy-Culex

48 plants - 8 = 40 plants

Seedset derived from semi-automatic counting on pictures:

- 1-3 (median 3) control inflorescences from each plant (57 from flies and 56 from mosquitoes, Ntot=113 control)

- 4-9 (median 5) test inflorescences from each plant (105 from flies and 94 from mosquitoes, Ntot = 199 test)

$$\text{seedset} = \frac{\text{fertilized}}{\text{fertilized} + \text{unfertilized}}$$

STERILE INSECT TECHNIQUE (SIT)

A method of biological insect control

Mass-rearing of insects takes place in special facilities.

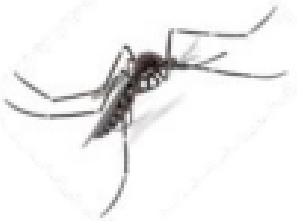
Male and female insects are separated. Ionizing radiation is used to sterilize the male insects.

The sterile male insects are released over towns or cities...

...where they compete with wild males to mate with females.

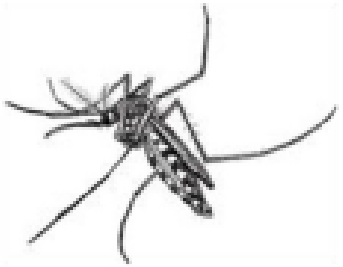
These females lay eggs that are infertile and bear no offspring, reducing the insect population.

Wolbachia is injected into dengue vector (*Aedes aegypti)* eggs



♂ *Wolbachia* infected

x



♀ Wild Vector

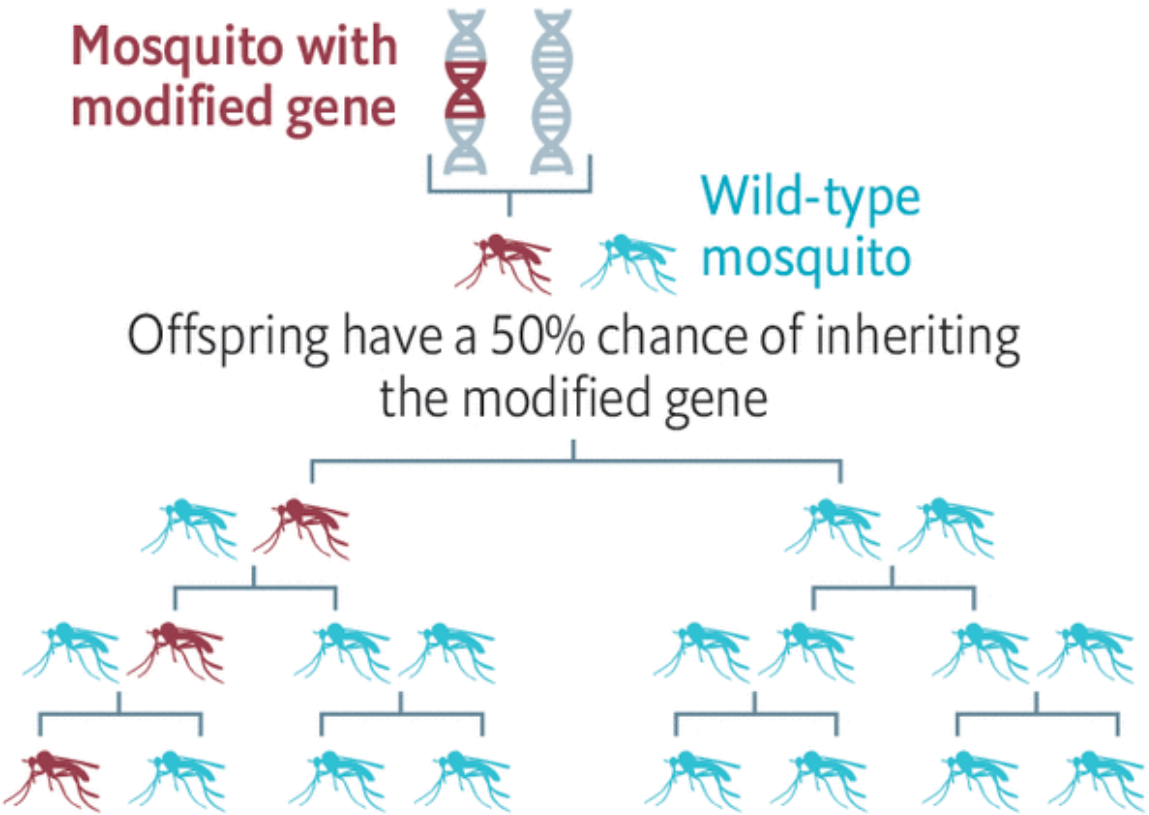
Eggs do not hatch due to Cytoplasmic Incompatibility

Drive-by killing

How gene drives can quickly change whole populations

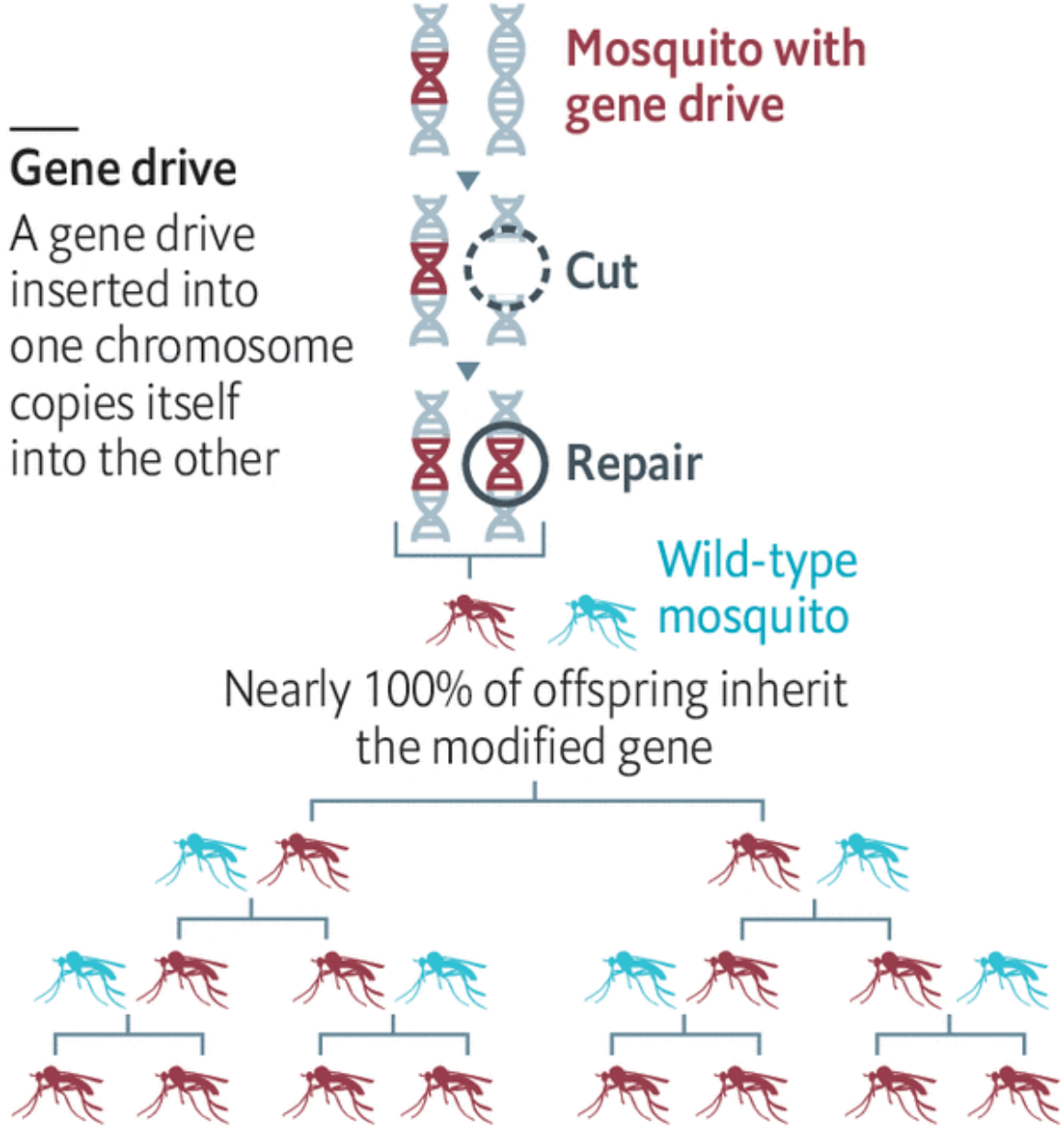
Normal genetic modification

A gene added to only one chromosome gets into half of offspring



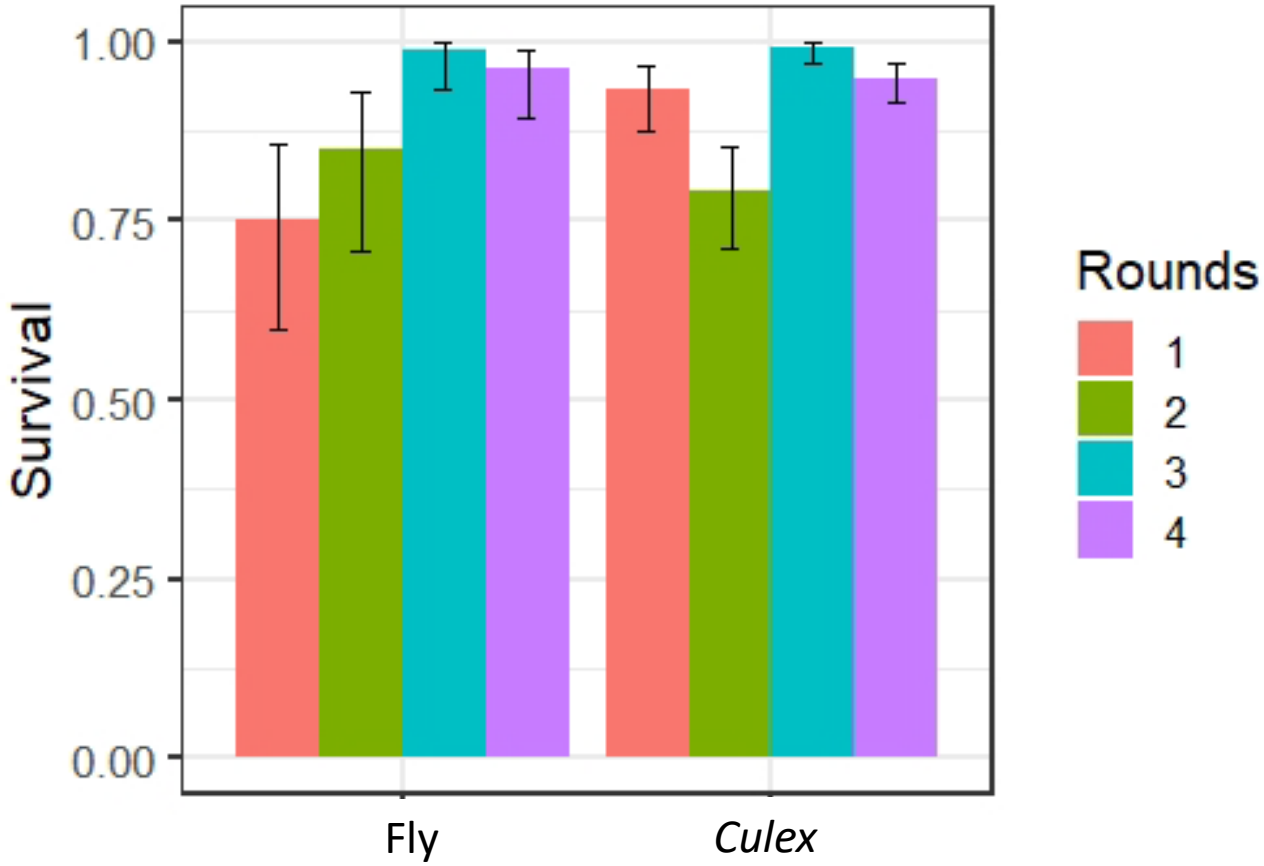
Gene drive

A gene drive inserted into one chromosome copies itself into the other



Tansy pollination: fly vs. *Culex pipiens*

Culex and fly survival during the two-day tests



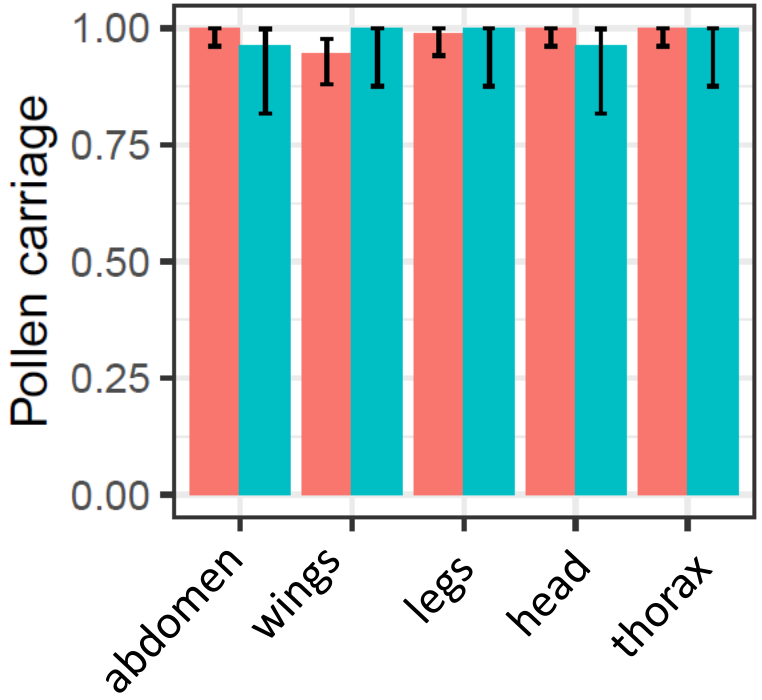
Fly overall survival of 91%

Culex overall survival of 93%

Results

Tansy pollination: fly vs. *Culex pipiens*

Pollen distribution in flies



Red bars = ♀

blue bars = ♂

Almost all flies (~100%) carried pollen on each body part

Results

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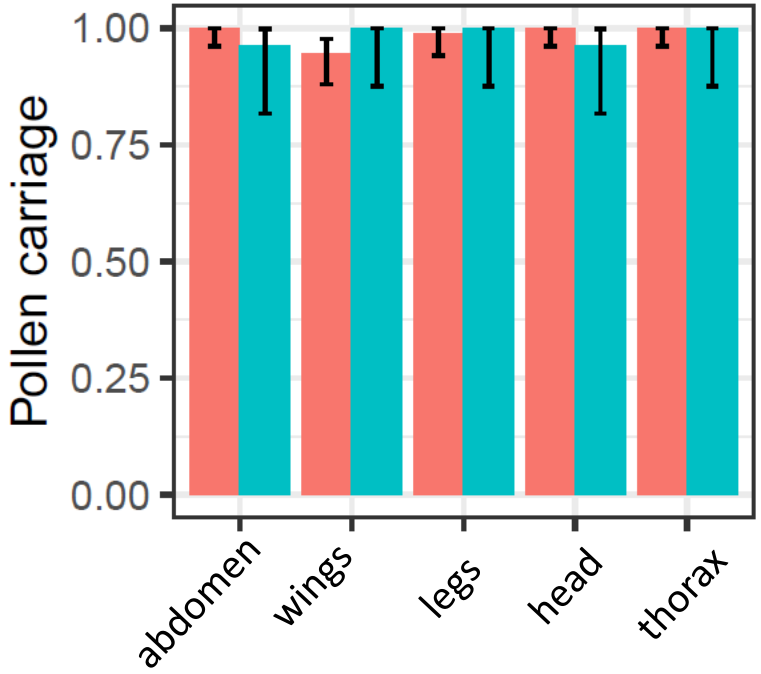

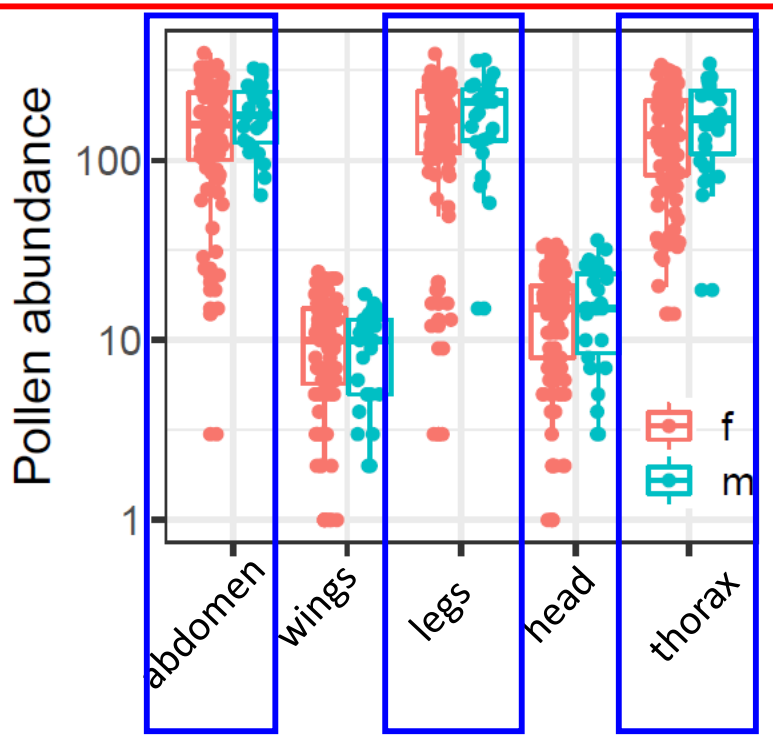

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> 100 pollen grains on abdomen, legs, and thorax

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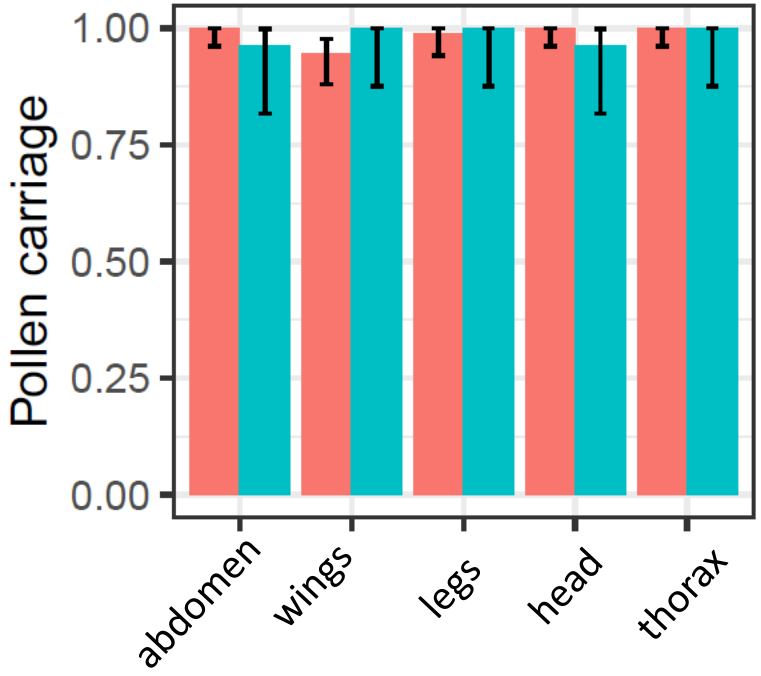

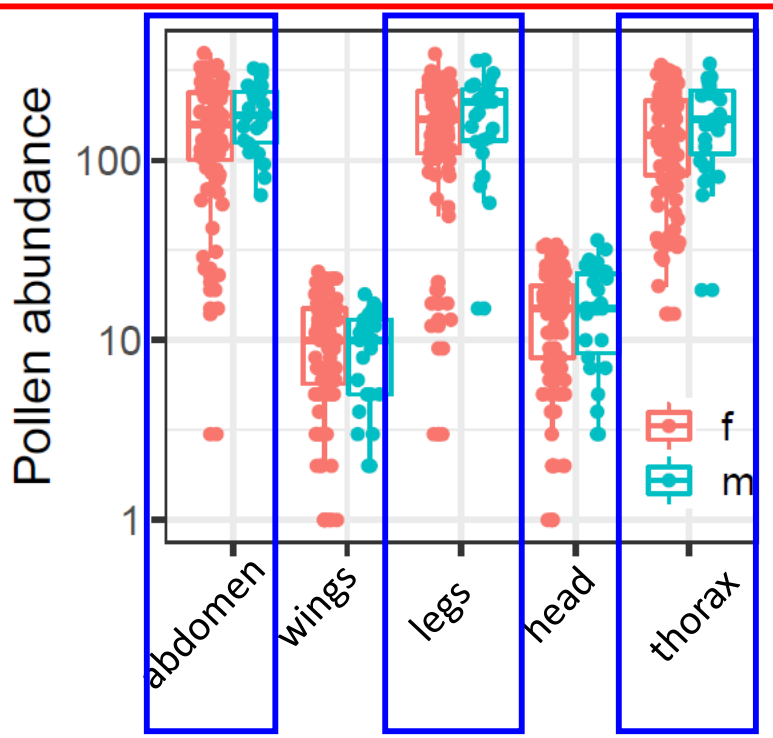

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No effect of fly sex on carriage and abundance

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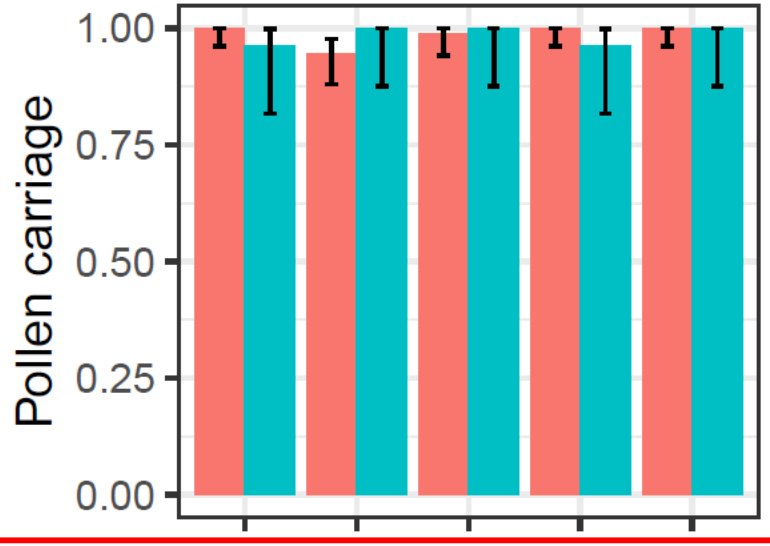
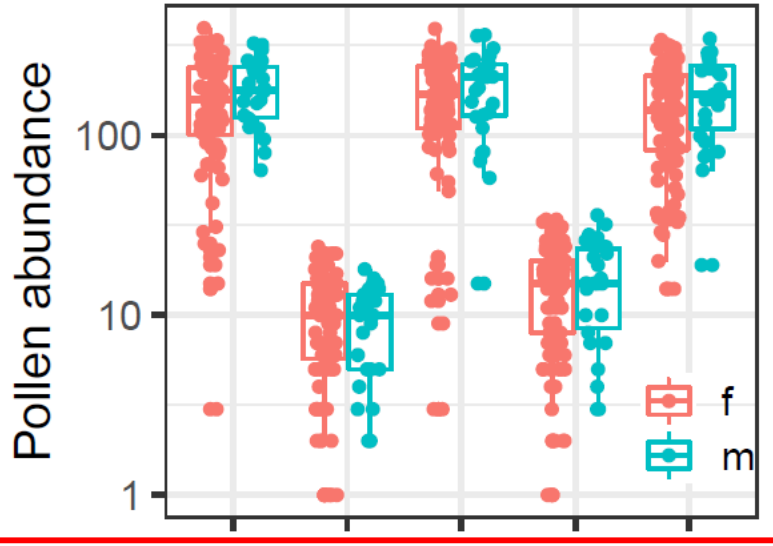
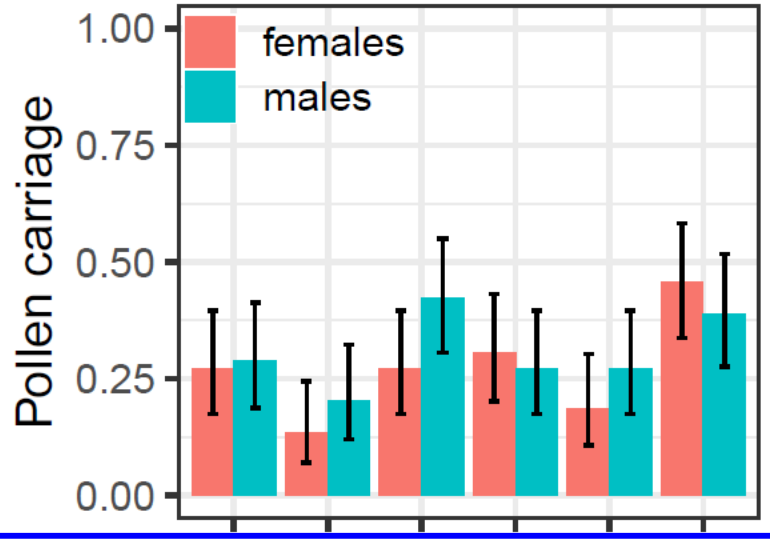
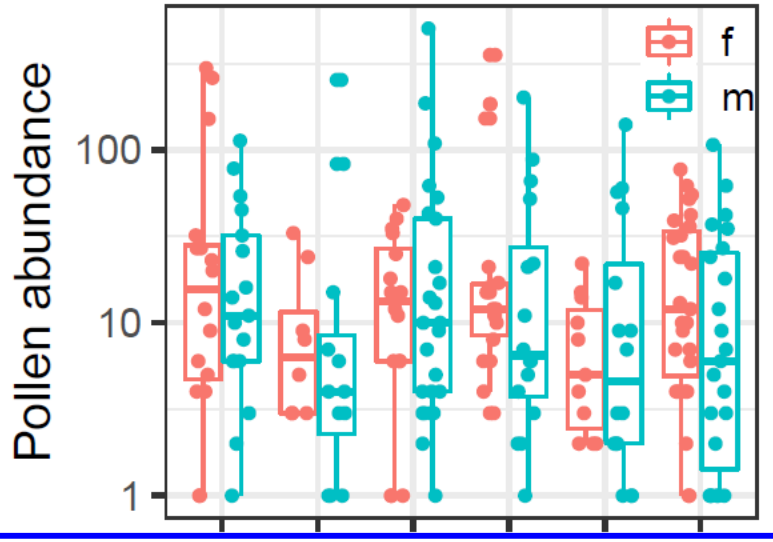




Pollen distribution in *Culex*





Results

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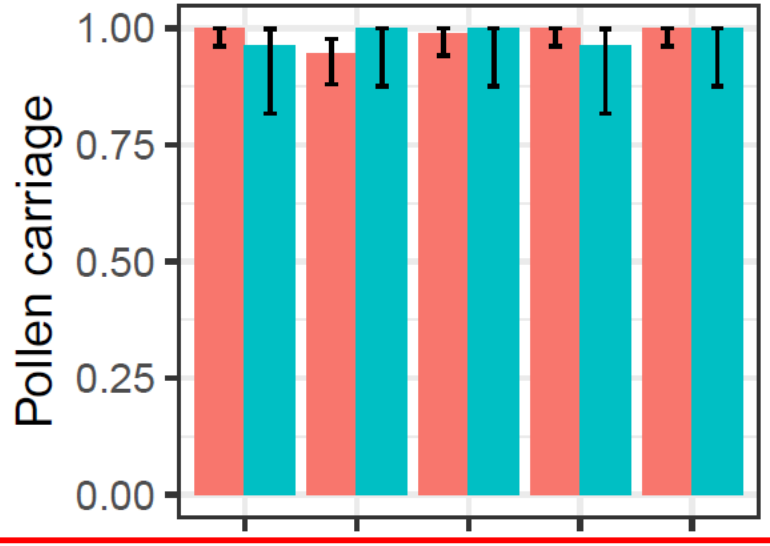
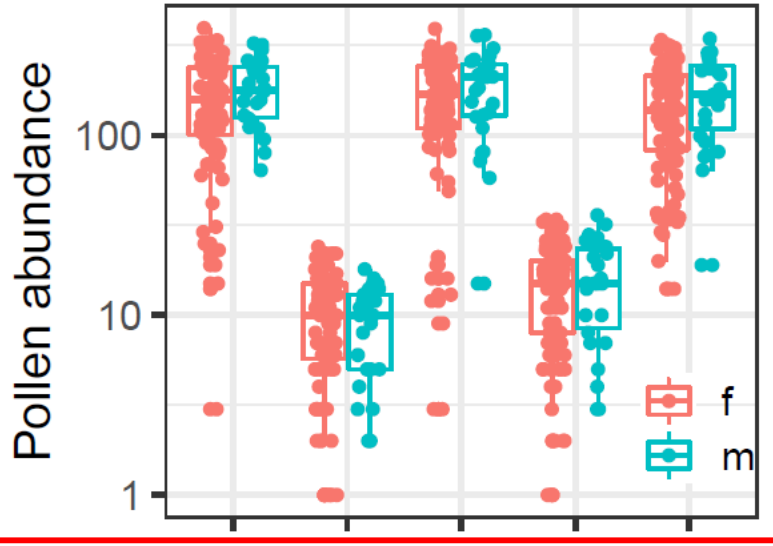
Pollen distribution in flies





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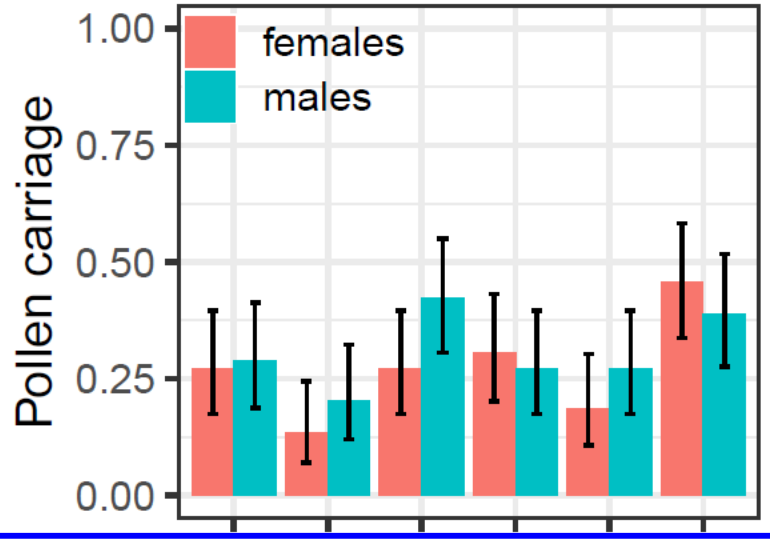
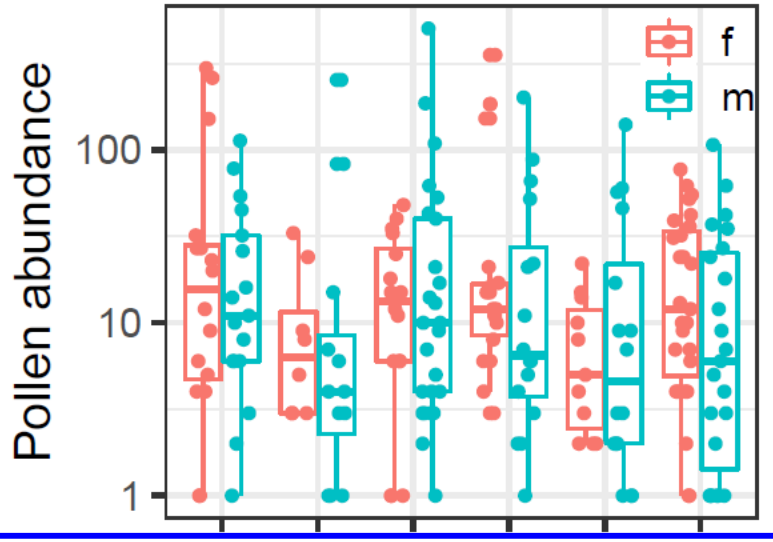
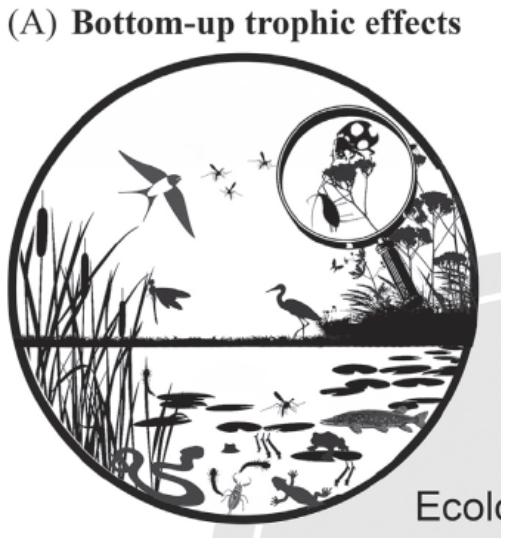




No effect of mosquito sex on pollen carriage and abundance

Environmental consequences of suppressing mosquitoes ?

1. Effects on predators ?



A DNA metabarcoding analyse of the feces of western bluebirds revealed that *Aedes spp*. were by far the most common item recovered, occurring in 50% of samples

Jedlicka et al. 2016 Auk

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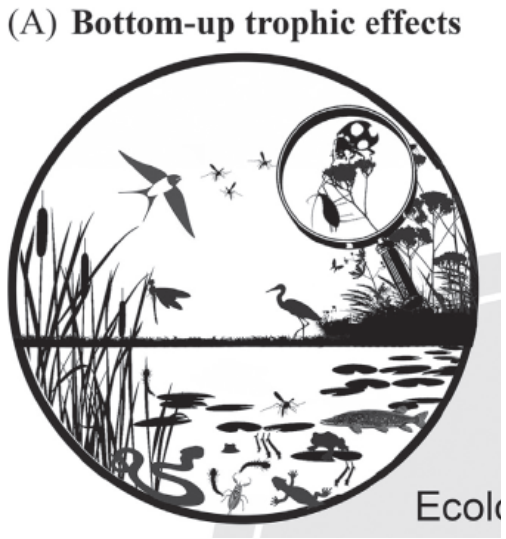

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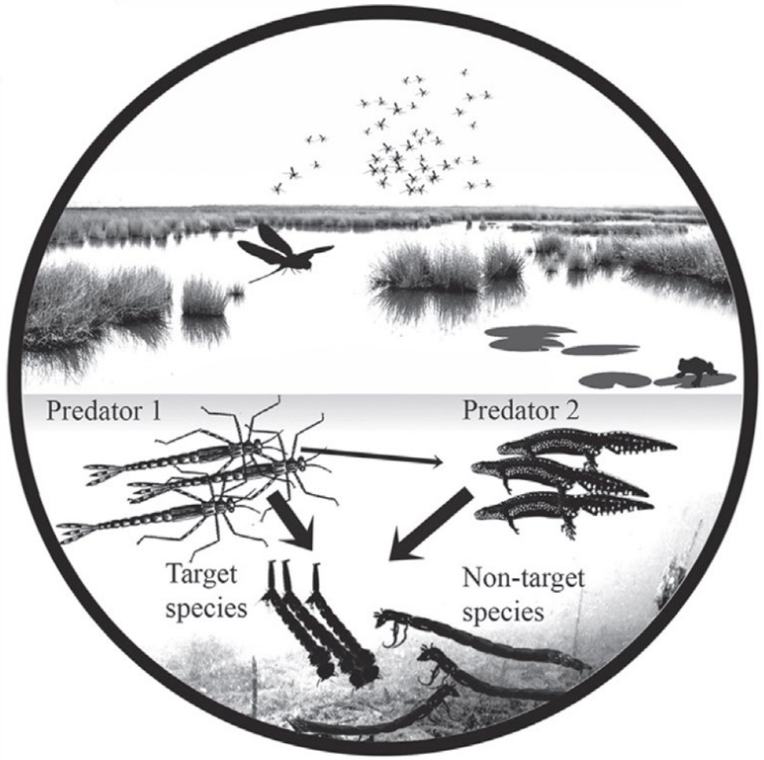
➢ **On this topic, see also Poster no.4 by Raquel Gutiérrez-Climente**

Jedlicka et al. 2016 Auk

Environmental consequences of suppressing mosquitoes ?

1. Effects on predators ?

absence of vector control

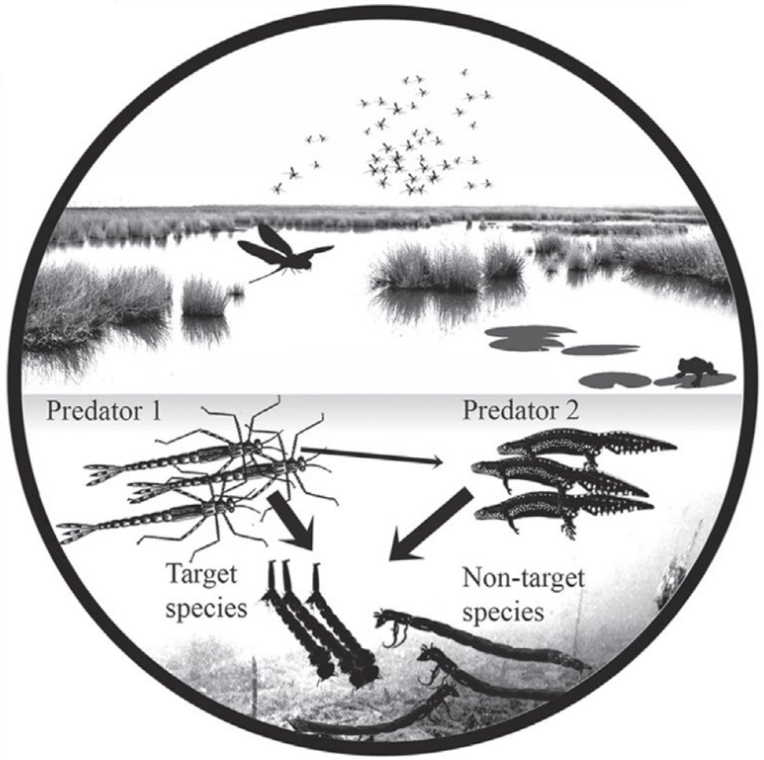


Allgeier et al. 2016 Sci Total Environmental

Environmental consequences of suppressing mosquitoes ?

absence of vector control

Mosquitoes (and chironomids) thrive and are preyed upon by both dragonfly larvae and newts. Newts can represent an occasional food item for dragonflies.



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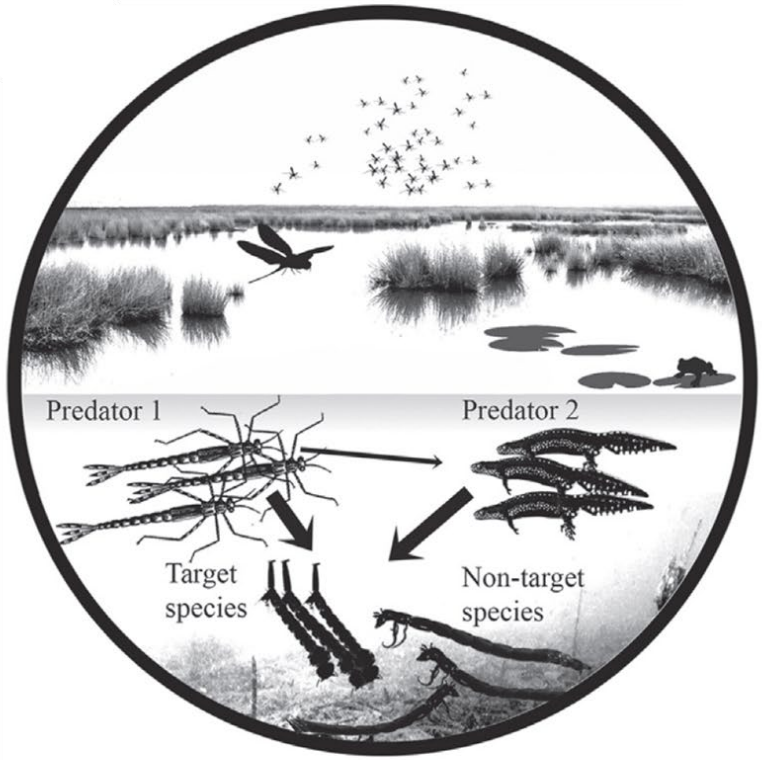


Bti Application

The abundance of mosies and chironomids decreases.
In turn, newt abundance drops not only because of the rarefaction of its preys, but also because of the increased predation rate by dragonflies

Allgeier et al. 2016 Sci Total Environmental

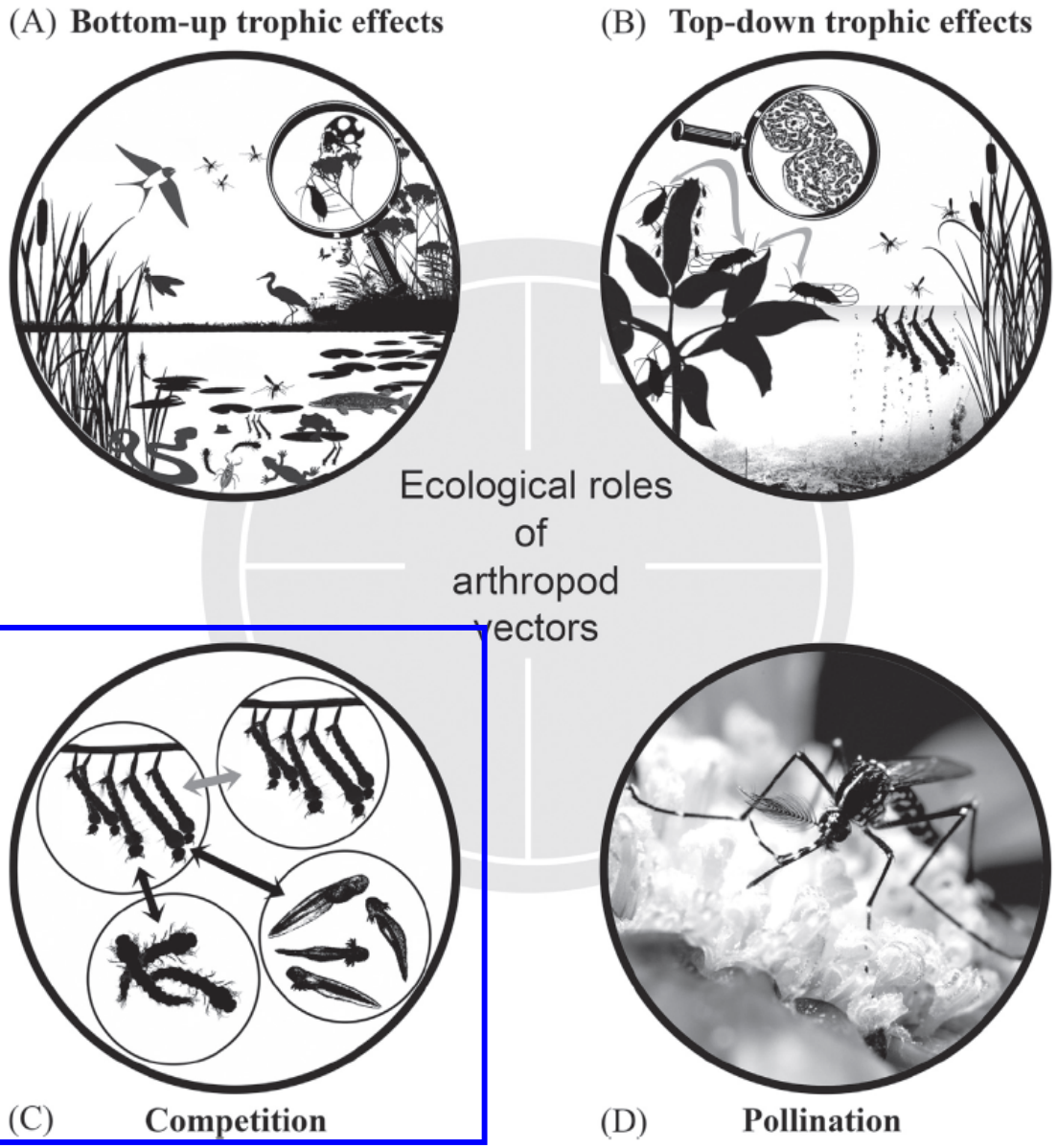
Environmental consequences of suppressing mosquitoes ?

field study in Kenya revealed that Bti significantly reduced the density of *Anopheles gambiae* and *An. funestus*, with no effects on the abundance and diversity of 11 taxa, including fish, frogs, snails, and aquatic insects

Derua et al. 2018 Ecol. Evol.

Environmental consequences of suppressing mosquitoes ?

1. **Effects on predators ?**



2. **Effects on prey populations, (decomposition and water purification) ?**

Lab experiment on intra-specific competition in *Aedes aegypti*

4. **Effects on plant reproduction?**

Lefèvre et al. 2022 Trends Parasitol.

Environmental consequences of suppressing mosquitoes ?

150 larvae

5 treatments

 + Ø No predator

 +  3 *Mesocyclops longisetus*

 +  3 *Anopheles barberi*

 +  3 *Corethrella appendiculata*

 +  Combined

Neale & Juliano (2021) *Ecol. Entomol*

Environmental consequences of suppressing mosquitoes ?

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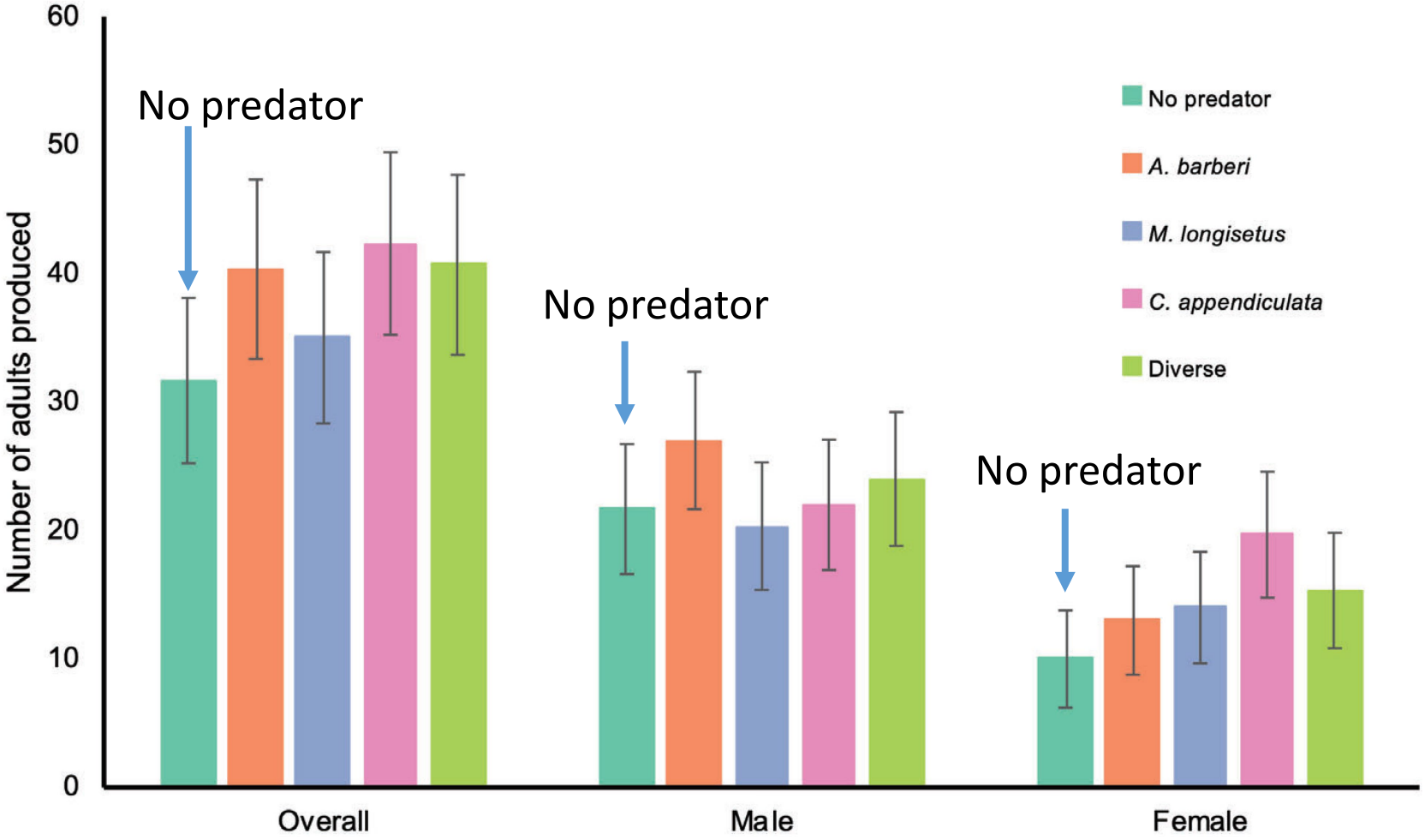

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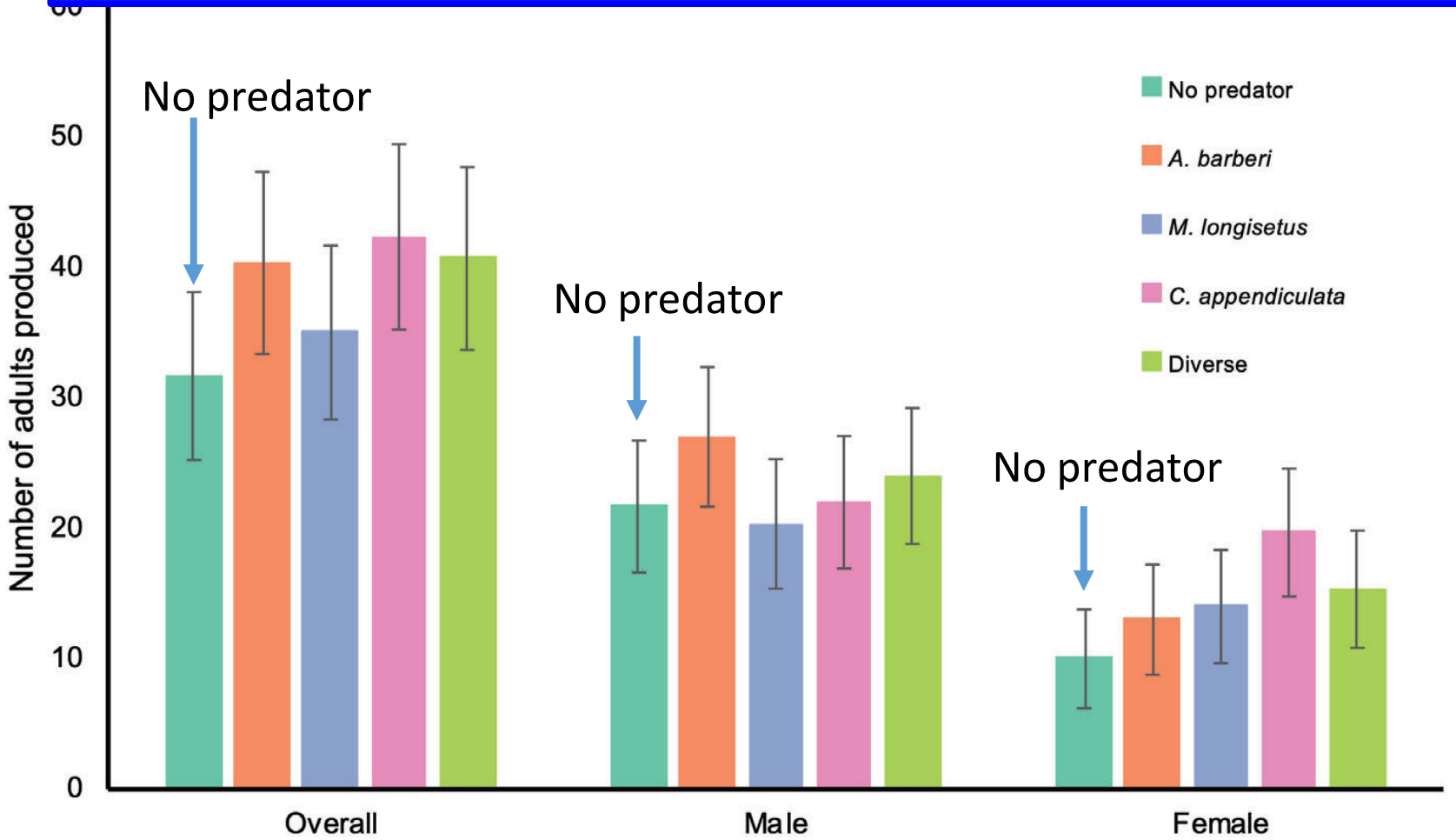
Environmental consequences of suppressing mosquitoes ?

150 larvae 5 treatments

→ predator-induced mortality increased population survival, a counter-intuitive result explained by the reduction in intraspecific competition generated by predation

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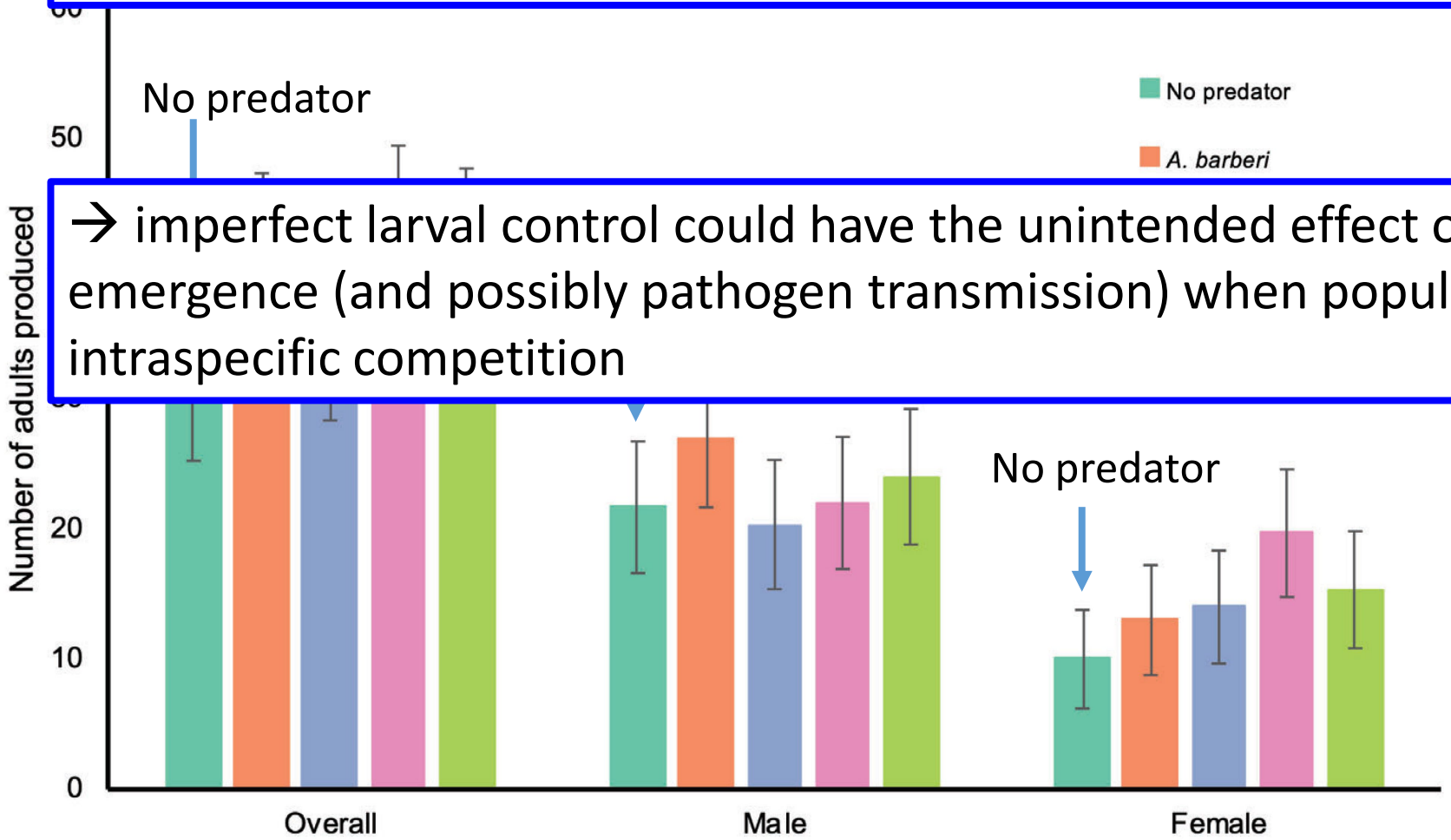
Neale & Juliano (2021) *Ecol. Entomol*

Environmental consequences of suppressing mosquitoes ?

150 larvae 5 treatments

→ predator-induced mortality increased population survival, a counter-intuitive result explained by the reduction in intraspecific competition

→ imperfect larval control could have the unintended effect of increasing adult emergence (and possibly pathogen transmission) when populations are released from intraspecific competition



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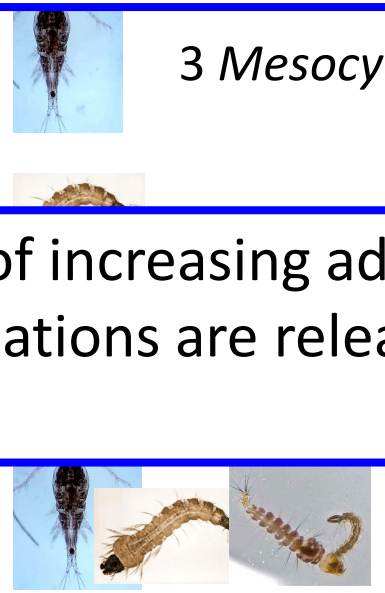

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