Physiological adaptation to environmental stress in insects

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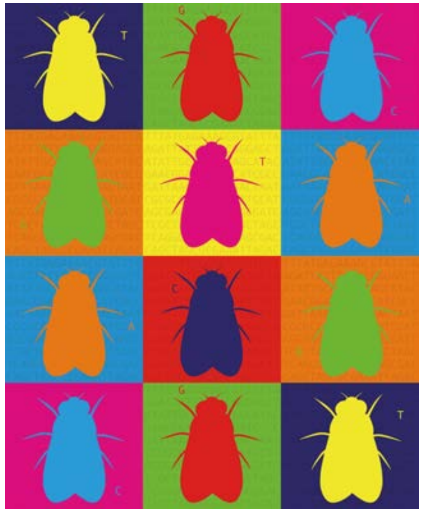
CBGP, France 2024

Response to environmental stress

Adapt or become extinct

Adaptation

Evolutionary change



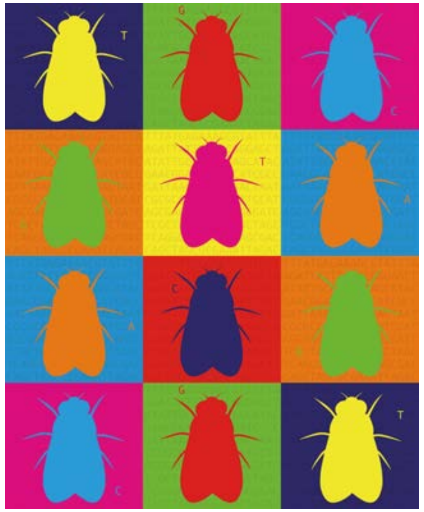
Phenotypic plasticity

Response to environmental stress

Adapt or become extinct

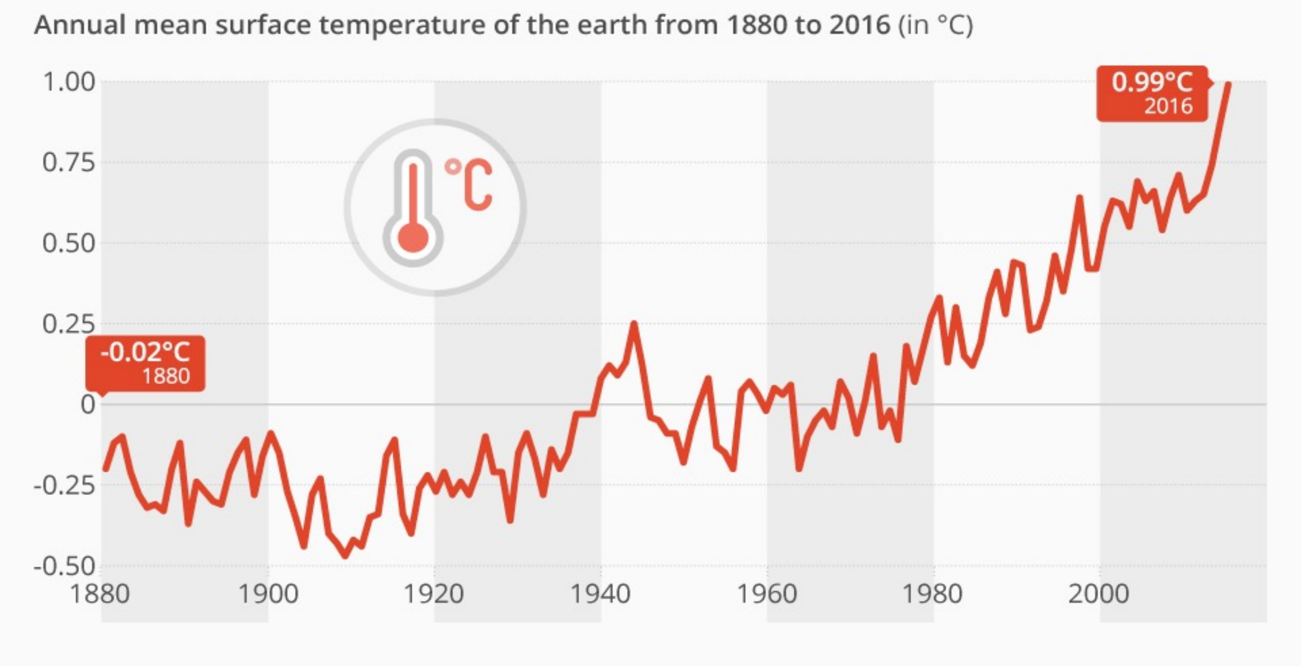
Adaptation

Evolutionary change

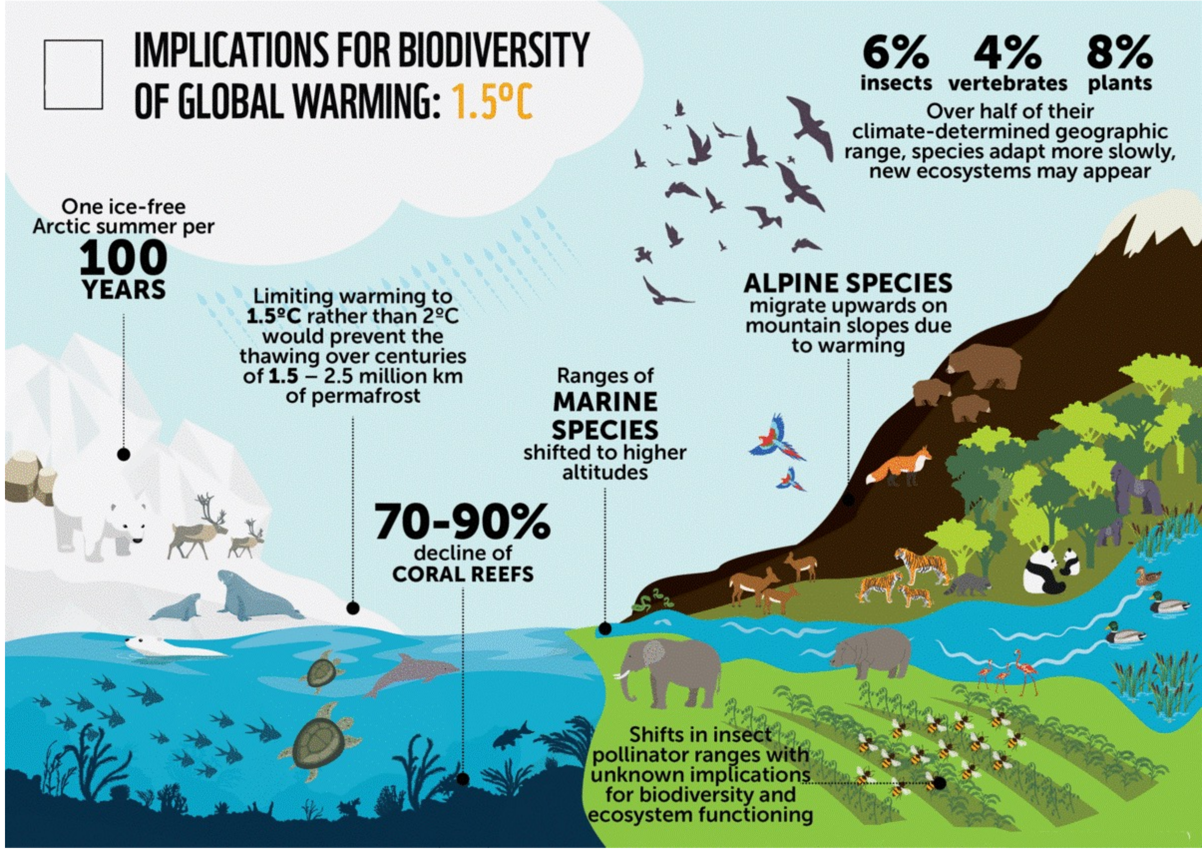


Phenotypic plasticity

The threat of global warming

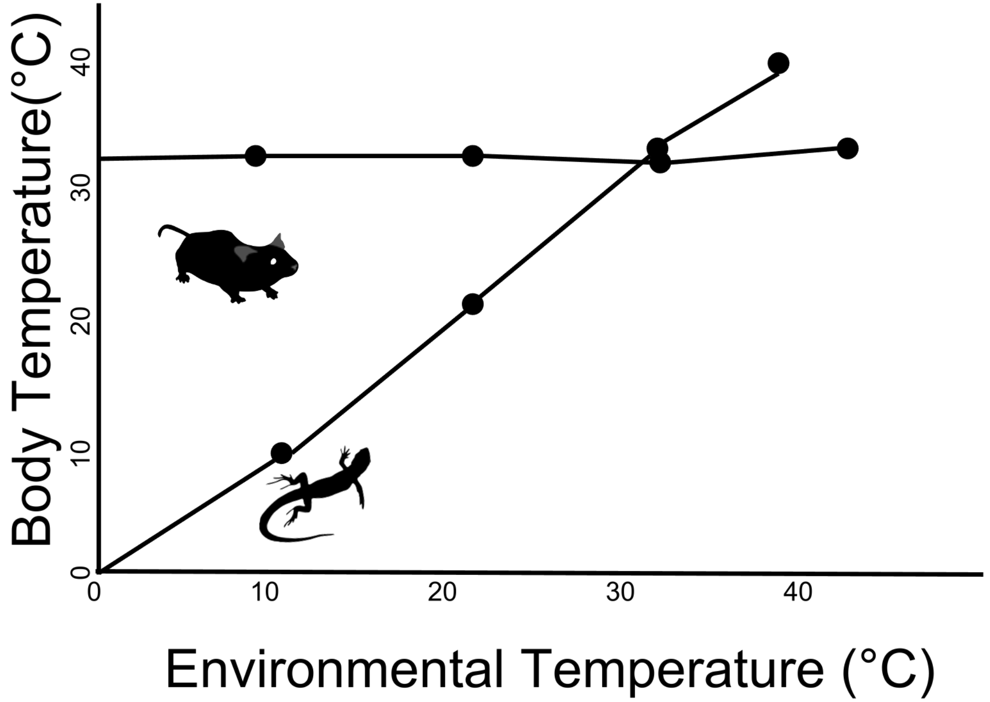


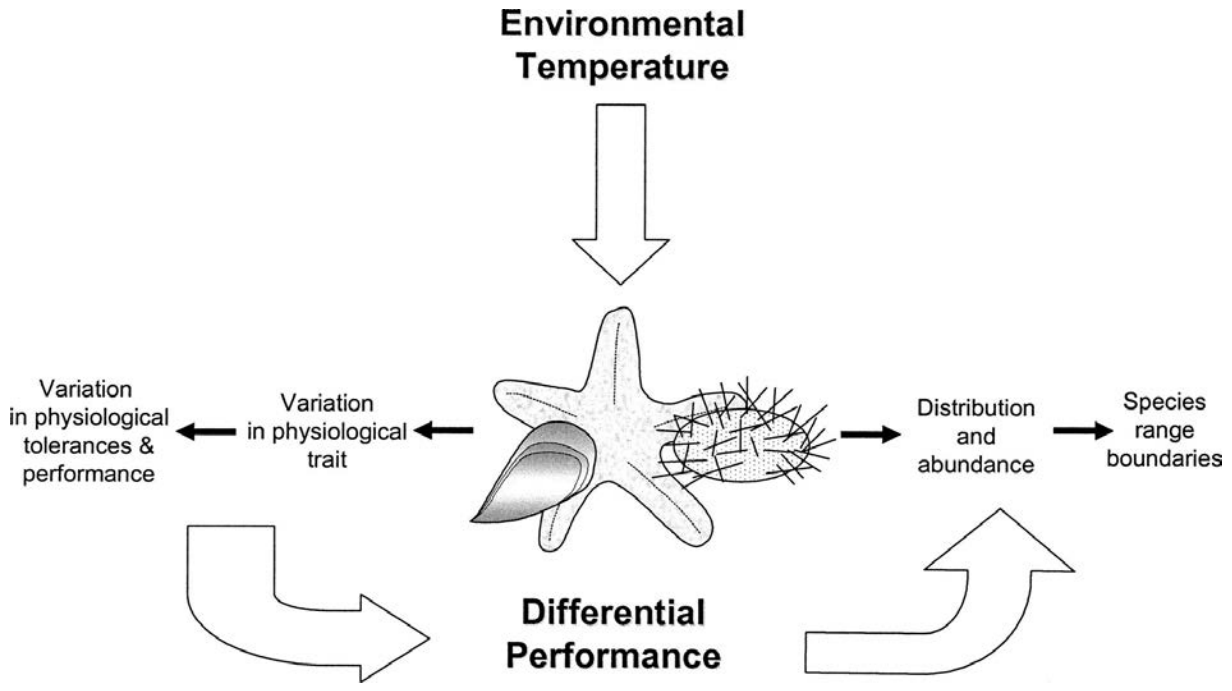
Rapid increase of environmental temperatures affects biodiversity



The threat of global warming

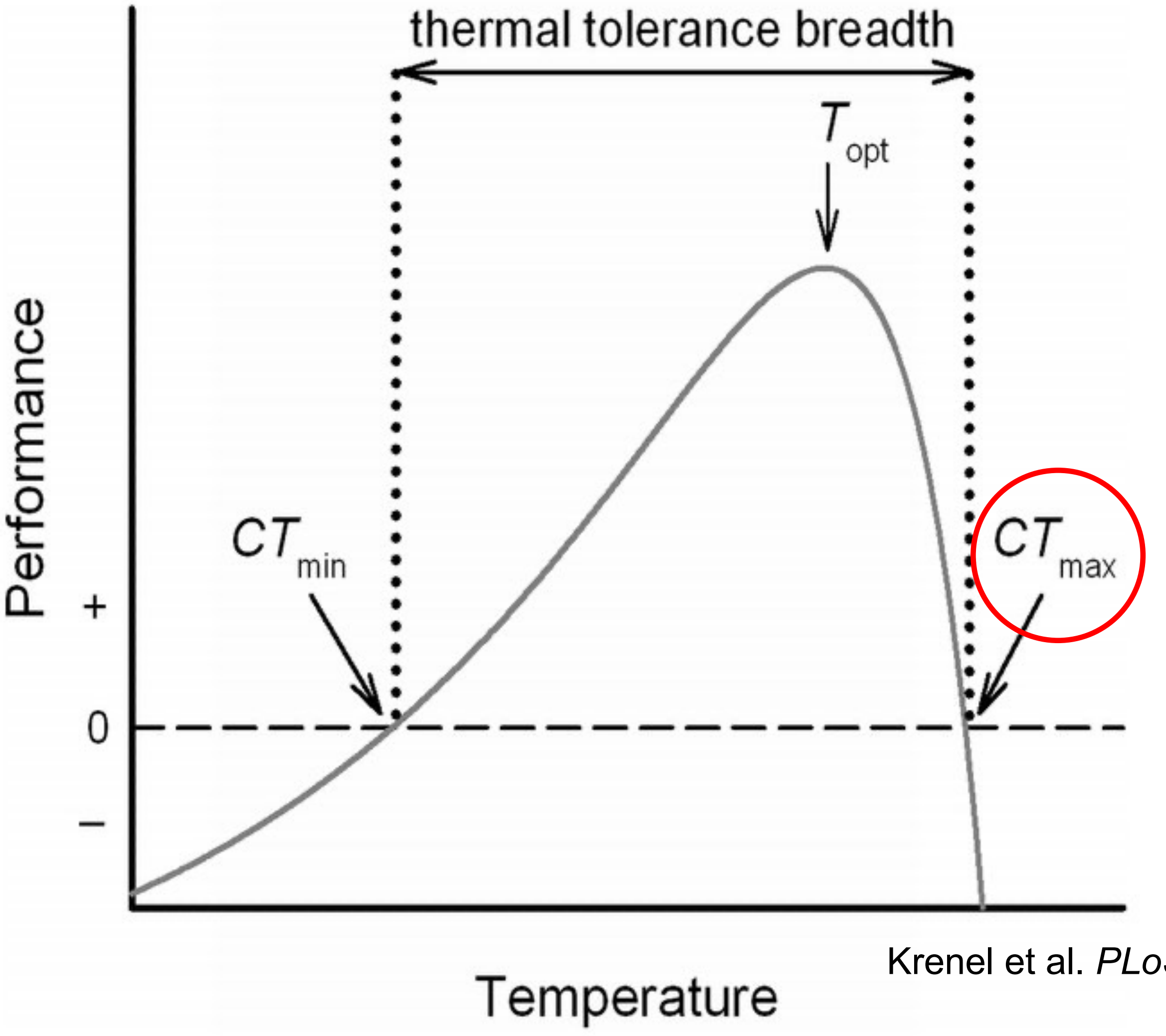
Extreme warming can be more important for ectotherms because their body temperature is directly influenced by the environmental temperature





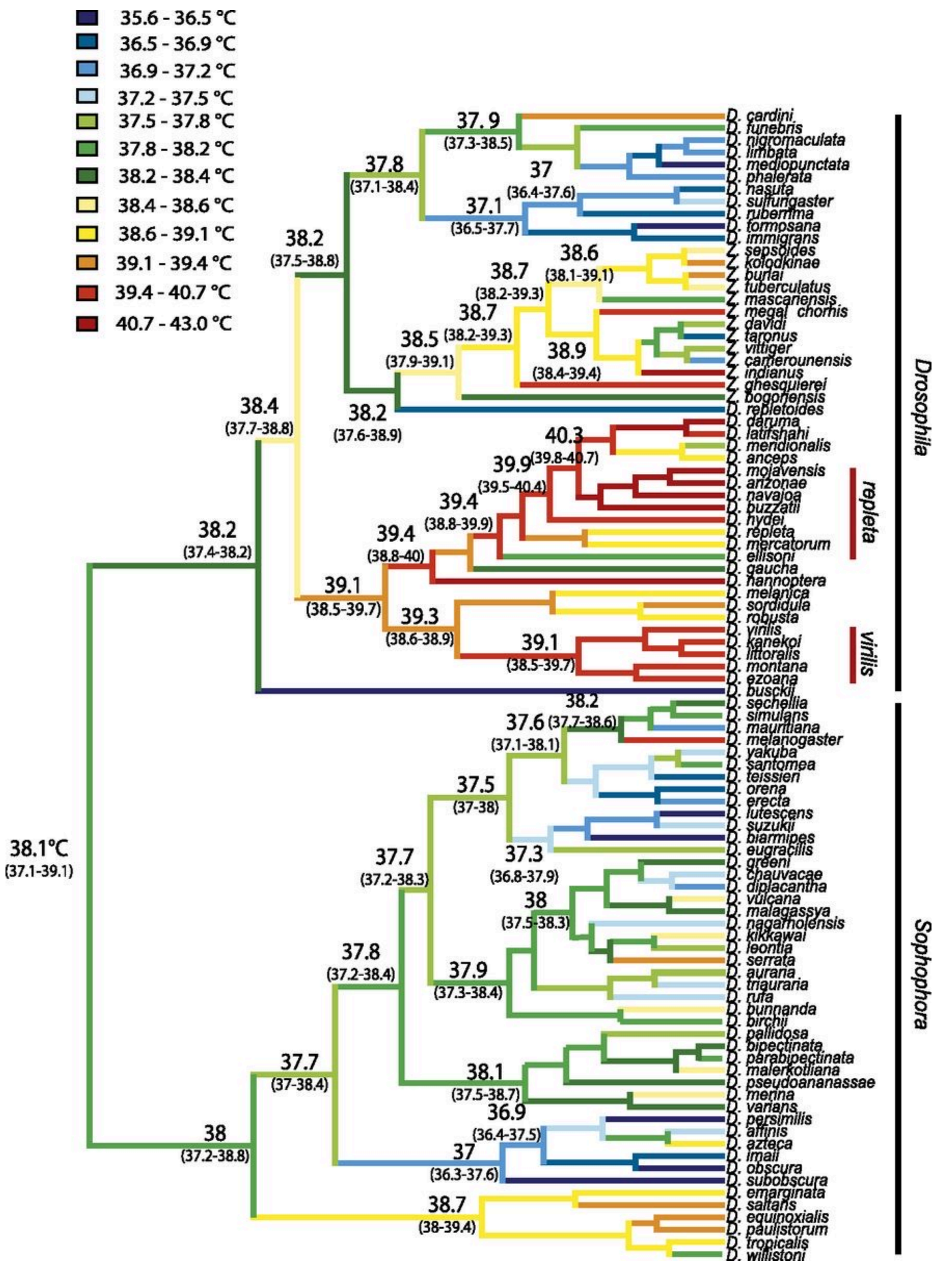
Hofmann. *Integ Comp Biol* 2005

Thermal performance of ectotherms



Krenel et al. *PLoS* 2012

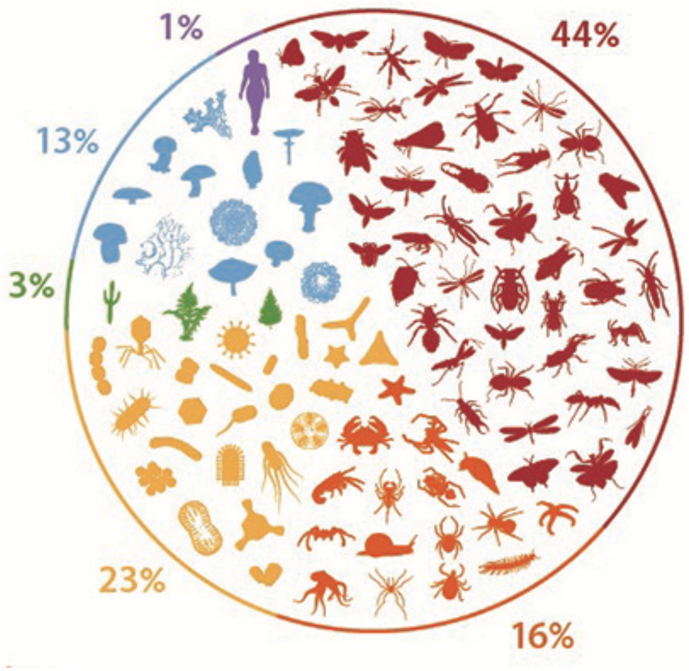
Thermal performance curve (TPC)



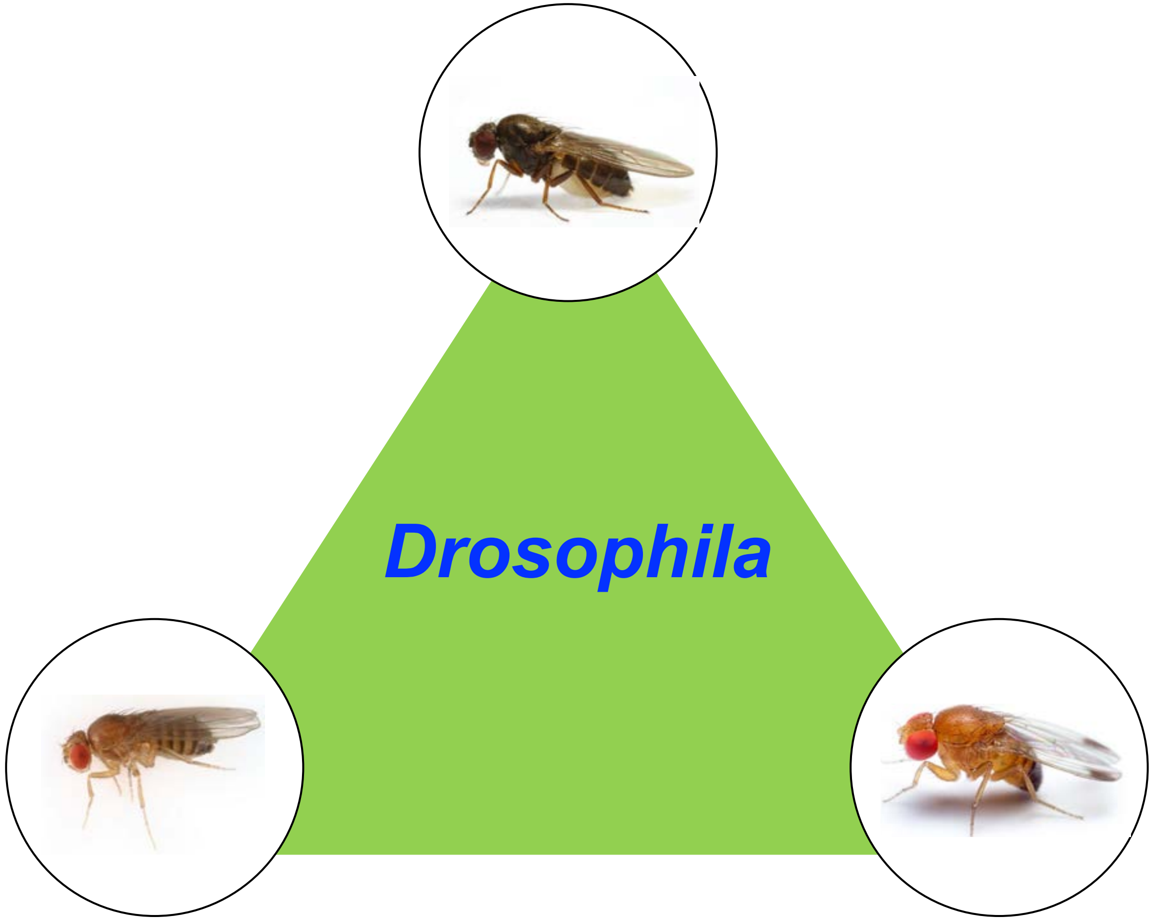
Kellermann et al. *PNAS* 2012

Drosophila: a very diverse taxon

Insects represent one of the most taxonomic group on Earth



Drosophilidae > 4390 species
Drosophila > 1600 species

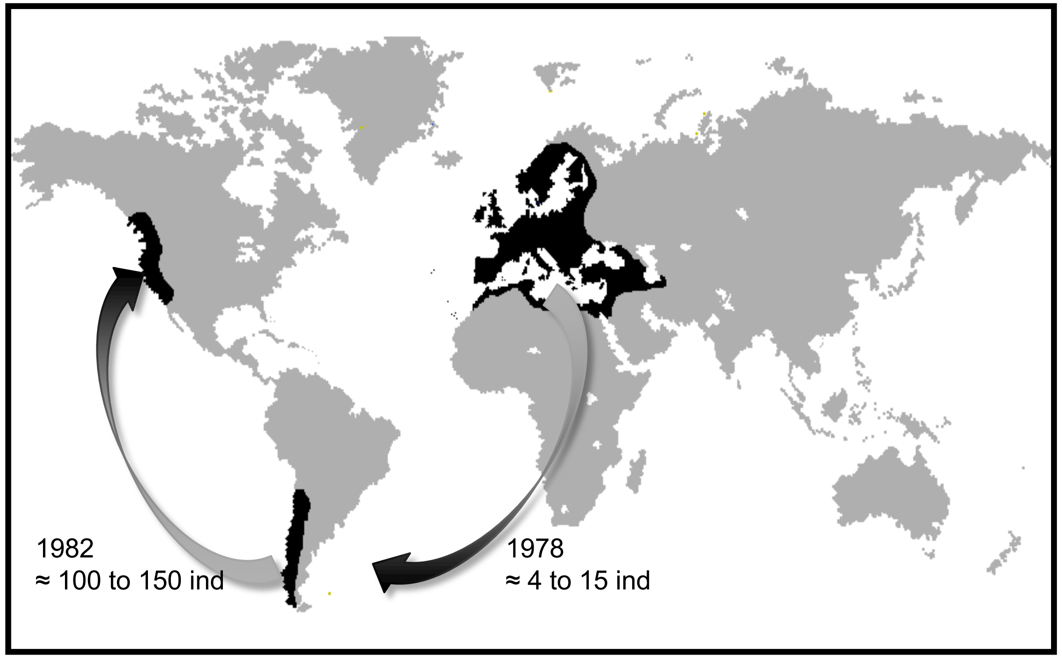


How we studied thermal adaptation in flies?

- Quantitative genetic studies
- Experimental selection
- Common-garden experiments

Drosophila subobscura

Thermal evolution in *Drosophila subobscura*



Pascual et al. *Mol Evol* 2007

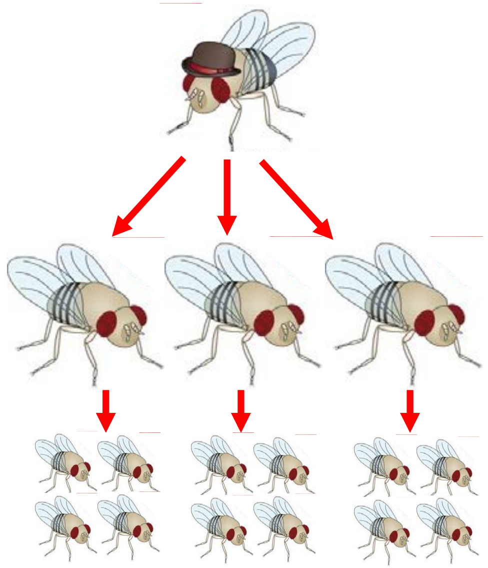
Despite strong bottleneck and founder effect on introduced populations (Pascual et al. *Mol Ecol* 2007), several phenotypic traits show latitudinal variation

- Polymorphism of chromosomal inversions (Huey et al. *Science* 2000; Balanyà et al. *Evolution* 2003)
- Body size (Balanyà et al. *Evolution* 2003)
- Thermal preference (Pascual & Huey *Ecology* 2009; Castañeda et al. *Am Nat* 2013)
- Thermal tolerance (Castañeda et al. *Evolution* 2015)
- Starvation resistance (Gilchrist et al. *Evol Appl* 2008)

Thermal evolution in *Drosophila subobscura*

60 full/half sibs

families



Journal of Evolutionary Biology 2019

Evolutionary potential of thermal preference and heat tolerance in *Drosophila subobscura*

Luis E. Castañeda[1] | Valèria Romero-Soriano[2] | Andrés Mesas[3] | Derek A. Roff[4] | Mauro Santos[5]

Trait	h^2 ± SE	*P* value
Thermal preference	0.066 ± 0.060	0.22
Acute-stress resistance	0.134 ± 0.065	0.05*
Chronic-stress resistance	0.084 ± 0.061	0.16

Heat tolerance of D. subobscura has the potential to evolve

Experimental evolution in the lab!!

Thermal evolution in *Drosophila subobscura*

PROCEEDINGS OF THE ROYAL SOCIETY B
Proc. R. Soc. B (2007) 274, 2935–2942
doi:10.1098/rspb.2007.0985
Published online 18 September 2007

Critical thermal limits depend on methodological context

John S. Terblanche*, Jacques A. Deere, Susana Clusella-Trullas, Charlene Janion and Steven L. Chown

Functional Ecology 2009, 23, 133–140
doi: 10.1111/j.1365-2435.2008.01481.x

Phenotypic variance, plasticity and heritability estimates of critical thermal limits depend on methodological context

Steven L. Chown[1]*, Keafon R. Jumbam[1], Jesper G. Sørensen[2] and John S. Terblanche[3]

Functional Ecology 2010
doi: 10.1111/j.1365-2435.2010.01778.x

PERSPECTIVE

Estimating the adaptive potential of critical thermal limits: methodological problems and evolutionary implications

Enrico L. Rezende[1], Miguel Tejedo[2] and Mauro Santos*[,1]

Journal of Thermal Biology 36 (2011) 409–416
Contents lists available at ScienceDirect
Journal of Thermal Biology
journal homepage: www.elsevier.com/locate/jtherbio

Assessing population and environmental effects on thermal resistance in *Drosophila melanogaster* using ecologically relevant assays

Johannes Overgaard[a,b,*], Ary A. Hoffmann[b], Torsten N. Kristensen[b,c,d]

Functional Ecology 2010, 24, 694–700
doi: 10.1111/j.1365-2435.2009.01666.x

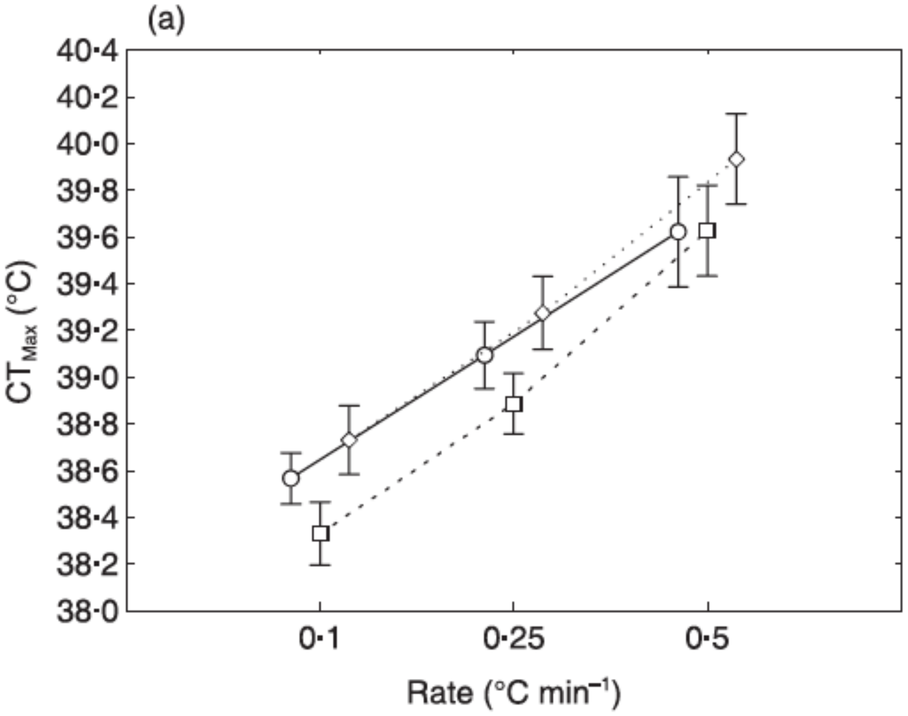
Thermal ramping rate influences evolutionary potential and species differences for upper thermal limits in *Drosophila*

Katherine A. Mitchell*[,1] and Ary A. Hoffmann[1,2]

PROCEEDINGS OF THE ROYAL SOCIETY B
Proc. R. Soc. B (2012) 279, 349–356
doi:10.1098/rspb.2011.0542
Published online 8 June 2011

Limited potential for adaptation to climate change in a broadly distributed marine crustacean

Morgan W. Kelly[1,2,*], Eric Sanford[1,2] and Richard K. Grosberg[1]

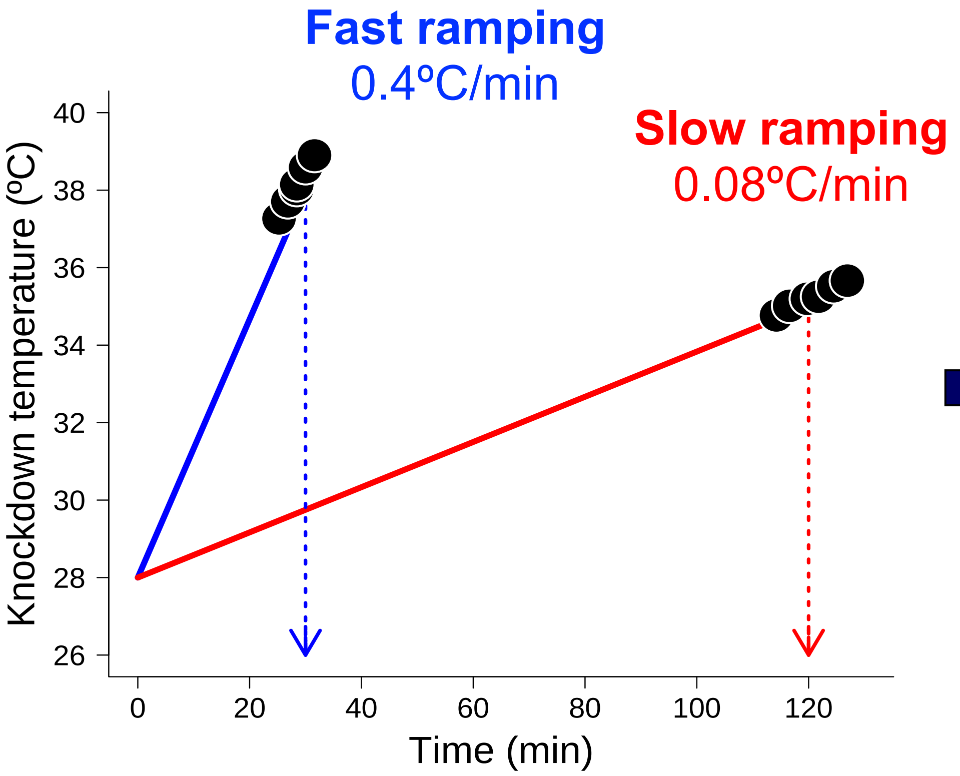


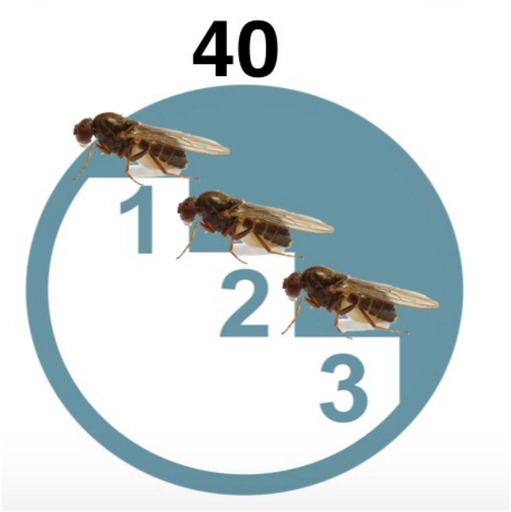
Slower the ramping rate, longer the assay length.
Therefore, higher is the contribution of uncontrolled effects.

- Stochasticity.
- Resource depeletion (fatigue, dehydratation)
- Short-term acclimation (hardening).

Thermal evolution in *Drosophila subobscura*

Artificial selection for 16 generations





Hypothesis

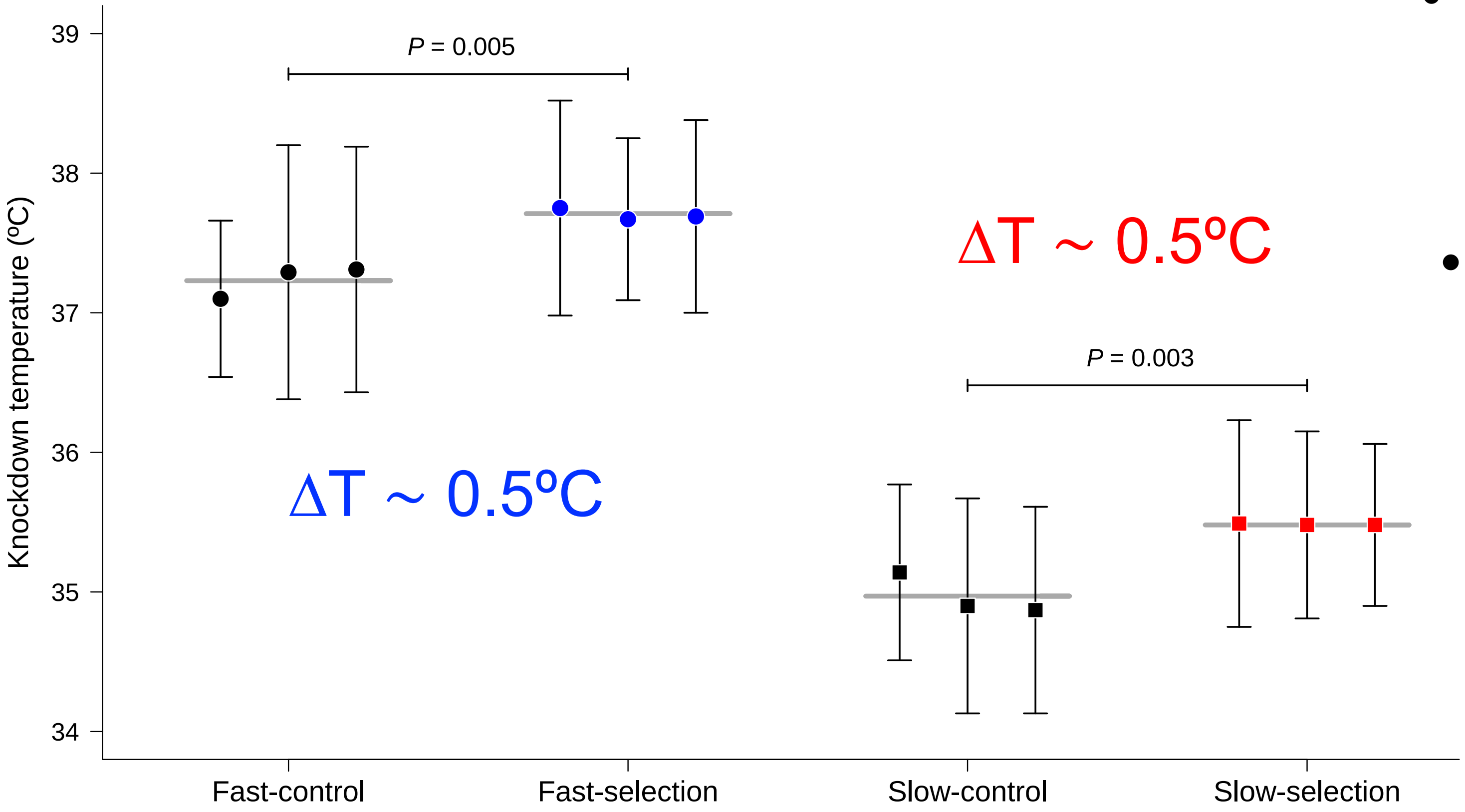
Fast-ramping selected lines will evolve higher heat tolerance than slow-ramping selected lines because differences in their heritabilities

Thermal evolution in *Drosophila subobscura*

Journal of Evolutionary Biology 2021

Experimental evolution on heat tolerance and thermal performance curves under contrasting thermal selection in *Drosophila subobscura*

Andrés Mesas[1] | Angélica Jaramillo[2] | Luis E. Castañeda[2]



- Evolution of heat tolerance but regardless ramping selection
- Significant realized heritability in both selection protocols

$h^2_r = 0.191 \pm 0.013$***

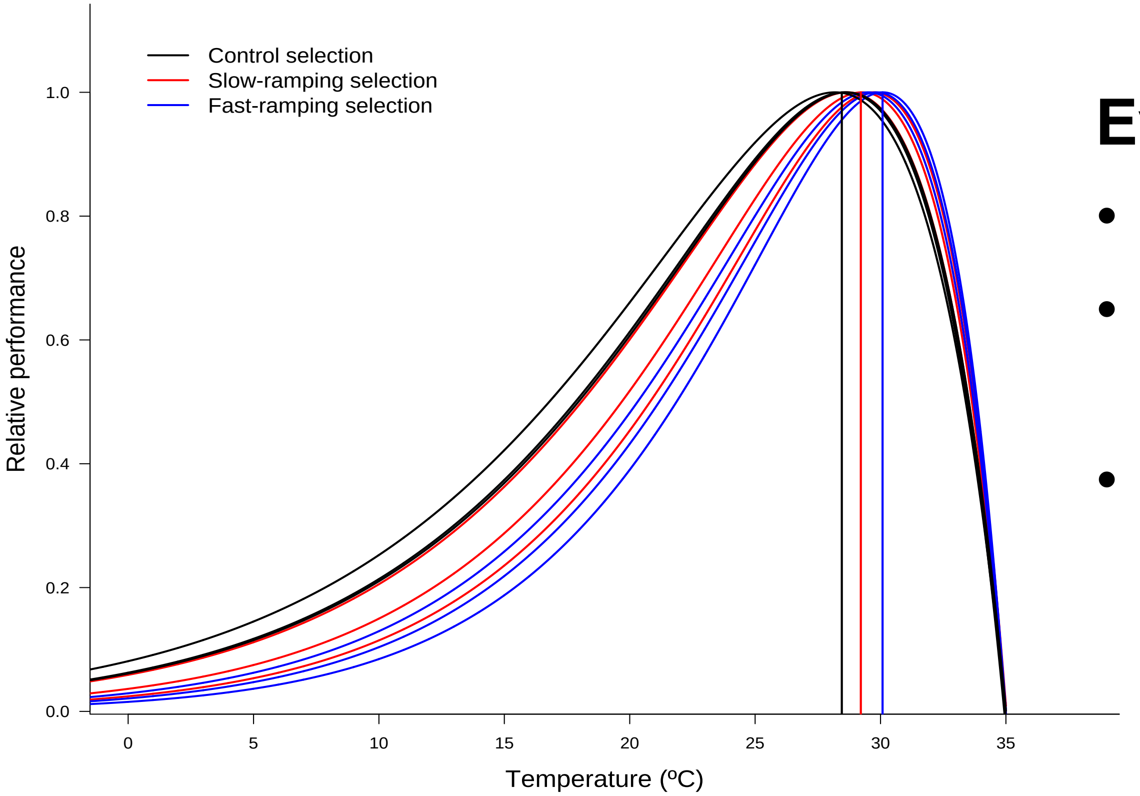
$h^2_r = 0.242 \pm 0.021$***

Thermal evolution in *Drosophila subobscura*

Journal of Evolutionary Biology 2021

Experimental evolution on heat tolerance and thermal performance curves under contrasting thermal selection in *Drosophila subobscura*

Andrés Mesas[1] | Angélica Jaramillo[2] | Luis E. Castañeda[2]



Evolution of TPC

- No changes of CTmax estimated from TPC
- Evolution of thermal optimum
  Fast > Slow = Control ($P = 0.03$)
- Evolution of thermal breadth
  Fast < Slow = Control ($P = 0.04$)

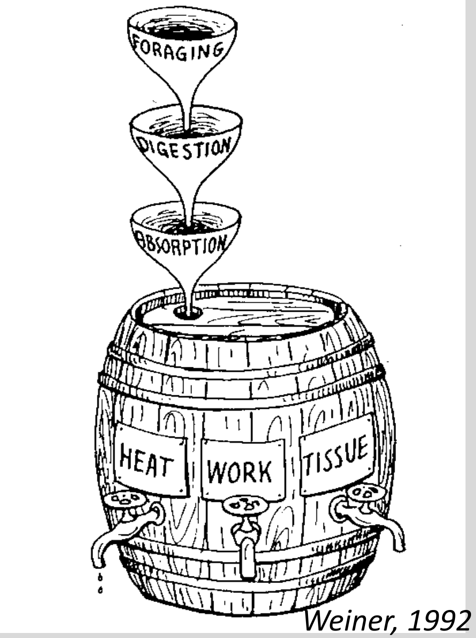
Thermal evolution in *Drosophila subobscura*

Evolution 2023

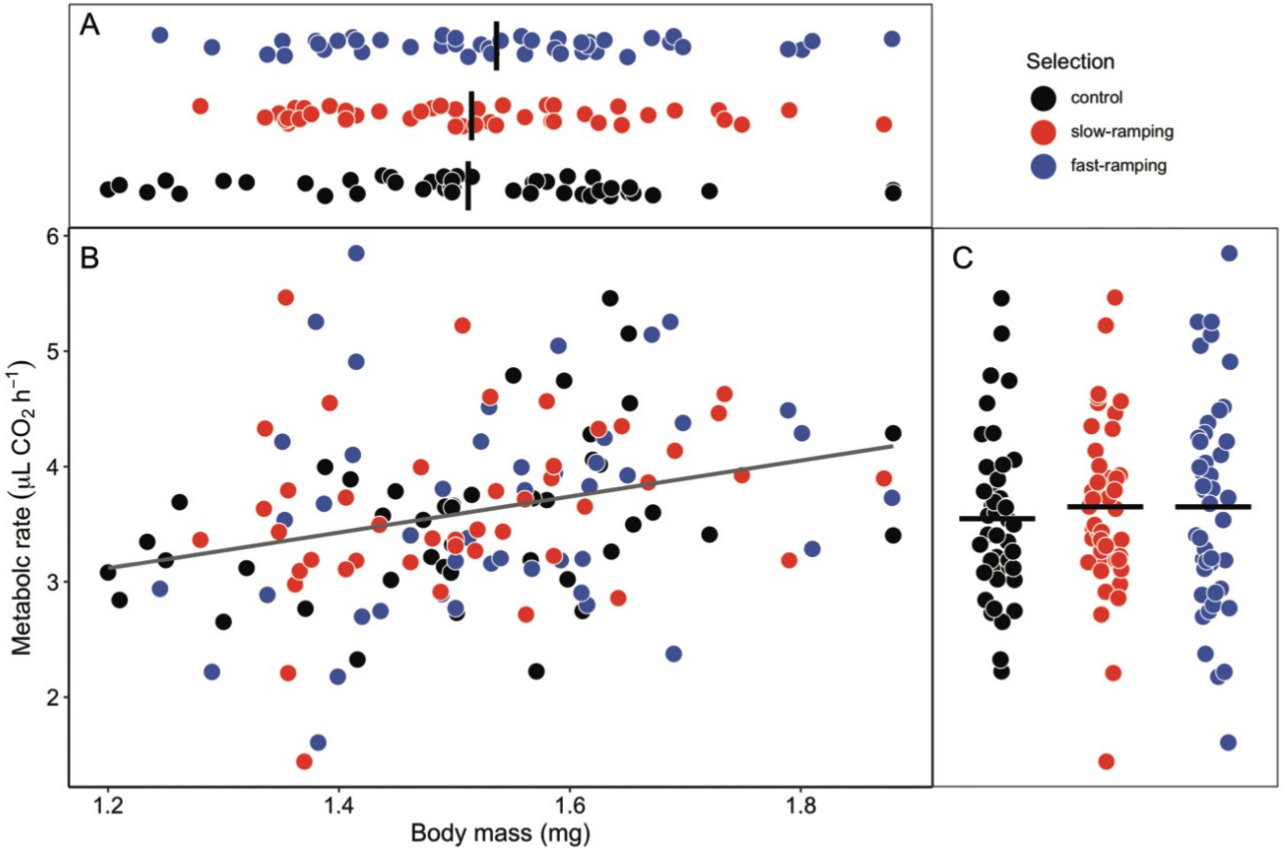
Evolutionary responses of energy metabolism, development, and reproduction to artificial selection for increasing heat tolerance in *Drosophila subobscura*

Andrés Mesas[1,2] and Luis E. Castañeda[3]

Principle of allocation



Weiner, 1992

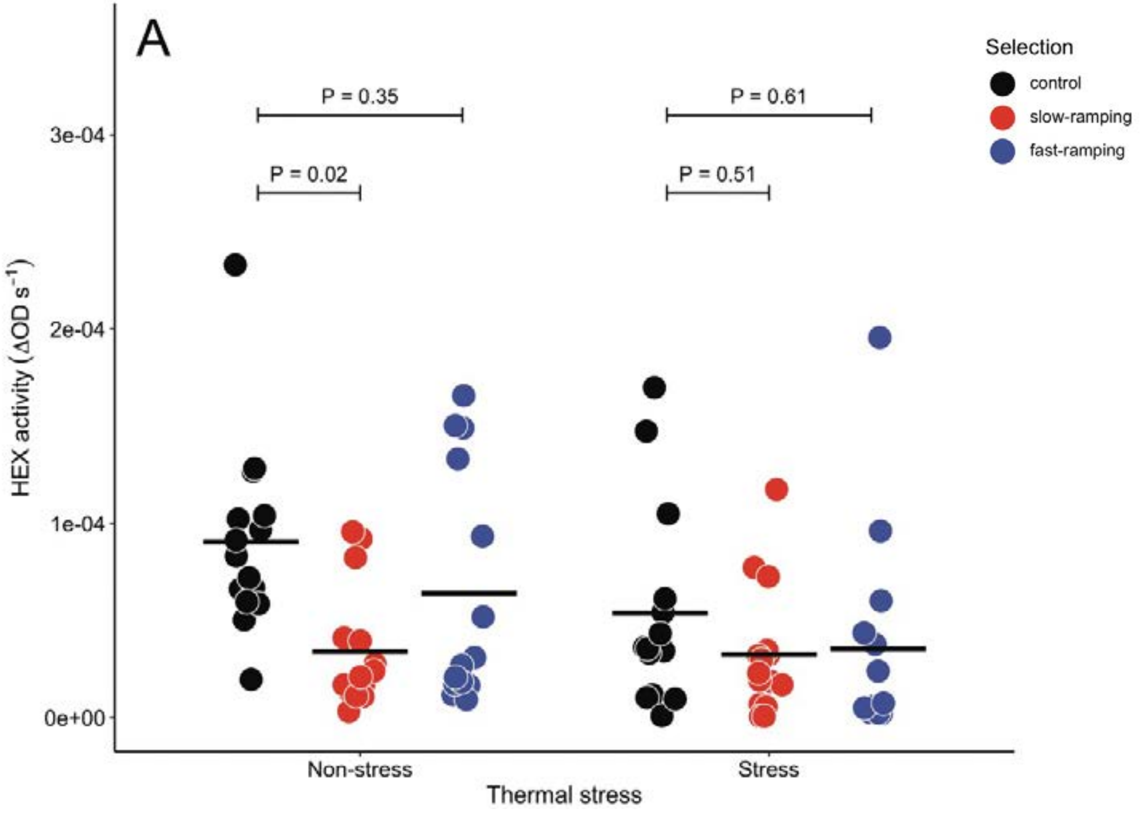


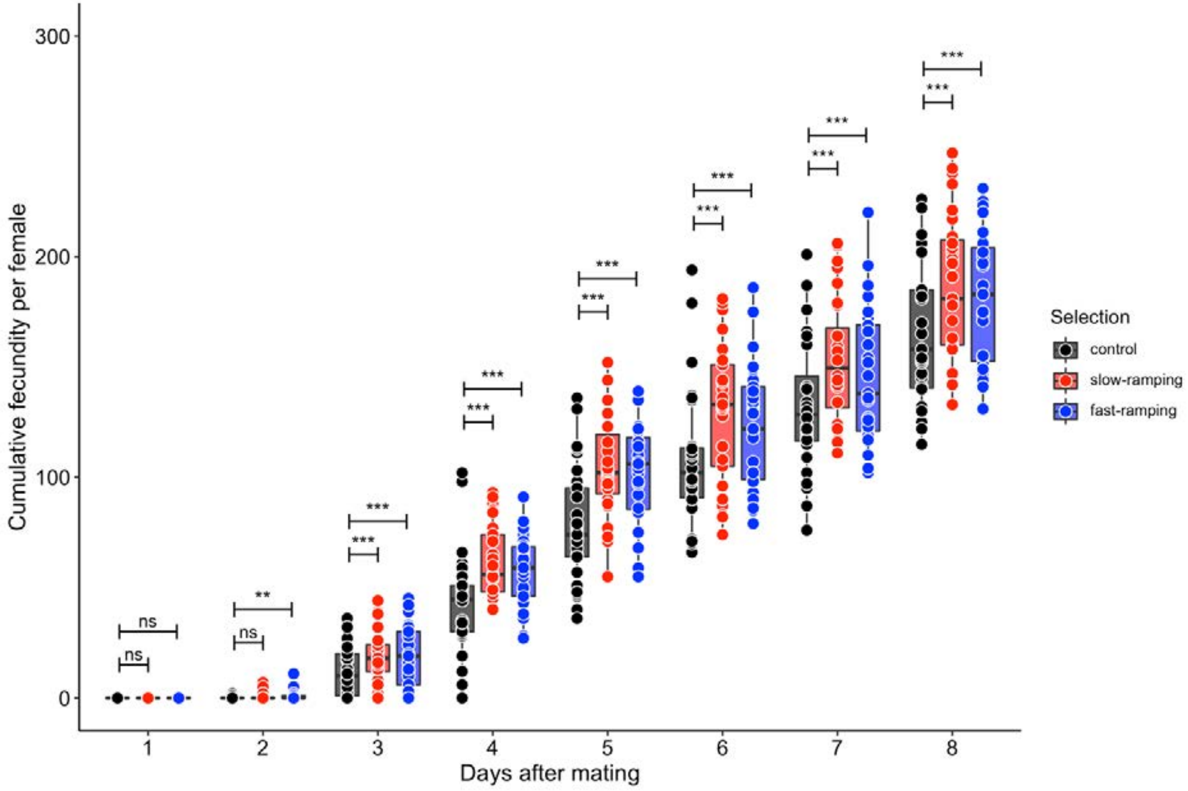
Thermal evolution in *Drosophila subobscura*

Evolution 2023

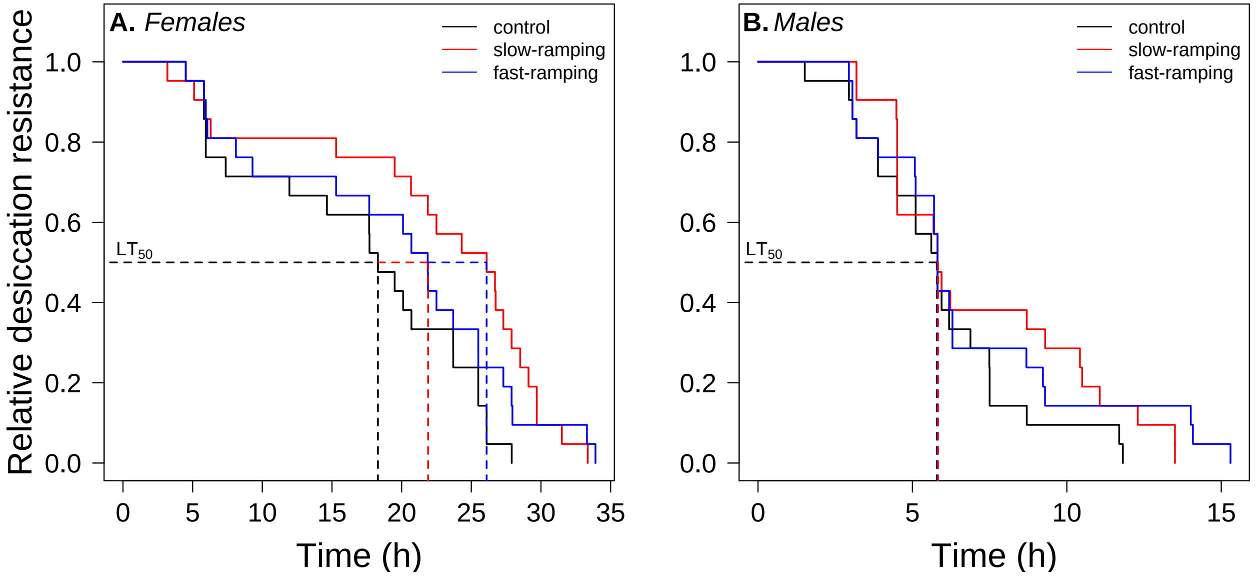
Evolutionary responses of energy metabolism, development, and reproduction to artificial selection for increasing heat tolerance in *Drosophila subobscura*

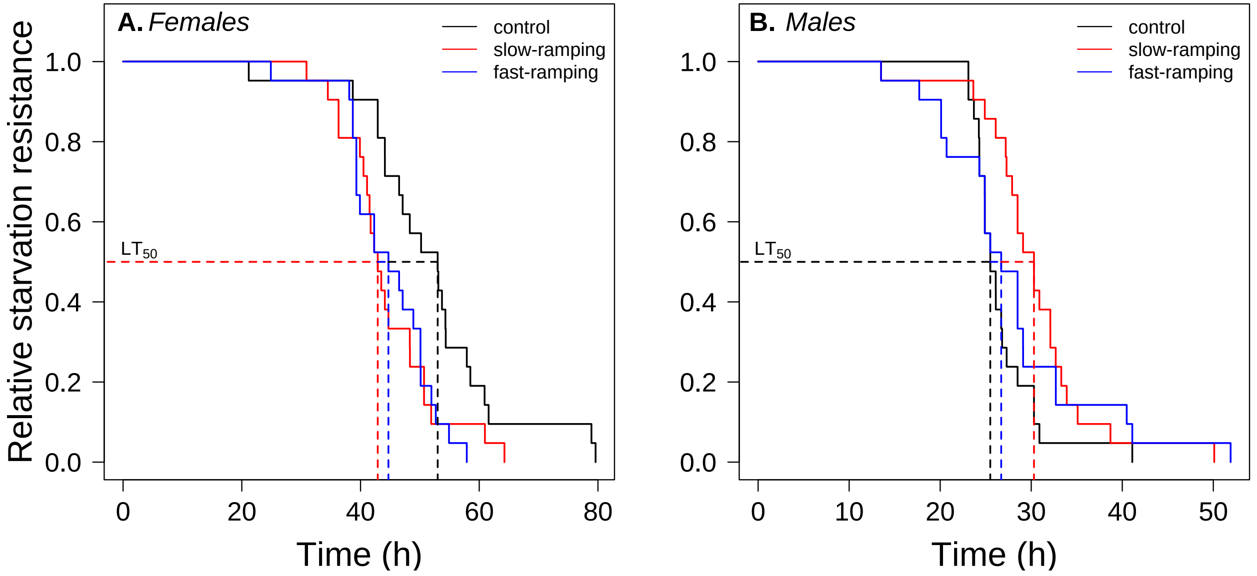
Andrés Mesas[1,2] and Luis E. Castañeda[3,]





Thermal evolution in *Drosophila subobscura*





Evolutionary response of females and males was different:

- Sexual antagonistic selection
- Different rate of resource use

Thermal evolution in *Drosophila subobscura*

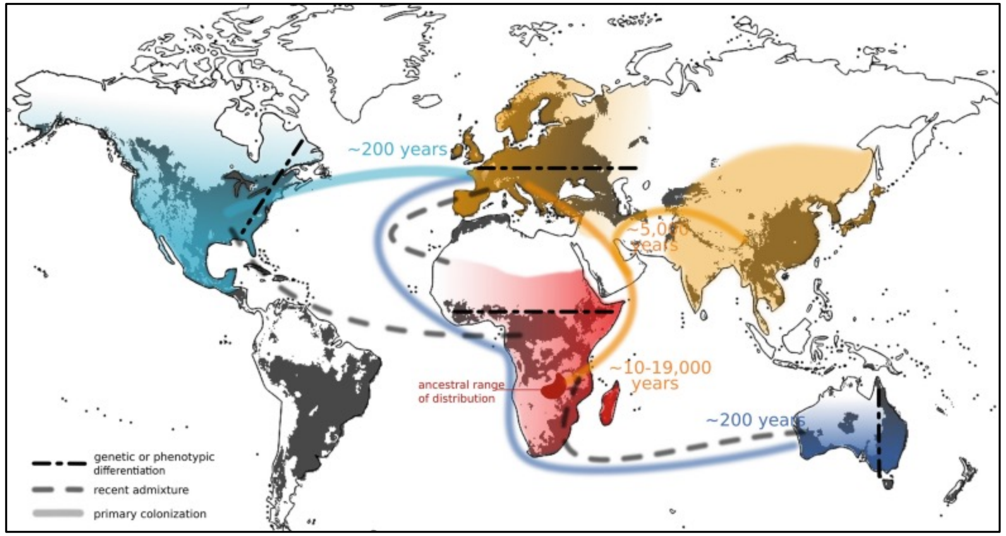
Thermal tolerance has the capacity to evolve under temperature-related selection

Thermal tolerance evolution impacts on other traits because (1) they share the same genetic architecture (e.g., locomotion) and/or (2) they have a functional relationship to energetic level (e.g., fecundity, viability)

Increased thermal tolerance is positively associated to fitness-related traits, which could facilitate the adaptive process in a warming world

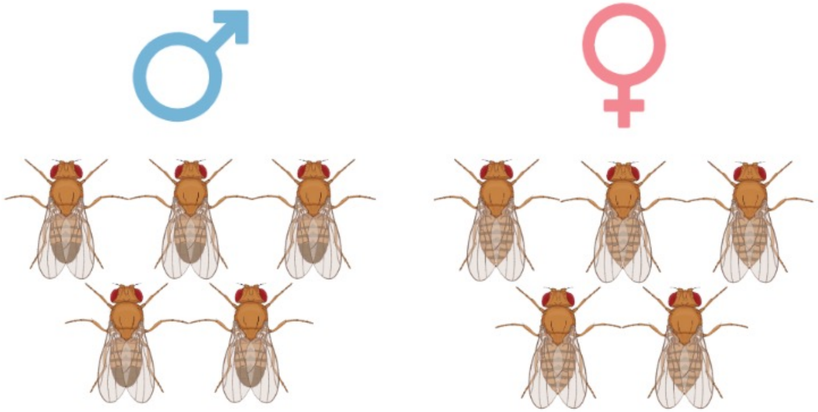
Drosophila melanogaster

Genetics of thermal tolerance in *Drosophila melanogaster*

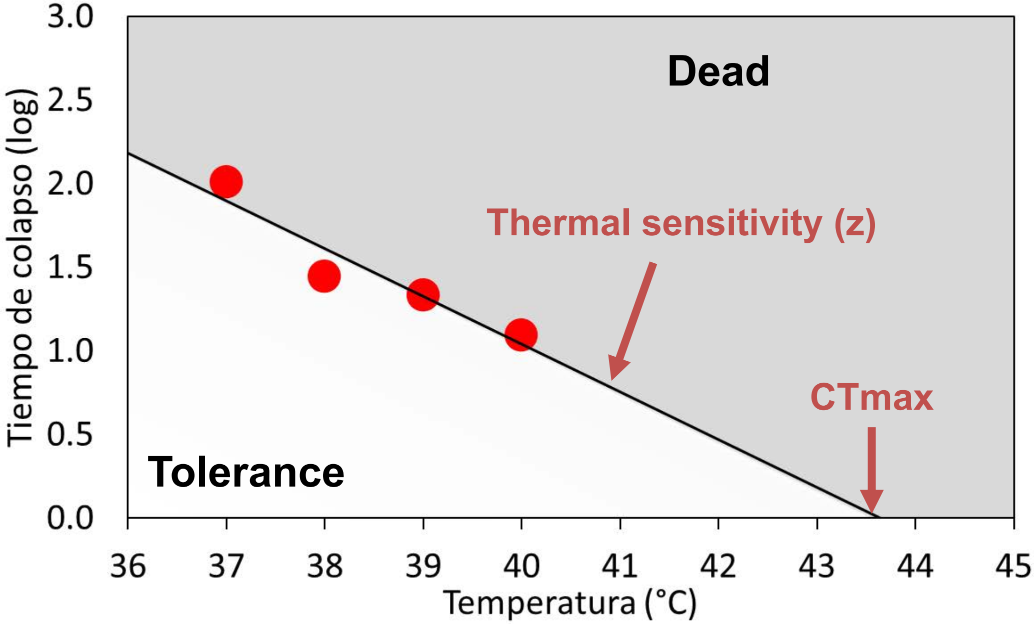


Haudry et al. *Evolution* 2020

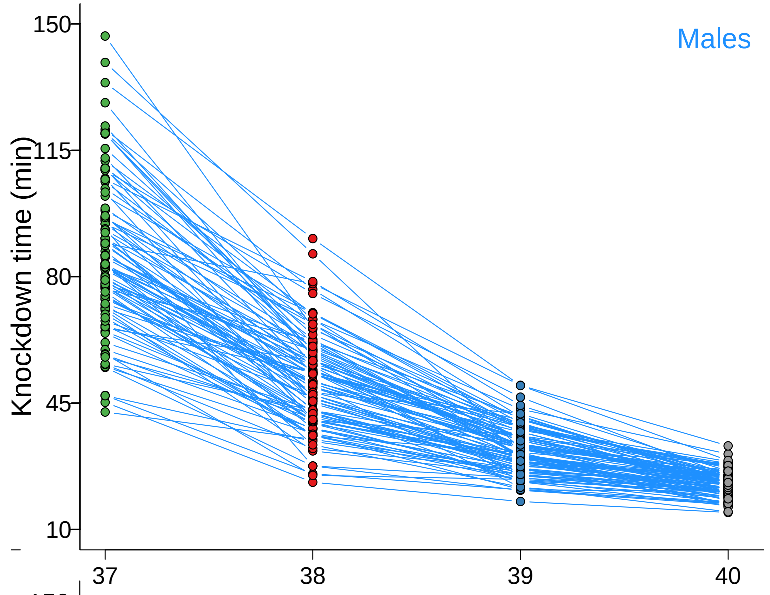
Drosophila Genetic Reference Panel (DGRP)

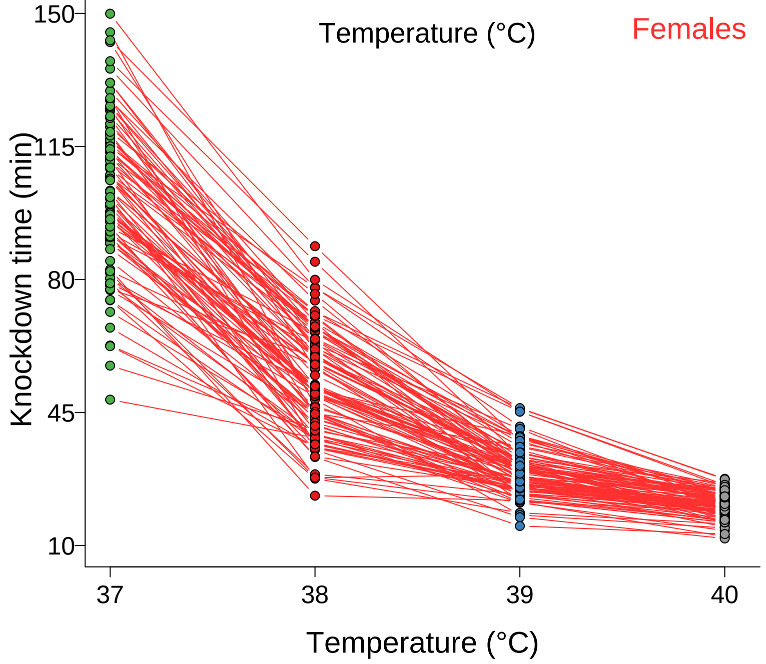


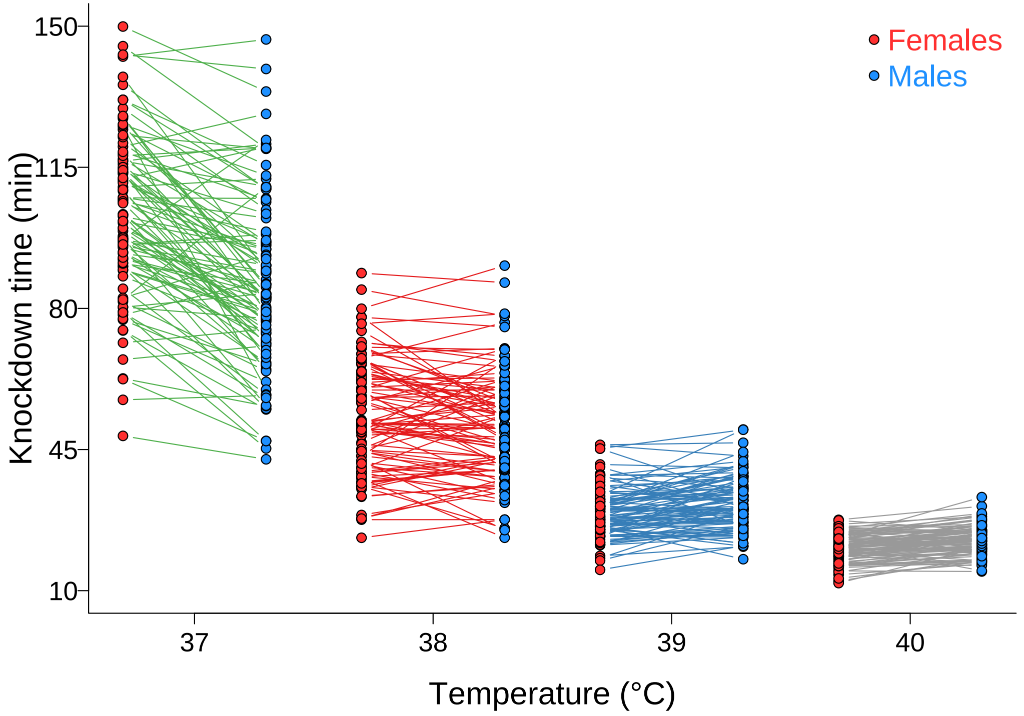
100 genotipos DGRP x 2 sexos x 4 temperaturas
x 5 replicas = 4000 moscas!!



Genetics of thermal tolerance in *Drosophila melanogaster*





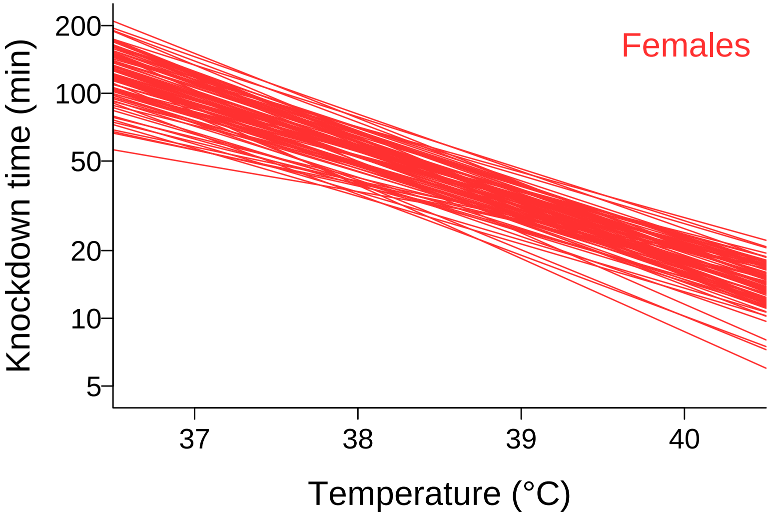


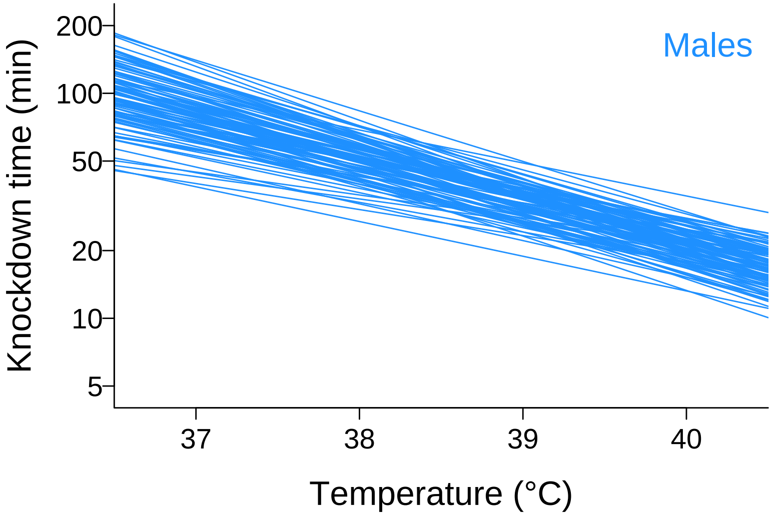
Matriz G

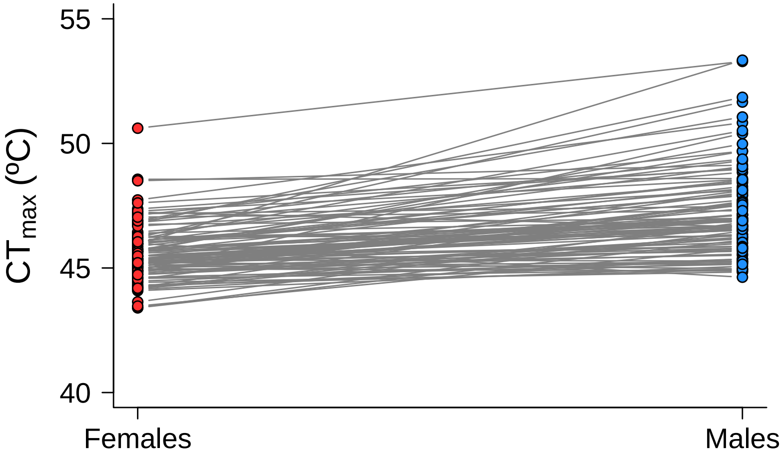
	37ºC	38ºC	39ºC	40ºC
37ºC	0.47			
38ºC	0.82	0.61		
39ºC	0.63	0.83	0.49	
40ºC	0.38	0.62	0.81	0.45

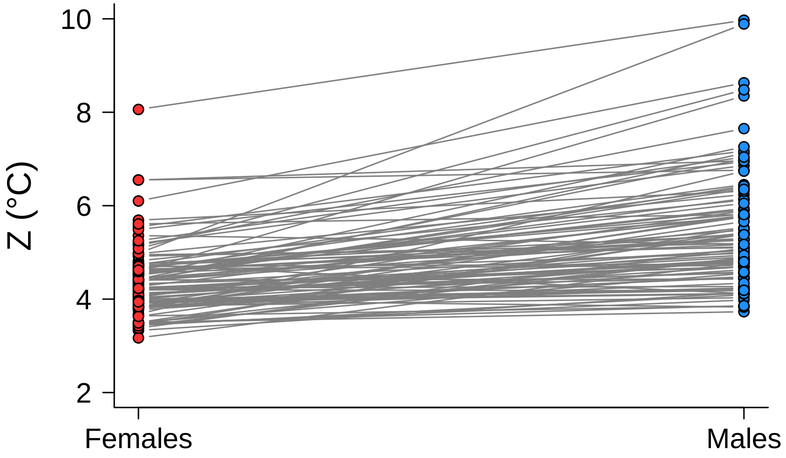
Soto et al. *In preparation*

Genetics of thermal tolerance landscape in *Drosophila melanogaster*





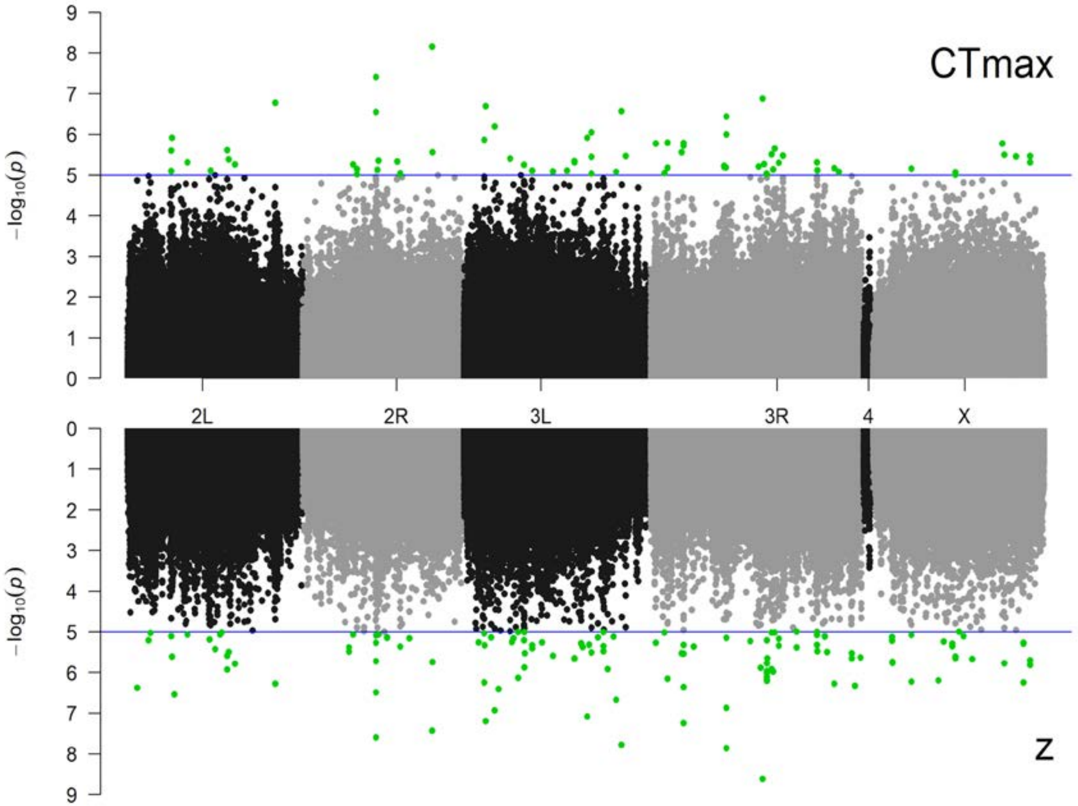


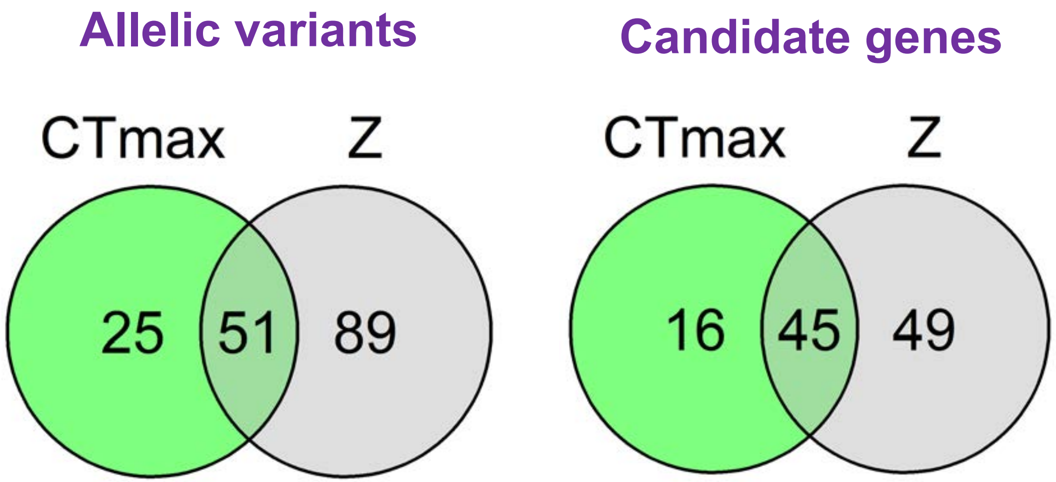


- Genetic variation on CTmax (H^2 = 0.57) and thermal sensitivity (H^2 = 0.60)
- Significant GxS on CTmax and thermal sensitivity (z)

Soto et al. *In preparation*

Genetics of thermal tolerance in *Drosophila melanogaster*



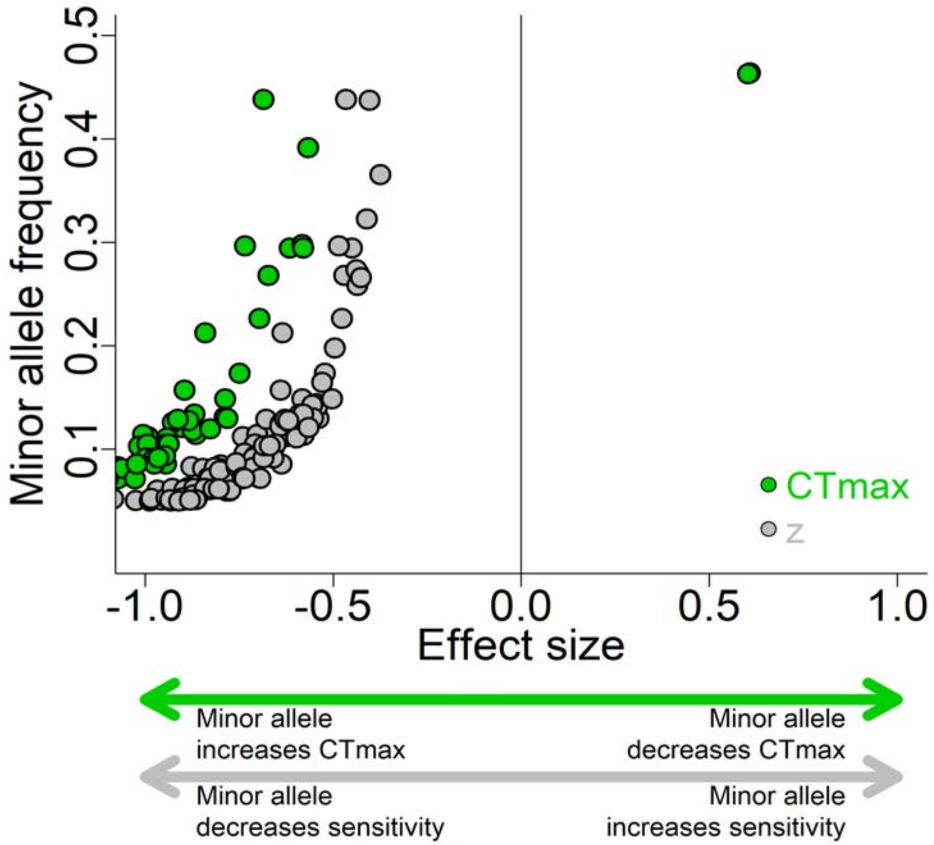


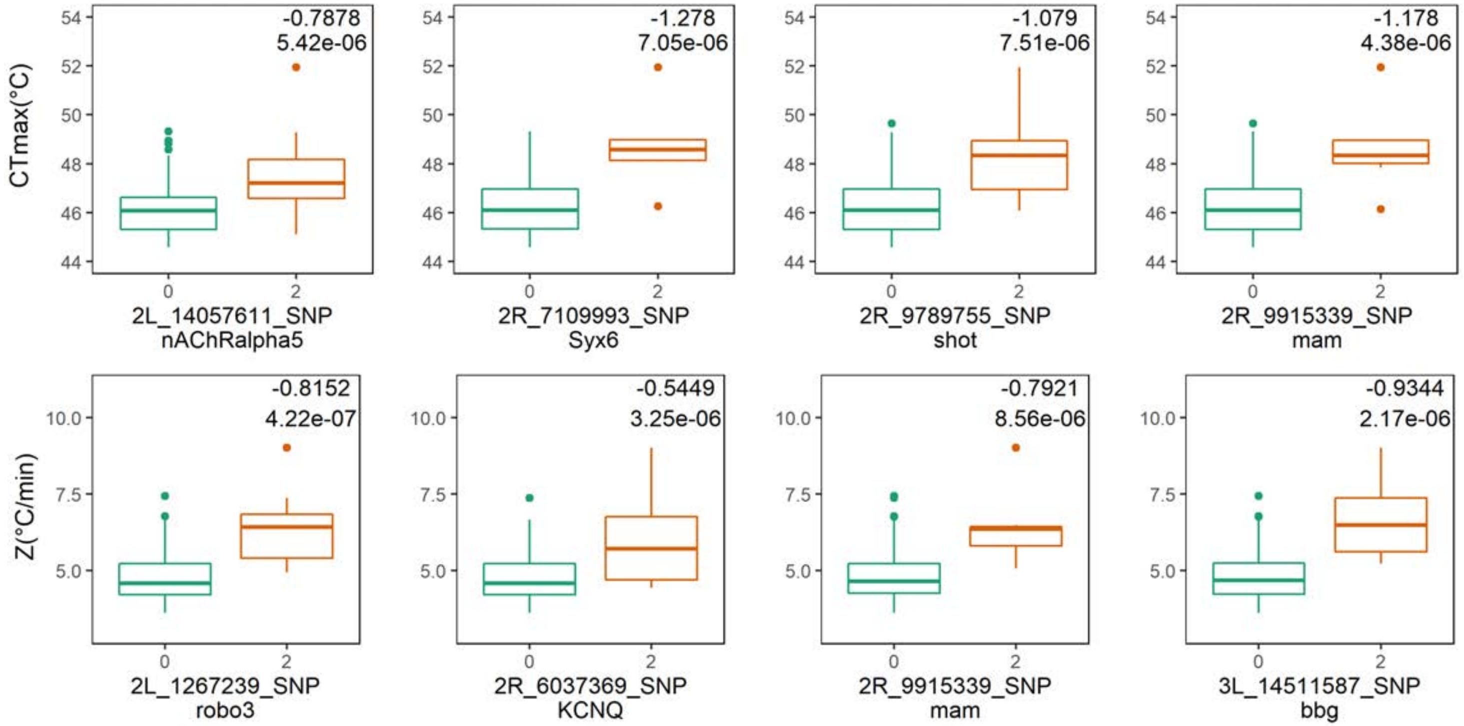
- Many candidate genes related to synapsis processing:
  nAChRalpha5: receptor subunits nicotinic acetylcholine
  fife: neurotransmitter release
  syx6: synaptic vesicles
  cac: presynaptic voltage-gated calcium channels

ID	Gene ontology	Genes	Expected	FDR
Biological processes				
GO:0008587	imaginal disc-derived wing margin morphogenesis	5	0.32	6.79×10^{-2}
GO:0007267	cell-cell signaling	10	1.83	6.62×10^{-2}
Cellular component				
GO:0030054	cell junction	12	2.7	7.88×10^{-3}
GO:0005886	plasma membrane	25	8.64	5.08×10^{-4}

Soto et al. *In preparation*

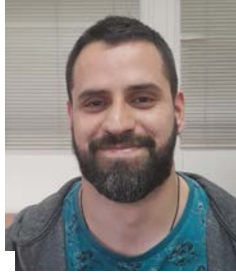
Genetics of thermal tolerance in *Drosophila melanogaster*





- Alleles with a high effect increasing CTmax are in low frequency in the DGRP.

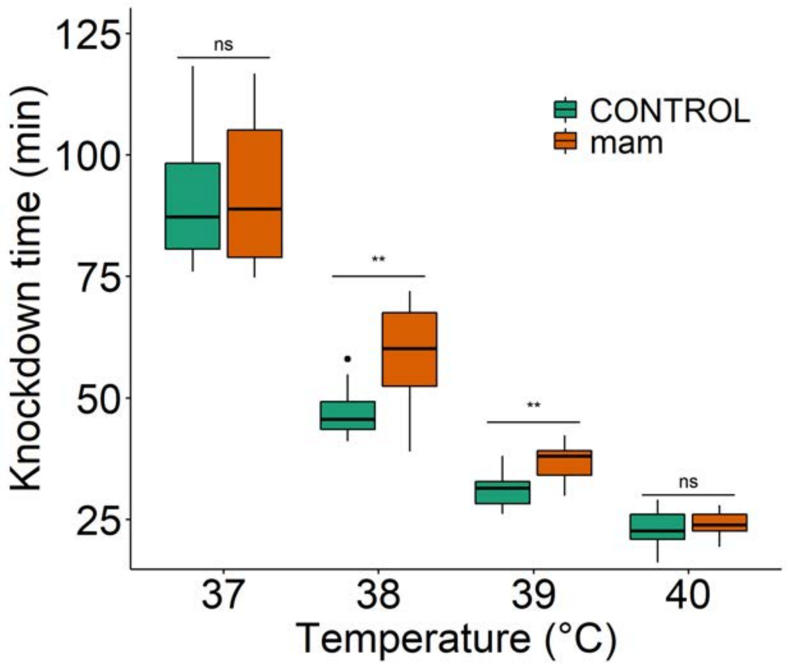
Genetics of thermal tolerance in *Drosophila melanogaster*

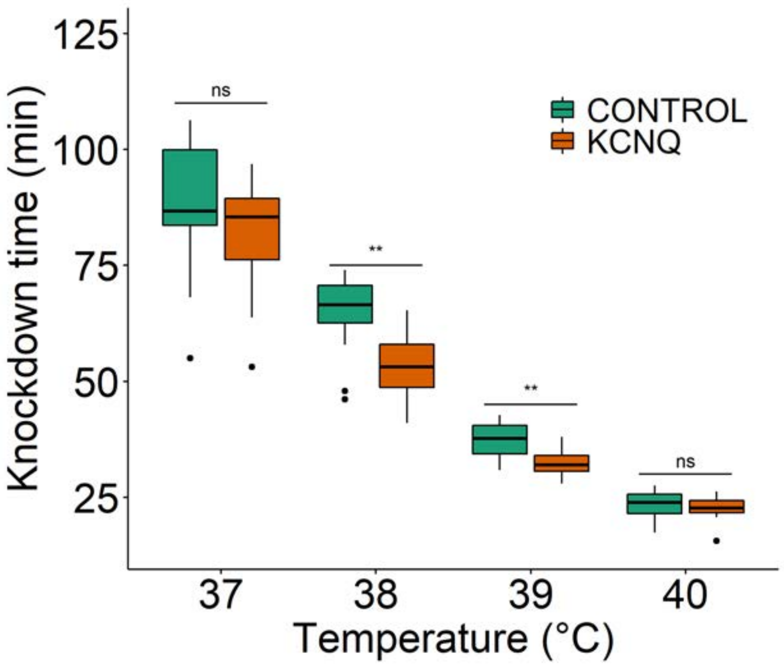


Functional assays

Whole body knockdown
(Tub-GAL4 driver)

Control





Soto et al. *In preparation*

- 25% of candidate genes show latitudinal variation reported in previous studies:
  East US: *ip63E*, *Ino80* and *MCO3*, *egg*
  Europe: *mam*, *MCO3*, *corn* and *sug*
- Temporal variation between summer and auttum: *sgg*, *Eip74EF*, *tei*, *cac*, CG7737 and CG34354

Genetics of thermal tolerance in *Drosophila melanogaster*

Thermal tolerance has the capacity to evolve under temperature-related selection

The thermal tolerance landscape exhibits phenotypic plasticity, which should contribute to the adaptation to global warming

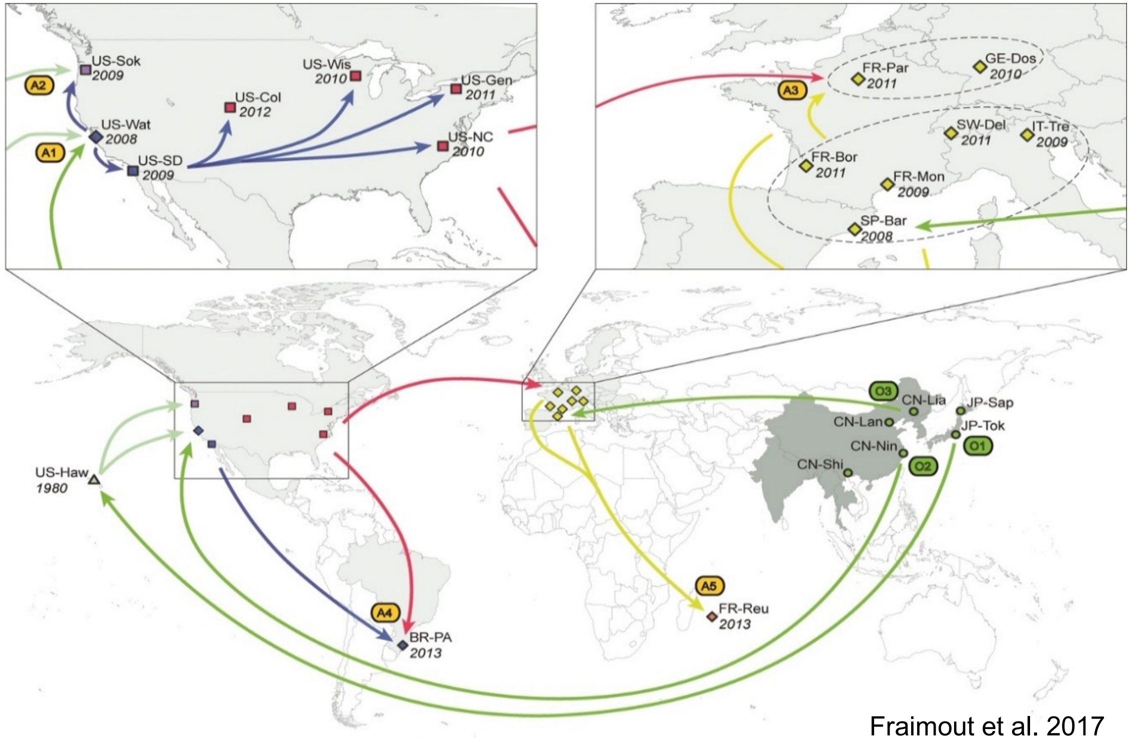
Genotype-by-environment and genotype-by-sex interactions could contribute to the maintenance of genetic populations under thermal selection

Candidate genes associated with the thermal tolerance landscape could be under selection in natural populations

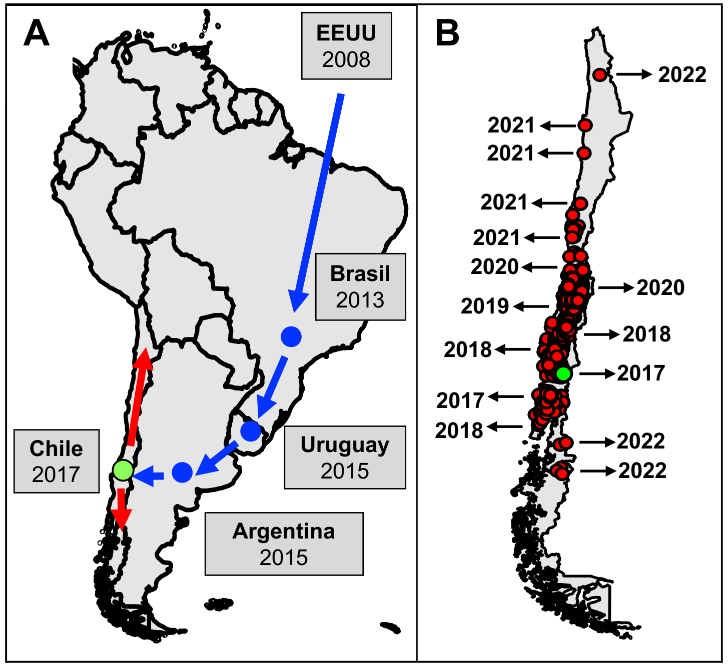
Drosophila suzukii

Invasion of *Drosophila suzukii* in Chile

The spotted wing Drosophila has an important impact on berries production in the world.



Fraimout et al. 2017



Invasion in North America and Europe has been well studied, but information in South America is missing.

Invasion of *Drosophila suzukii* in Chile

Genetic variation at mitochondrial level (COI)

Population	samples size	Haplotypes	Diversity	Polymorphic sites	Range
Chile	58	4	0,591	7	Invasive
Argentina	22	4	0,710	7	Invasive
Brasil	91	5	0,760	7	Invasive
USA	60	6	0,766	9	Invasive
Canadá	26	4	0,578	8	Invasive
Europa	16	6	0,850	8	Invasive
China	32	14	0,877	13	Native
Japón	35	18	0,913	18	Native
Corea del Sur	159	58	0,942	39	Native

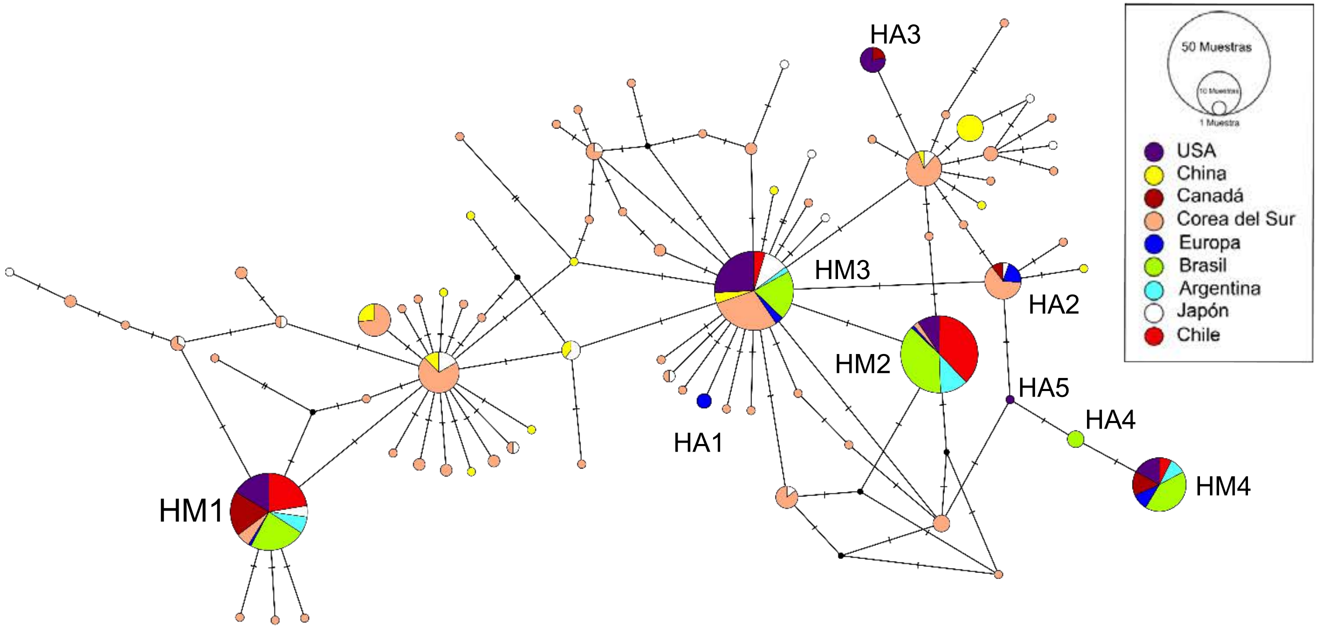
Invasive populations show a low number of haplotypes, low genetic diversity and reduced genetic polymorphism

Invasion of *Drosophila suzukii* in Chile

Genetic differentiation at mitochondrial level (COI)

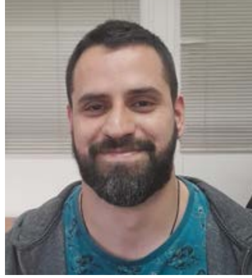
	Argentina	Brasil	USA	Canadá	Europa	Japón	Corea del Sur	China
Corea del Sur								0.049*
Japón							0.005	0.058*
Europa						0.058*	0.050*	0.115*
Canadá					0.203*	0.189*	0.190*	0.267*
USA				0.171*	0.082*	0.042*	0.076*	0.140*
Brasil			0.051*	0.172*	0.091*	0.100*	0.107*	0.166*
Argentina		-0.011	0.097*	0.187*	0.129*	0.137*	0.133*	0.193*
Chile	-0.007	0.047*	0.170*	0.256*	0.241*	0.215*	0.193*	0.273*

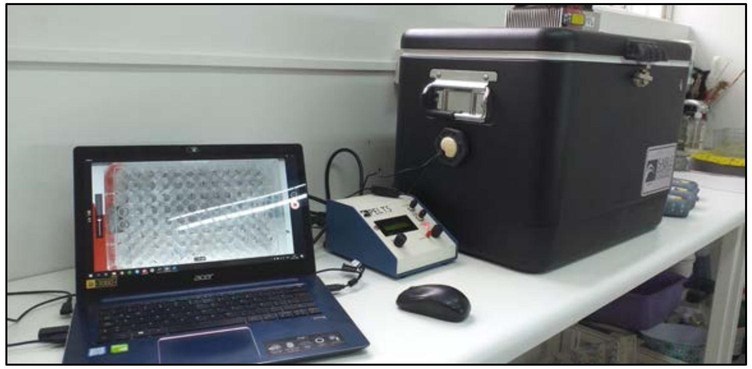
FST: 1.00, 0.75, 0.50, 0.25, 0.00

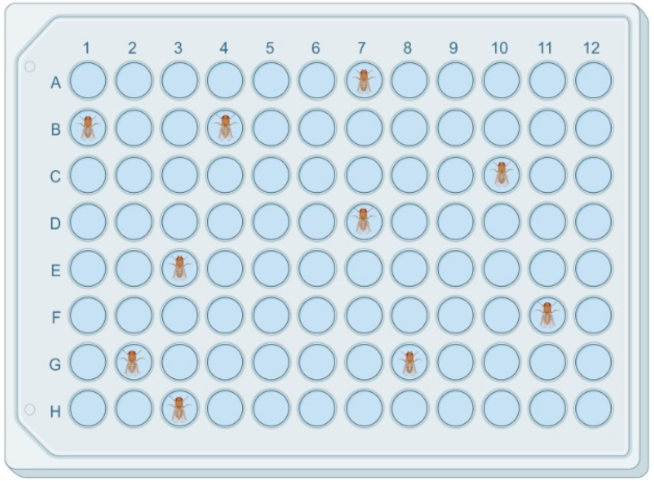


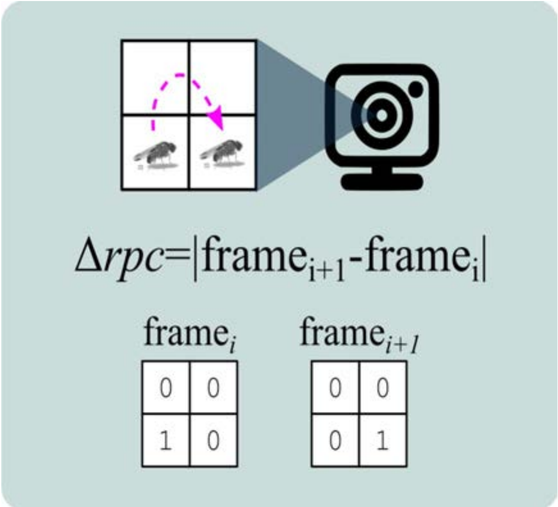
Chilean populations has the most common haplotypes and is show a low differentiation with Argentinean populations.

Thermal tolerance of *Drosophila suzukii*

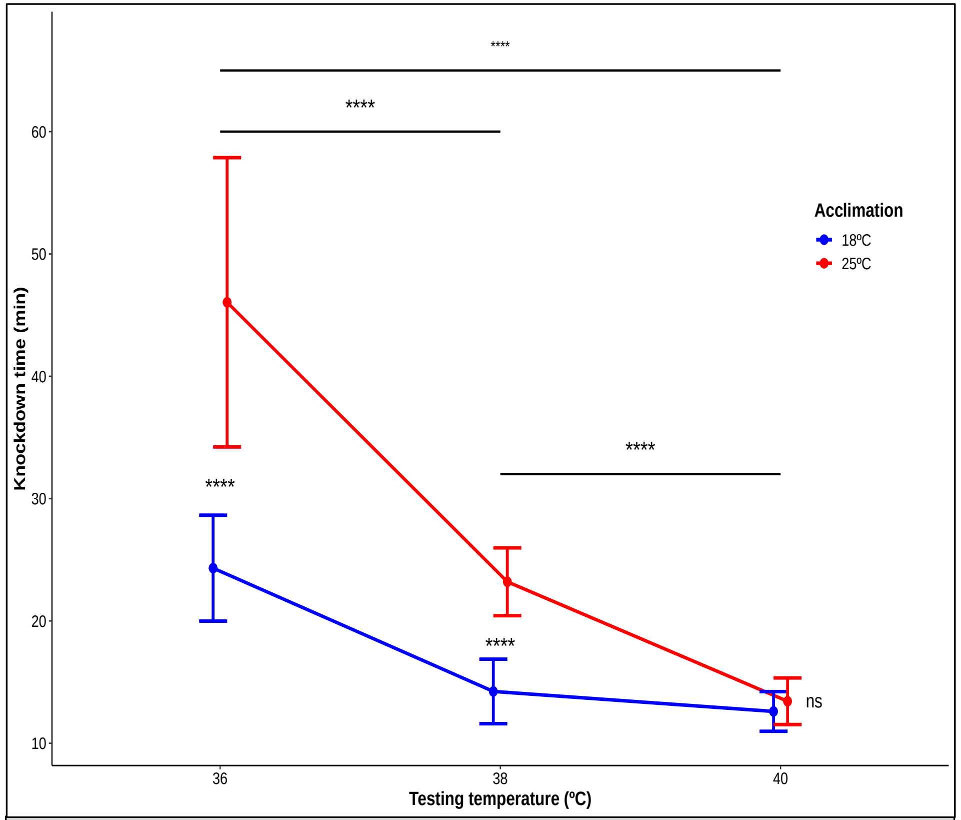




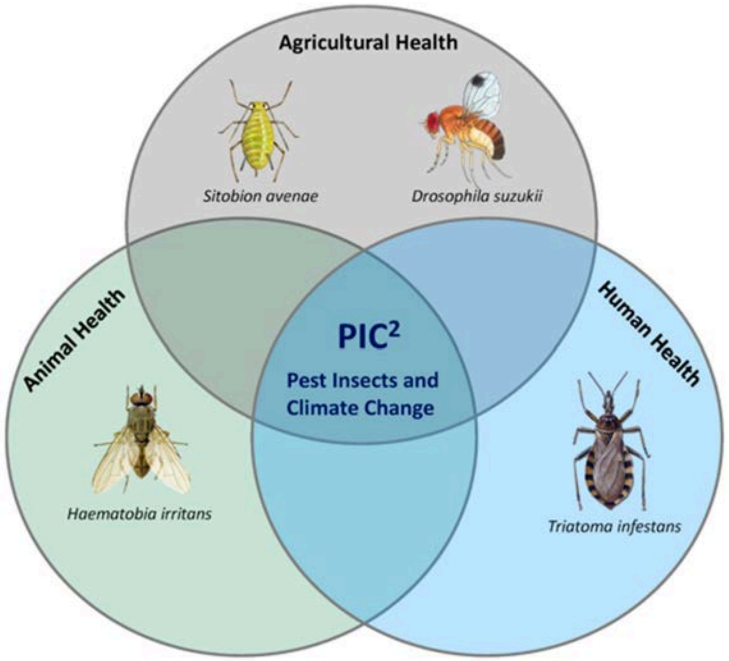




Awde D et al. 2020. Journal of Visualized Experiments



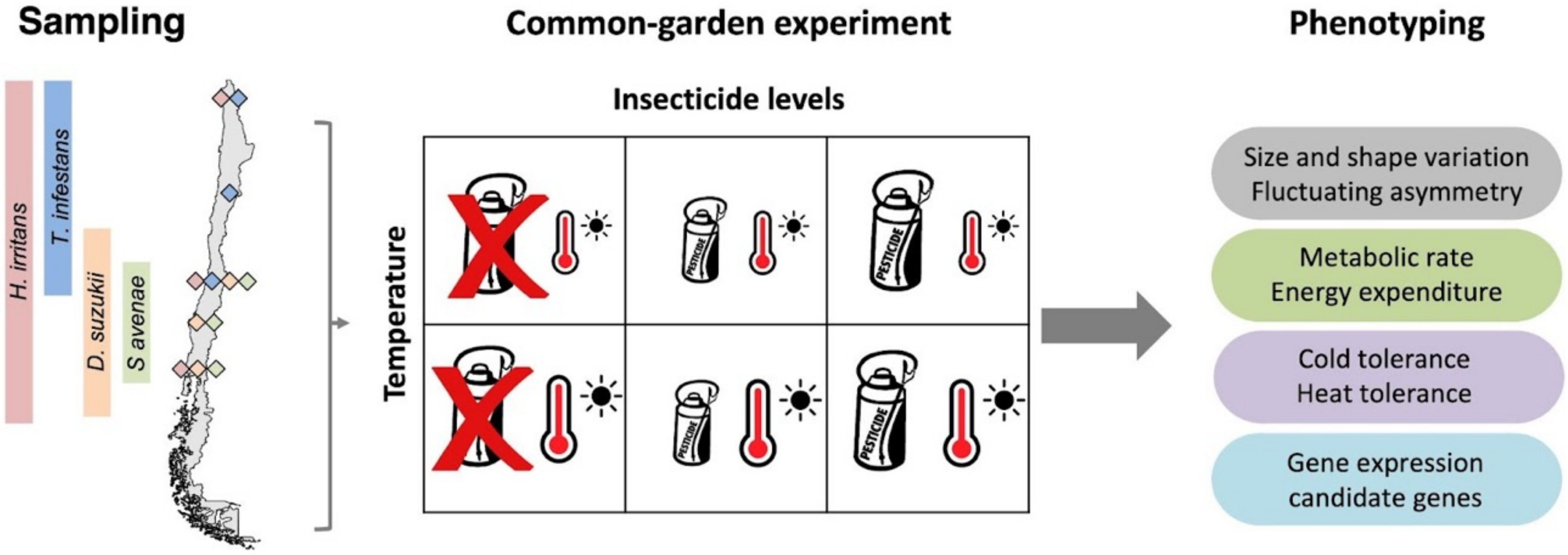
Research Ring in Pest Insects and Climate Change (PIC^2)



MAIN GOAL

to investigate the genetic, phenotypic, and ecological bases explaining the redistribution and adaptations in response to temperature and management practices in pest insects relevant to food security and public health.

Research Ring in Pest Insects and Climate Change (PIC^2)



Whole-genome sequencing

Metabarcoding

Invasion of *Drosophila suzukii* in Chile

Recent introduction and rapid geographic expansion

Reduced genetic diversity

Phenotypic plasticity in physiological traits as thermal tolerance

Next steps include to investigate the contribution of local adaptation and phenotypic level to the rapid spreading and establishment of this invasive range in a extensive geographic/climatic range in Chile

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ICBM
INSTITUTO DE CIENCIAS BIOMÉDICAS

Integrative Biology Lab

- Under and Postgraduate students
- Postdocts (Anillo + FONDECYT)

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