Ecological discontinuity packages genes into discrete units of diversity

Romain Villoutreix

Romain.villoutreix@gmail.com

Authors

Romain Villoutreix

Clarissa Ferreira de Carvalho

Jeff Feder

Zach Gompert

Patrik Nosil

cnrs

erc

Centre d'Ecologie Fonctionnelle & Evolutive

UNIFESP
Universidade Federal de São Paulo
1933

University of Notre Dame

Utah State University

Continuous vs discrete variation

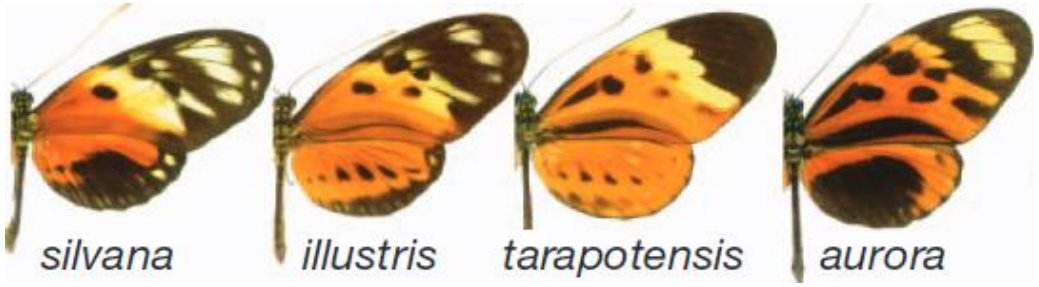
Continuous variation

Arctia plantaginis

From Carita *et al.,* 2011, Behavioral Ecology.

Discrete variation

Heliconius numata



From Joron *et al.,* 2011, Nature.

Discrete morphs have fascinated biologists for a long time

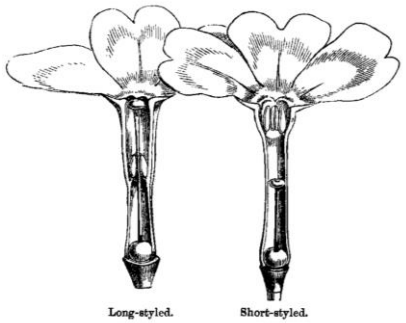
Charles Darwin

Gregor Mendel

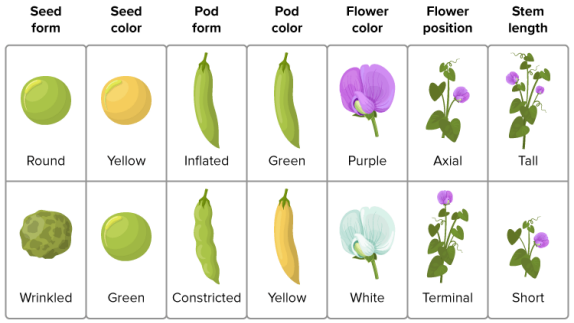
Ronald Aylmer Fisher

Edmund Brisco Ford

Primula sp.



Pisum sativum

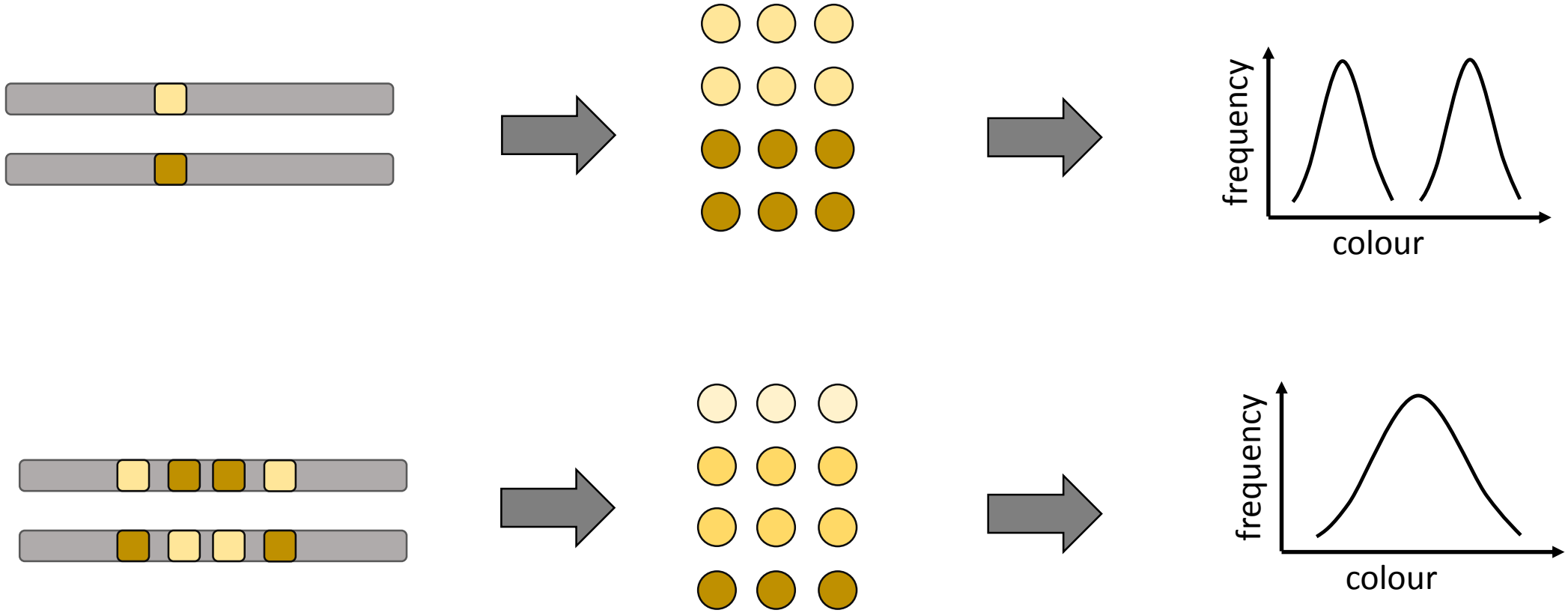


Cepea nemoralis

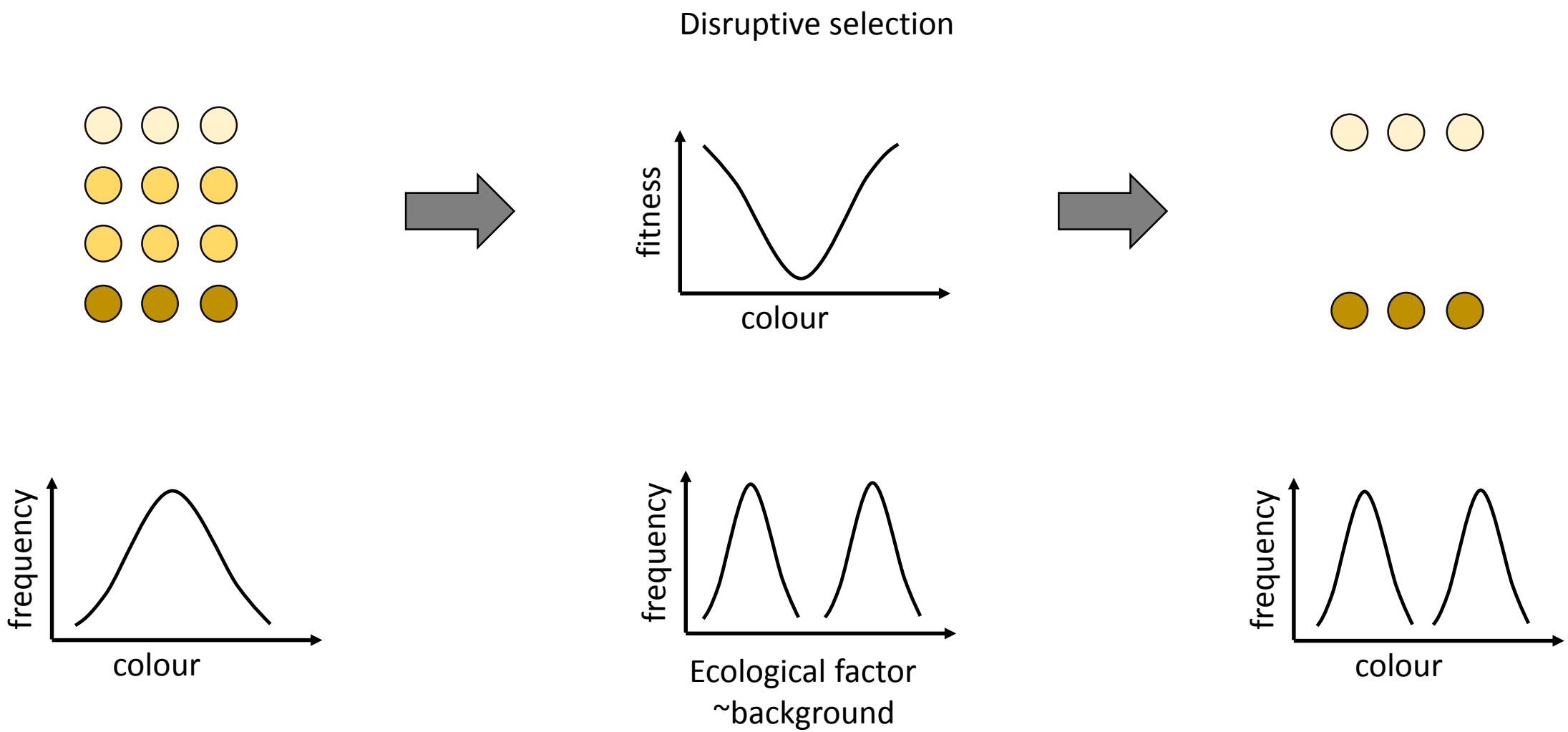
Callimorpha dominula

Continuous vs discrete variation: genetic factors

Number of loci

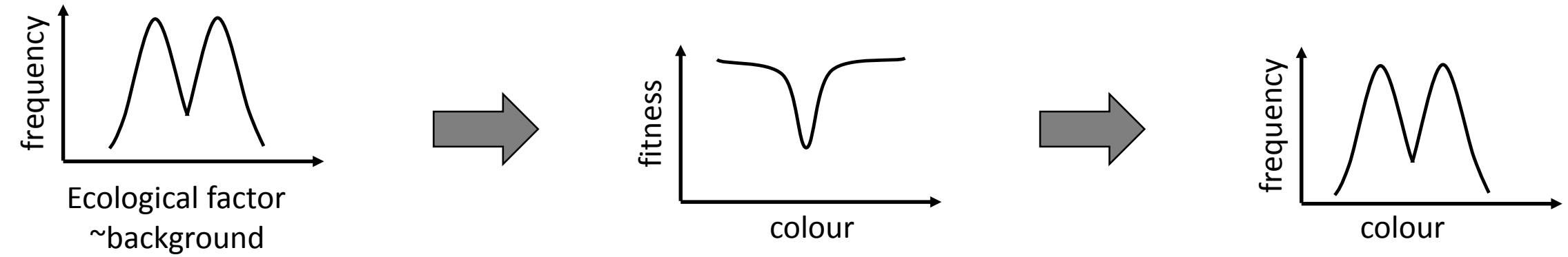


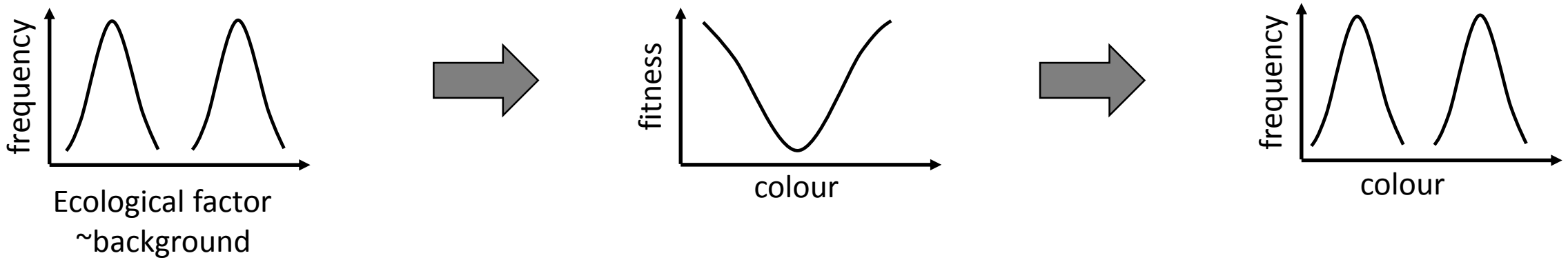
Continuous vs discrete variation: ecological discontinuity



Continuous vs discrete variation: ecological discontinuity

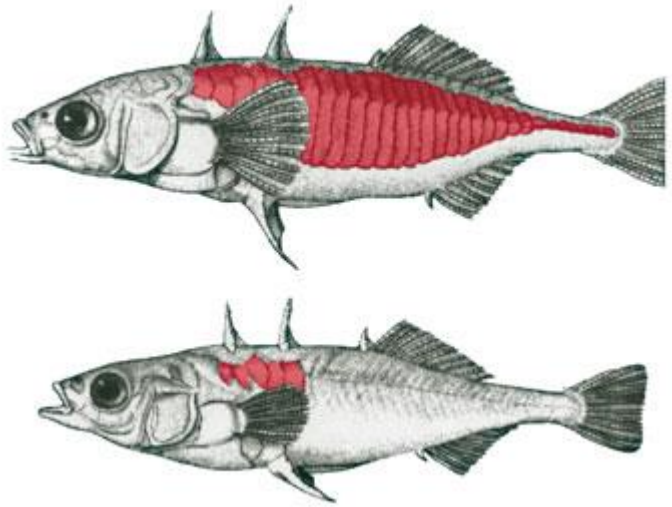
Expectations



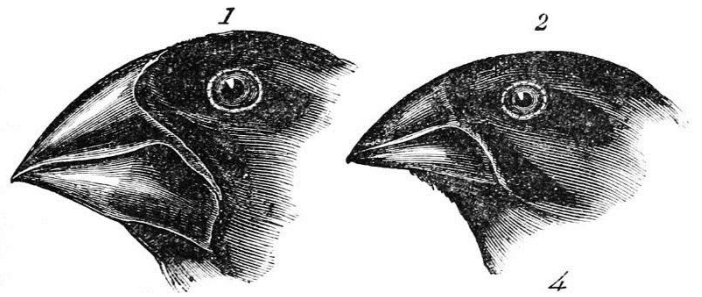


Ecological discontinuity and disruptive selection

Peromyscus sp.



Gasterosteus aculeatus



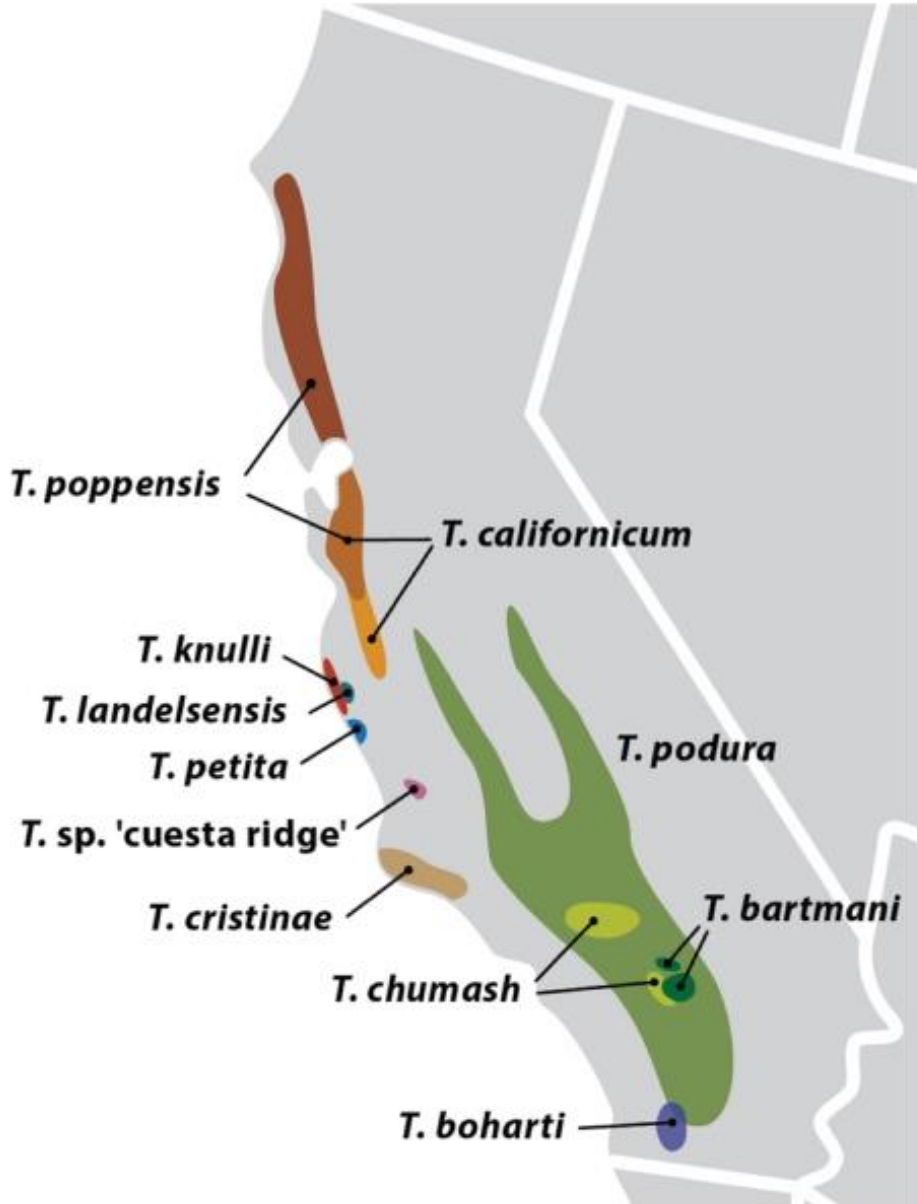
Geospiza sp.

Ecological factor sometimes unknown

(Disruptive) selection inferred rather than estimated

→ A single level of ecological discontinuity studied


M. Muschick photo



11 sexual species (root ~ 30Mya)

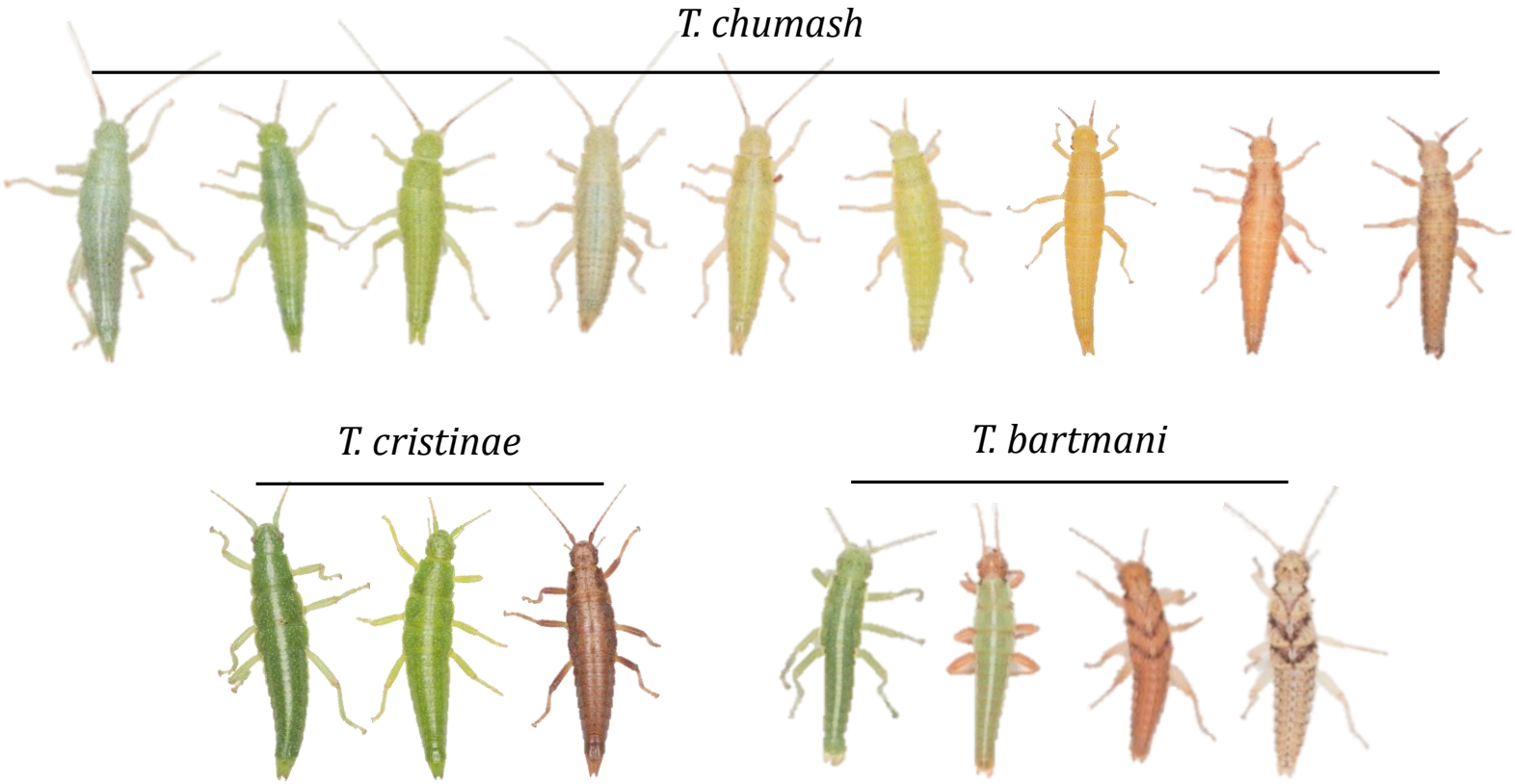
Coastal

Chaparral

Alpine


M. Muschick photo

Body colouration in *Timema* sp.

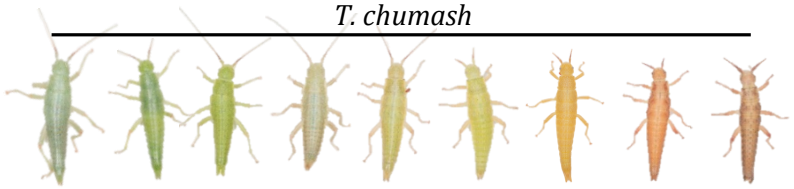


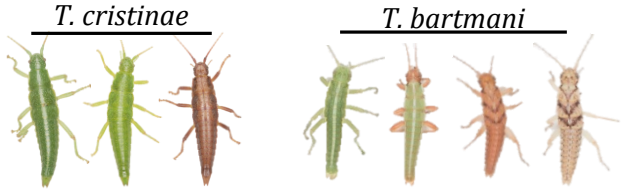
Genetically encoded (Villoutreix *et al.* Science 2020)

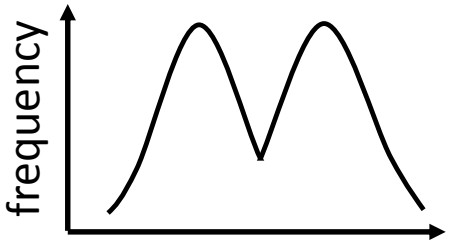
Different degrees of discontinuity, but never formally quantified

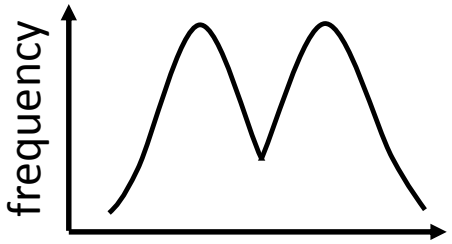
We never quantified host plant colouration (leaves vs stems)

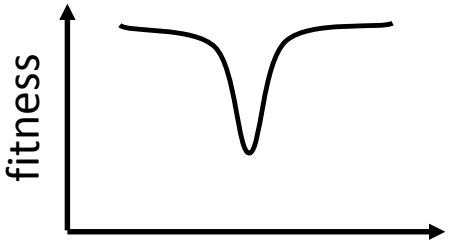
Expectations in *Timema* sp.

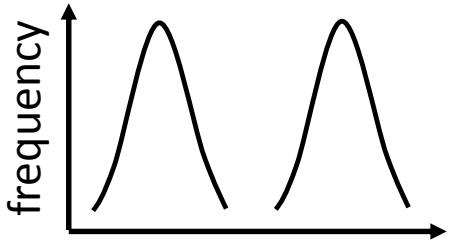


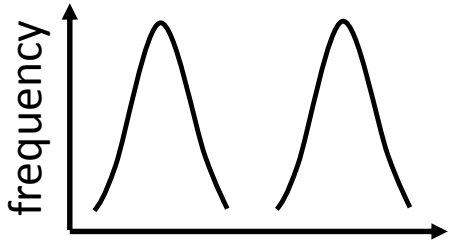


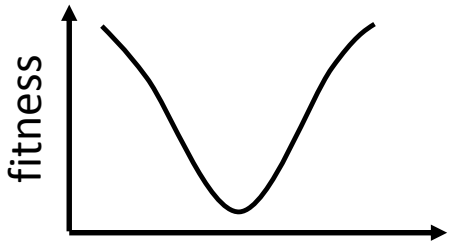




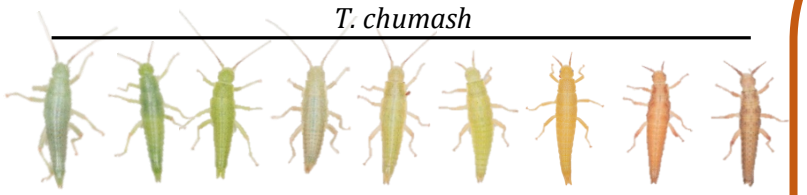


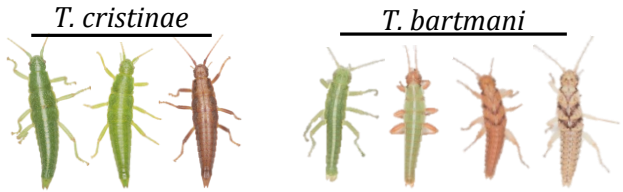


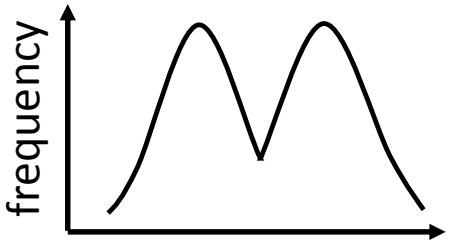


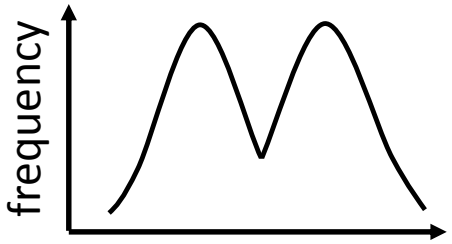


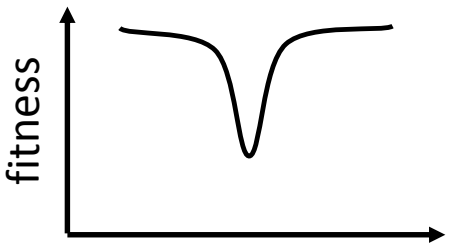
Expectations in *Timema* sp.

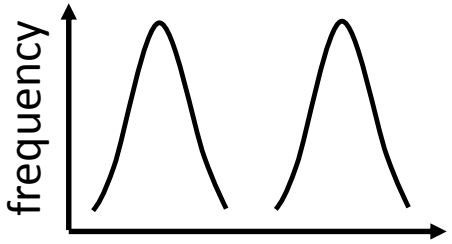


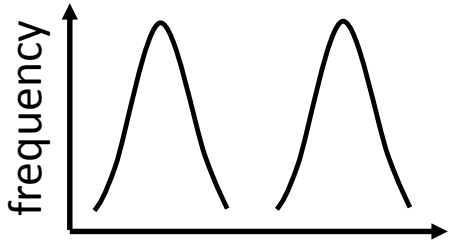


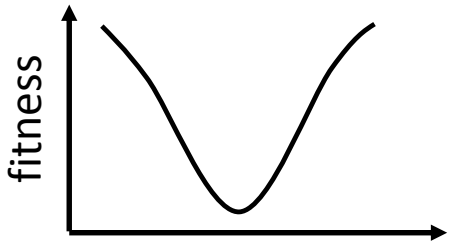








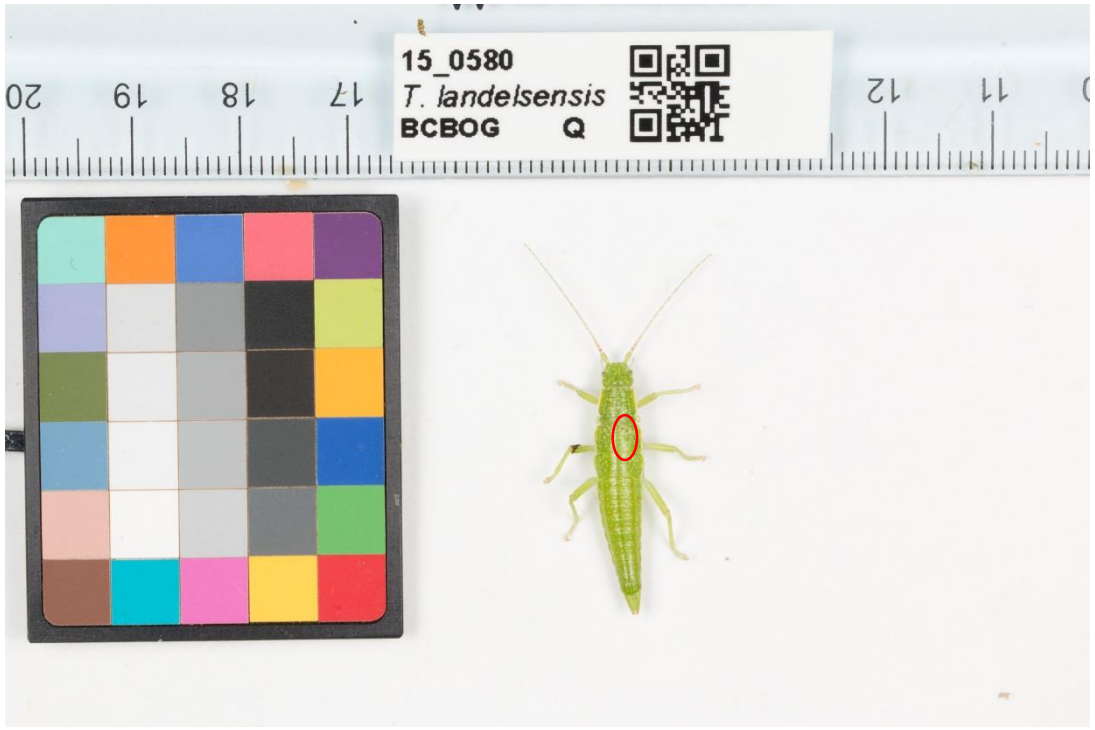




Sampling of *Timema* natural populations

Sampling of natural populations in 2015, plus previous sampling in 2013 (3 populations, 881 insects, 3 species)

Quantification of colour in *Timema* sp.

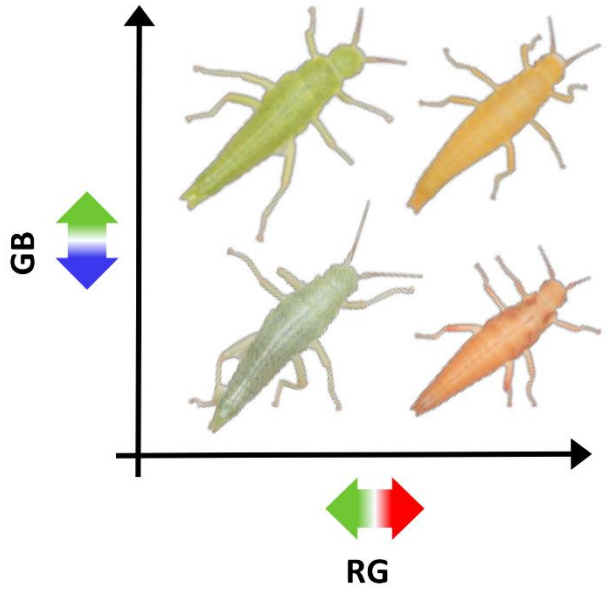


Standardized pictures

Amount of red, green and blue

Quantification of colour in *Timema* sp.

(b) RG - GB color space

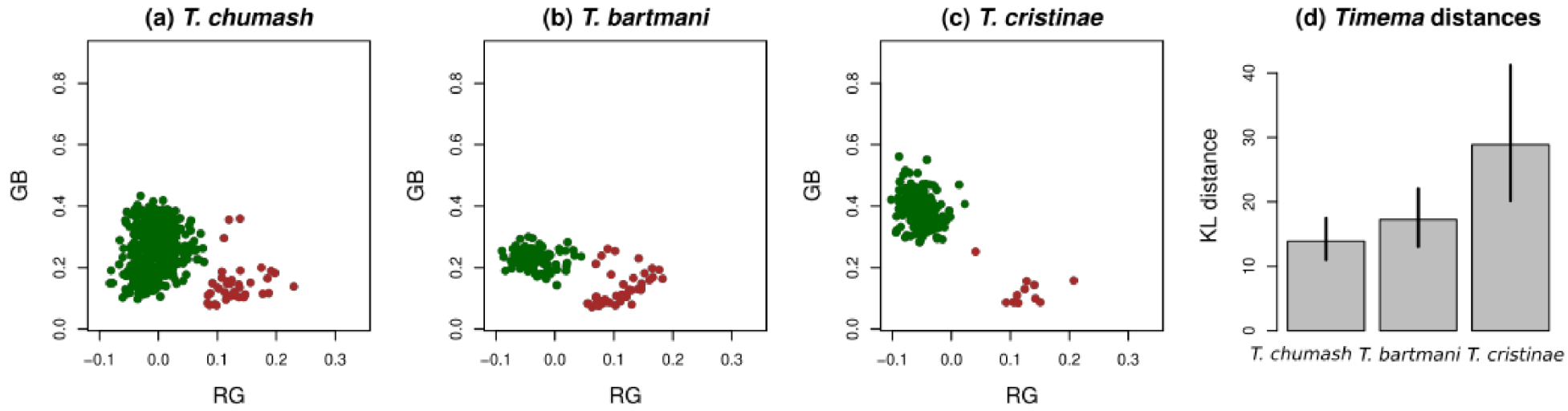


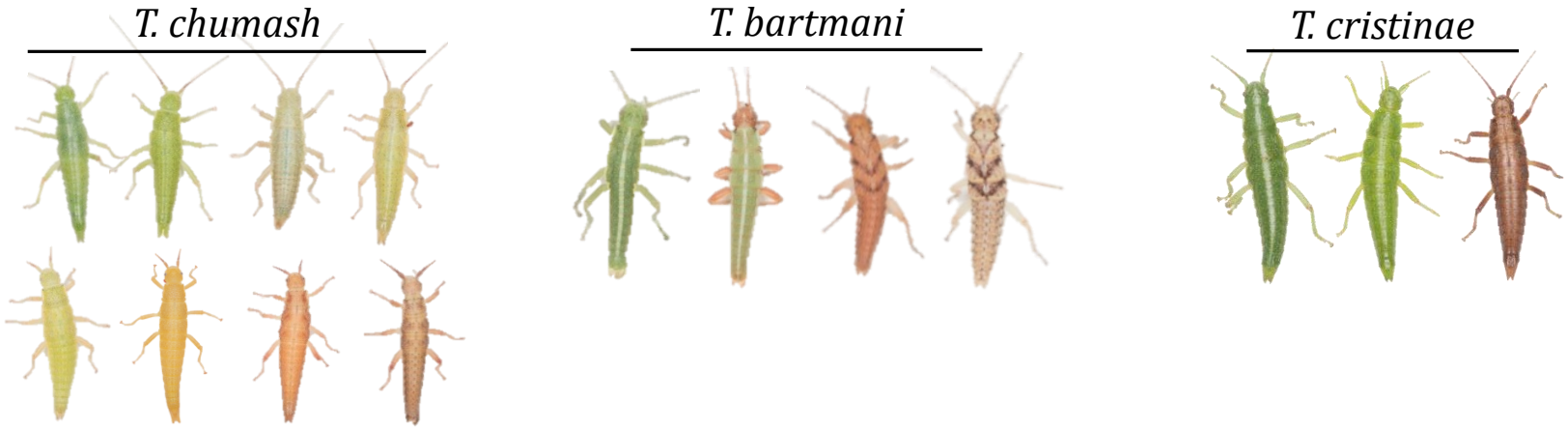
Standardized pictures

Amount of red, green and blue colour

Colour space: Red/Green (RG) and Green/Blue (GB) ratios (Endler, 2012)

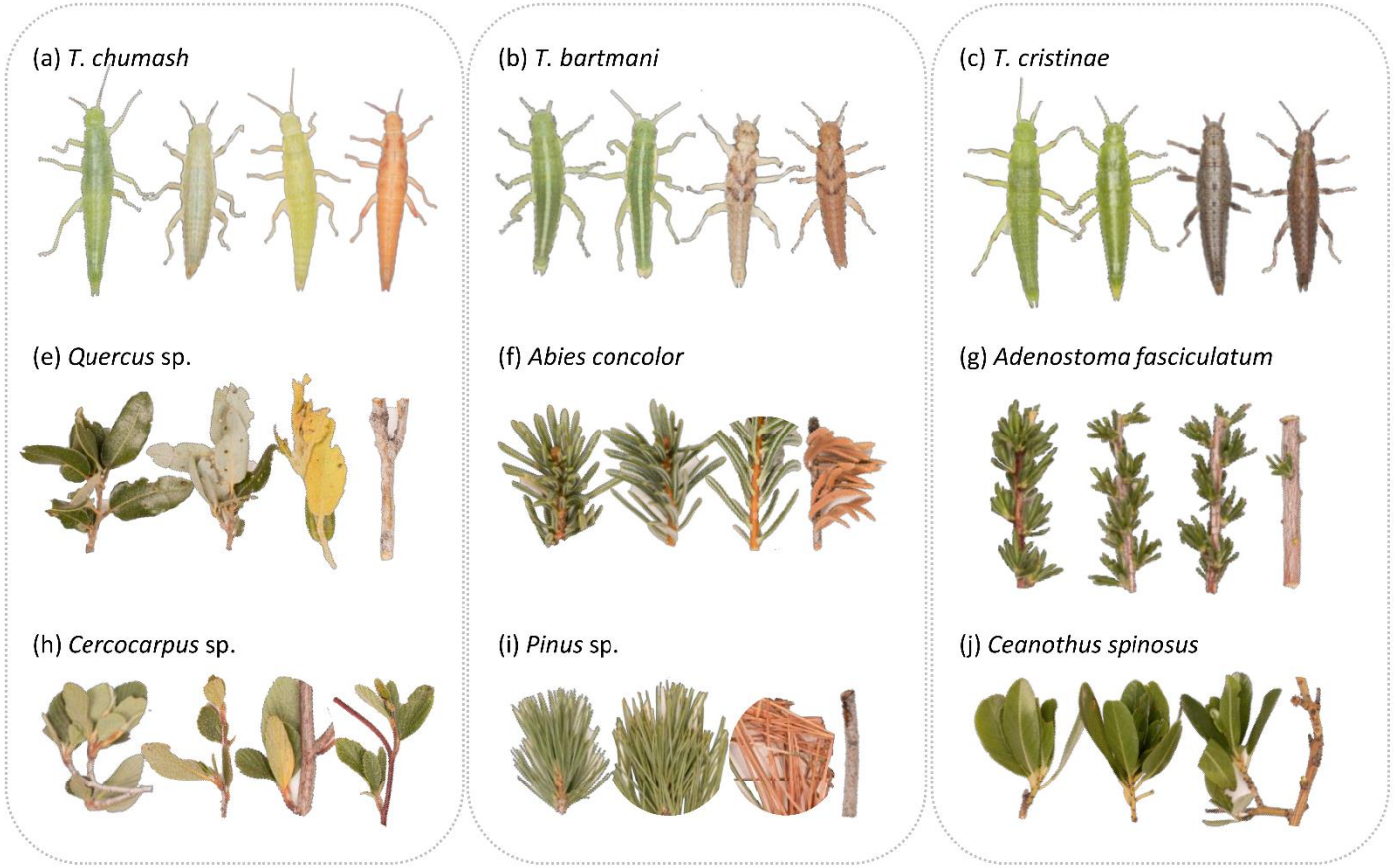
Colour morphs are less discontinuous in *T. chumash*





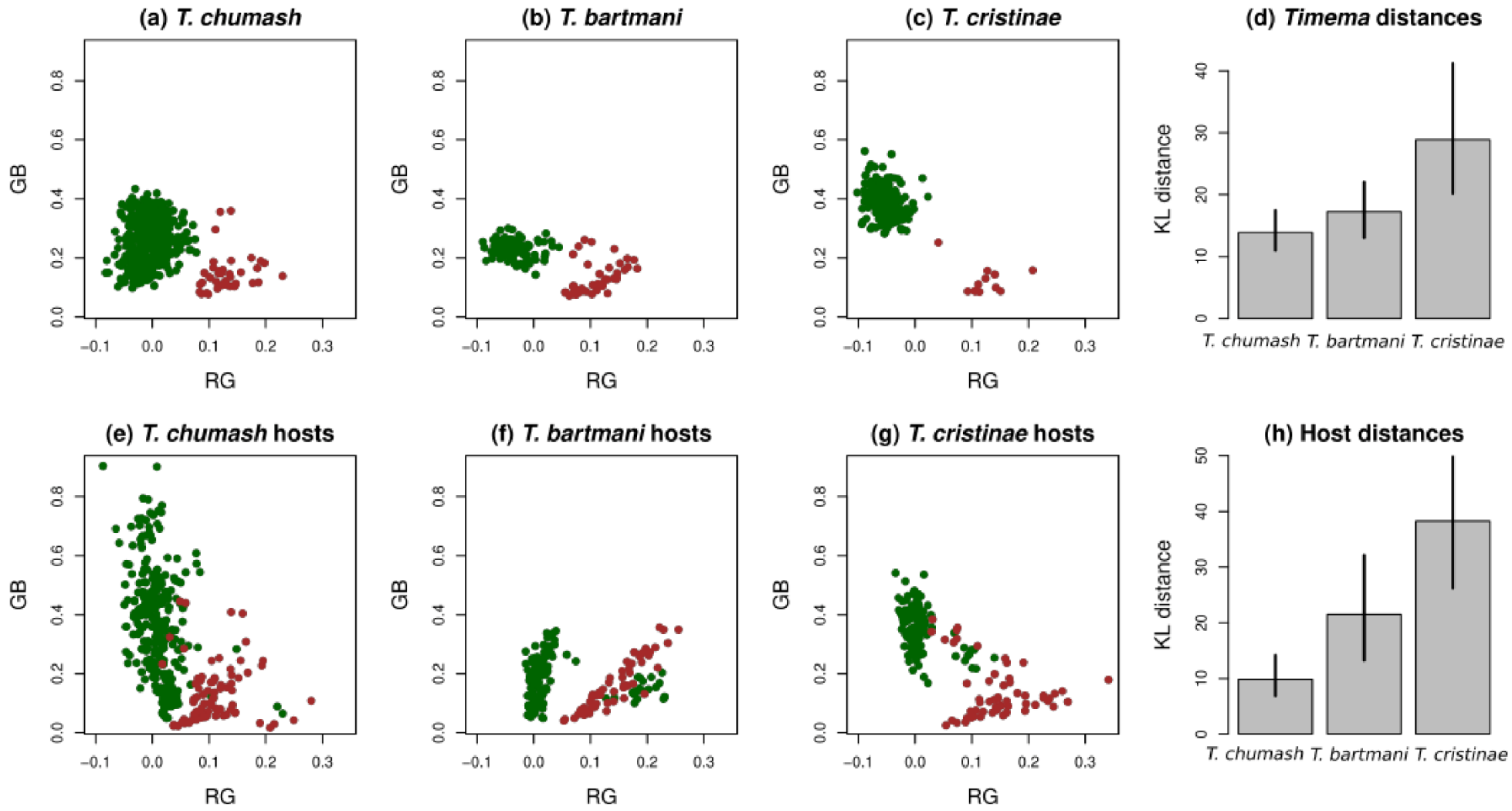
Are *T. chumash's* host plants less differentiated in colour than *T. barmani's* and *T. cristinae's* ?

Quantification of host plants colour

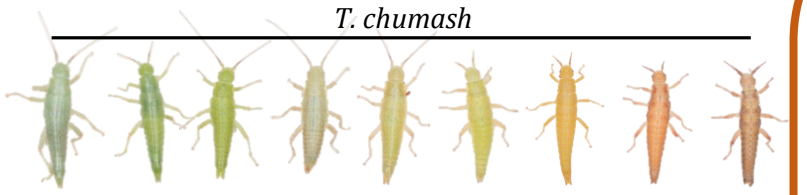


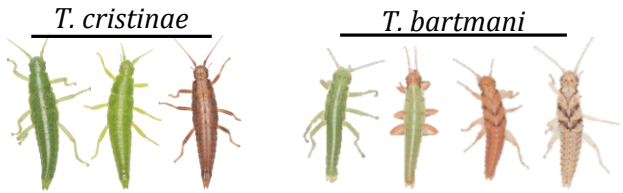
Approach similar to *Timema* for quantifying the colour of host plants (6 species, 203 samples, 781 measurements, both leaves and stems)

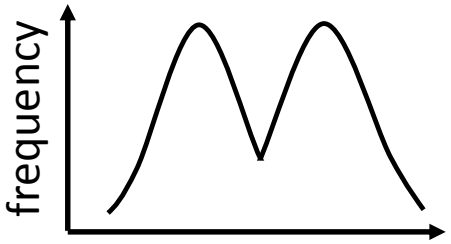
T. chumash's hosts are less discontinuous

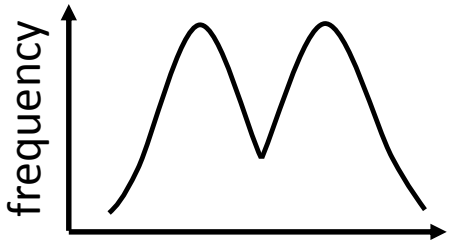


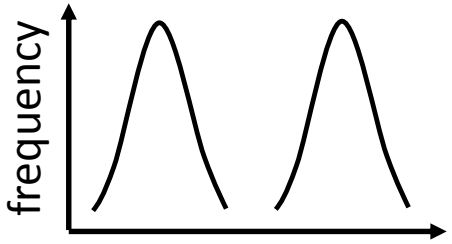
Expectations in *Timema* sp.

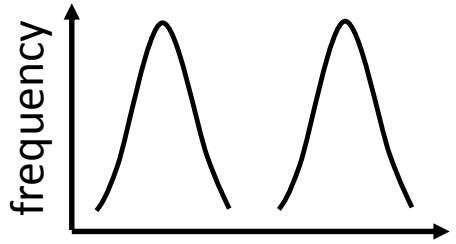


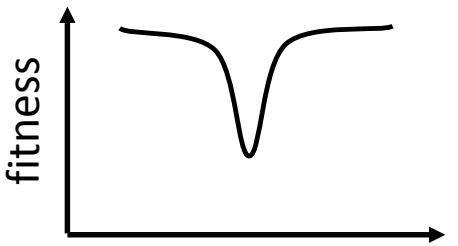


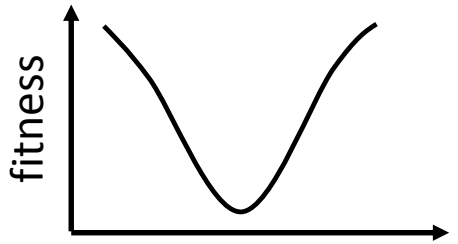






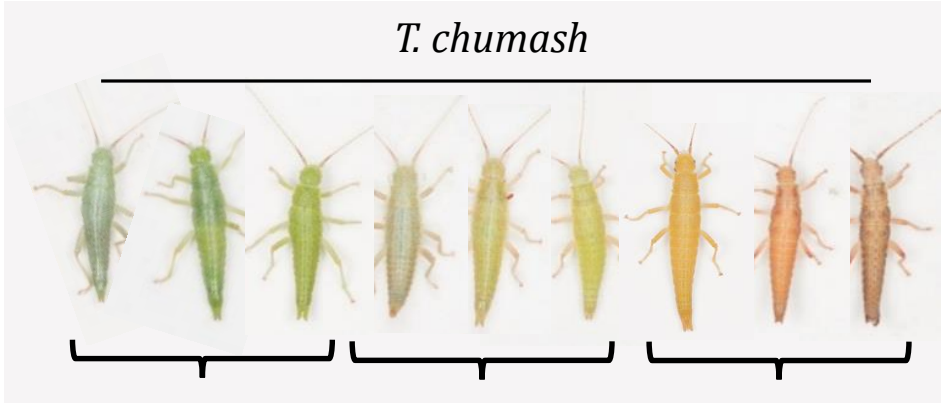




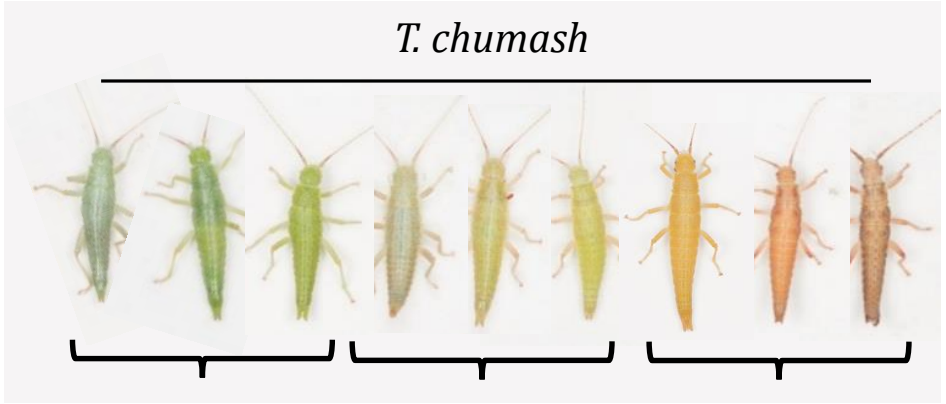


?

Mark recapture on different host plants in *T. chumash*



Disruptive selection varies between host plants



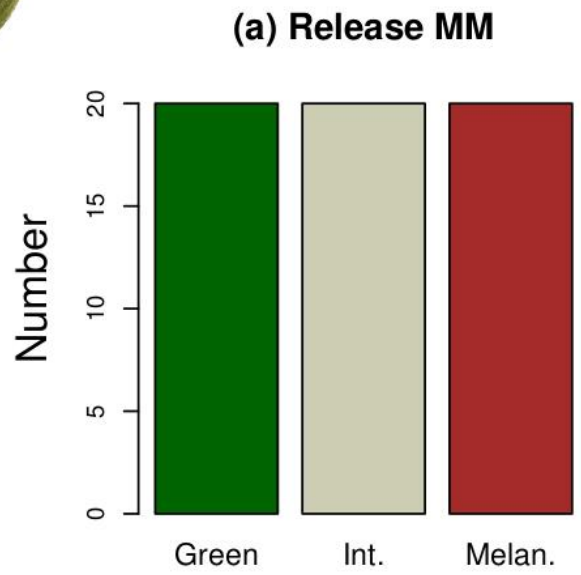
(g) *Adenostoma fasciculatum*

(h) *Cercocarpus* sp.

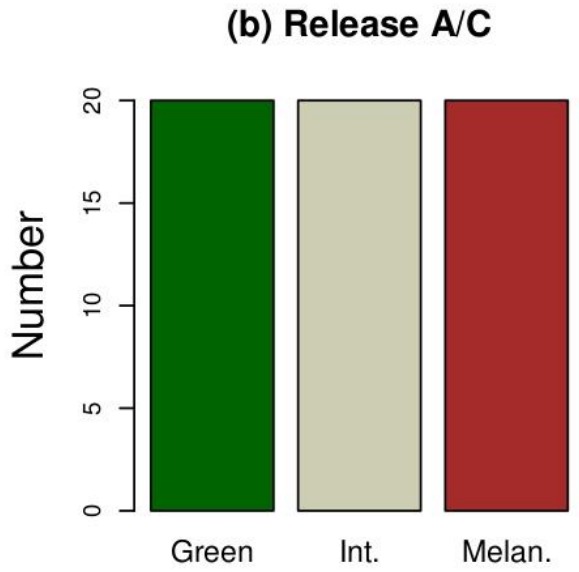
(j) *Ceanothus spinosus*

120 individuals in total

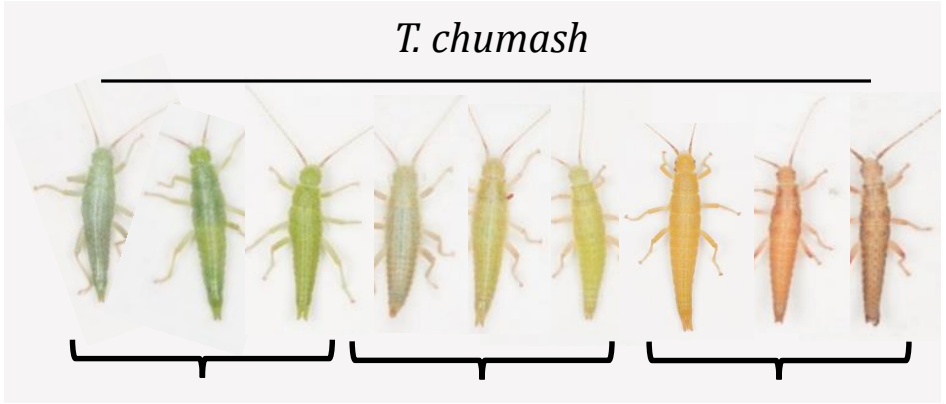
More continuous host plant



Highly discontinuous host plants



Disruptive selection varies between host plants



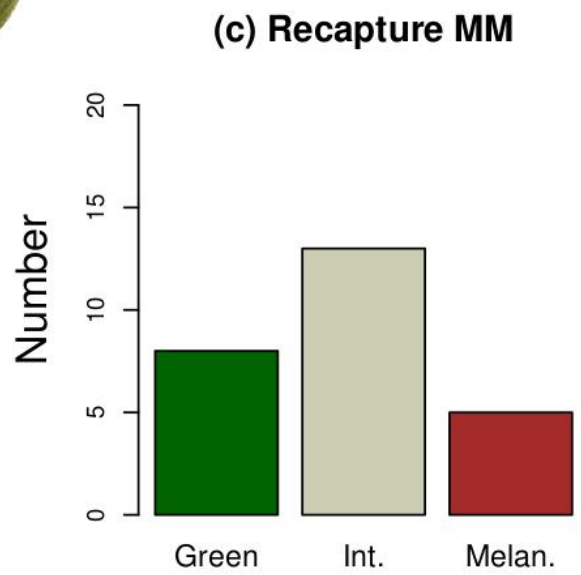
(g) *Adenostoma fasciculatum*

(h) *Cercocarpus* sp.

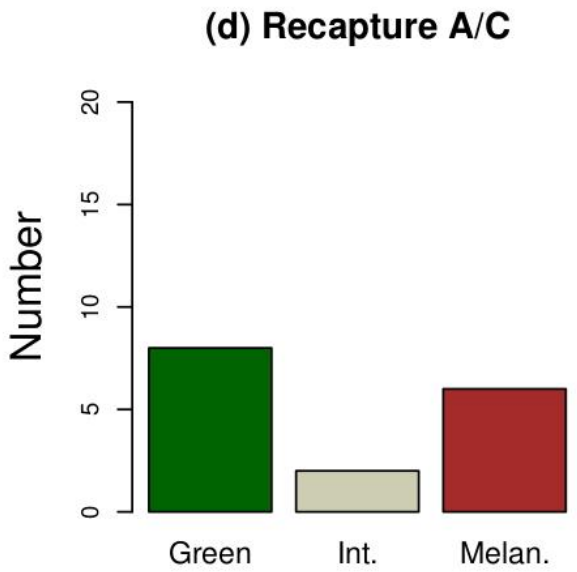
(j) *Ceanothus spinosus*

120 individuals in total
42 recaptured (35%)

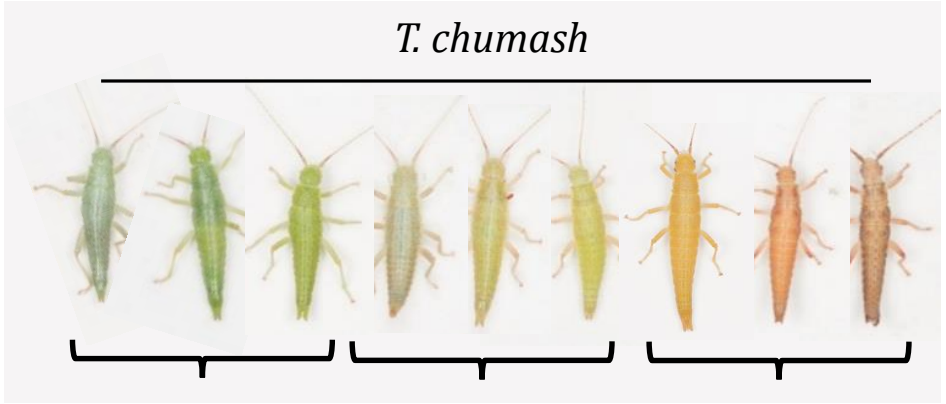
More continuous host plant



Highly discontinuous host plants



Disruptive selection varies between host plants

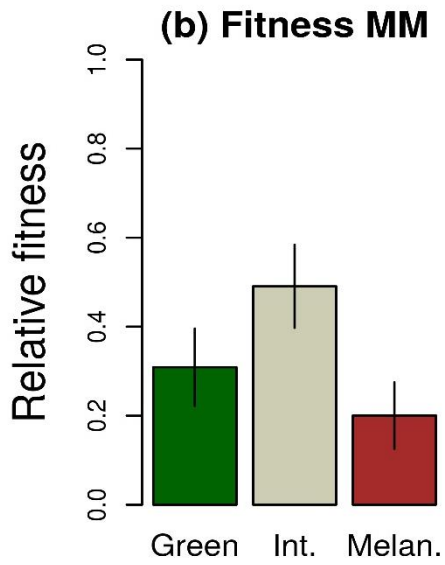


(g) *Adenostoma fasciculatum*

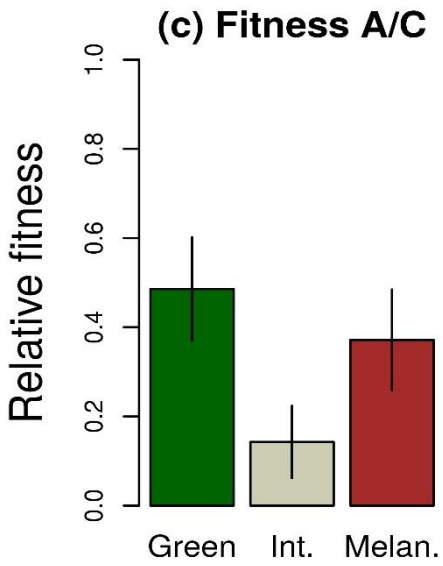
(h) *Cercocarpus* sp.

Intermediates survival MM > A/C.
P.P. = 0.99
(multinomial-Dirichlet model)

More continuous host plant

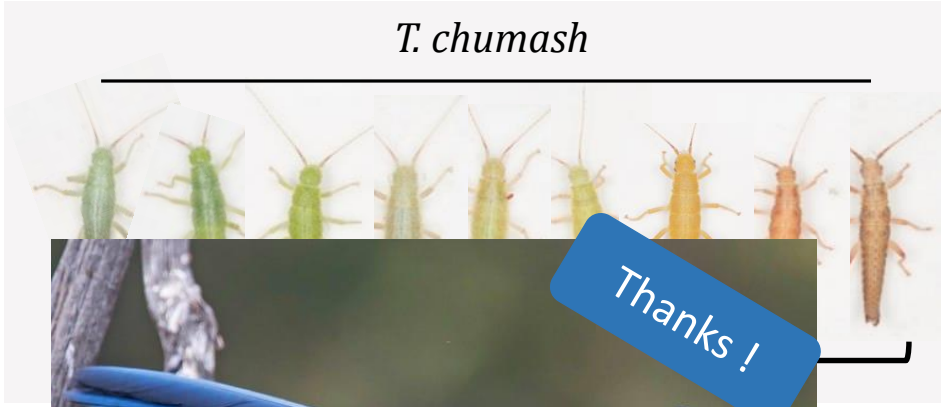


Highly discontinuous host plants



(j) *Ceanothus spinosus*

Disruptive selection varies between host plants



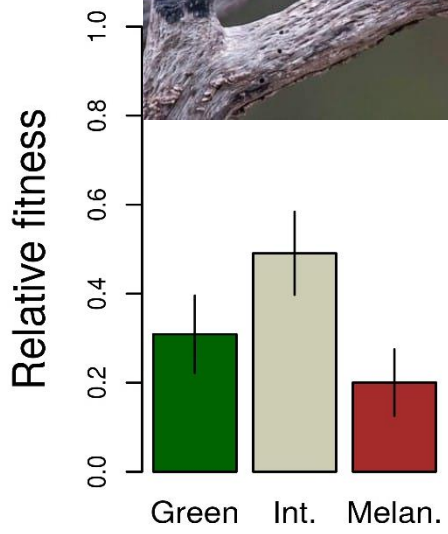
(h) *Cercocarpus* sp.

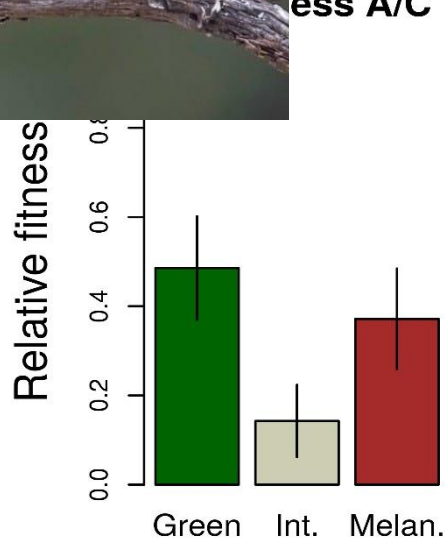
Intermediates survival MM > A/C.
P.P. = 0.99
(multinomial-Dirichlet model)

More co…

…ous host plants

…ess A/C

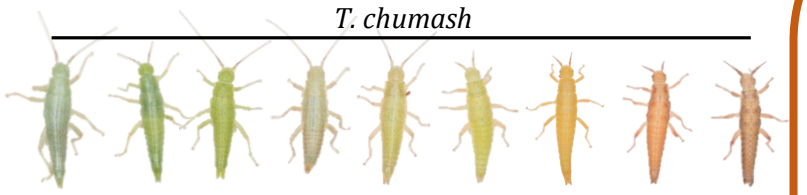


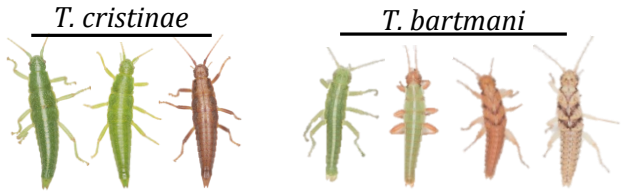


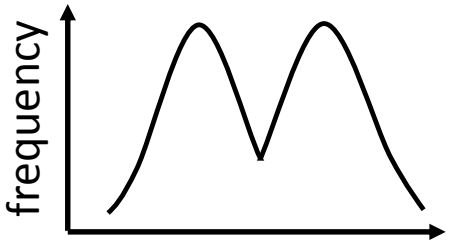
(g) *Adenostoma fasciculatum*

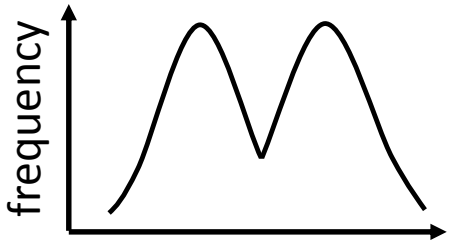
(j) *Ceanothus spinosus*

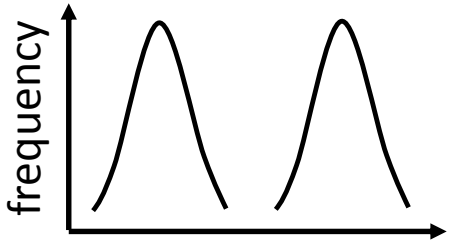
Expectations in *Timema* sp.

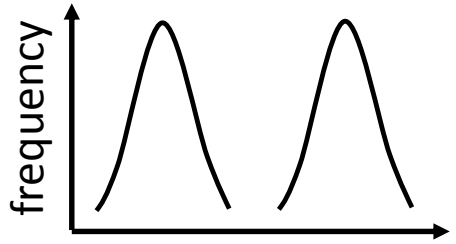


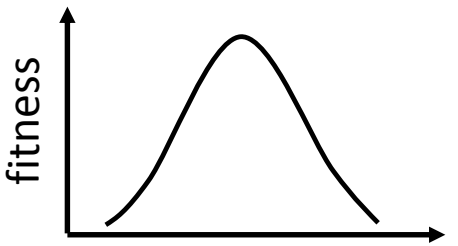


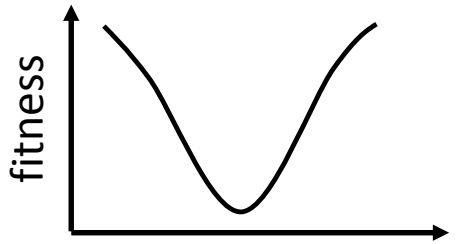




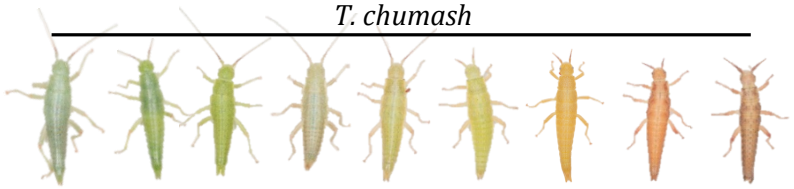


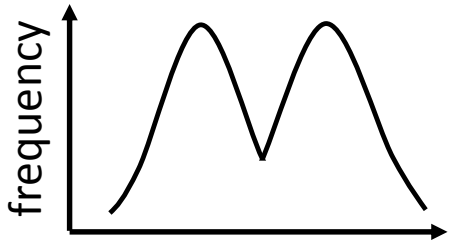


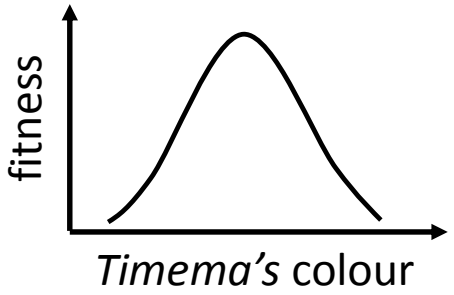




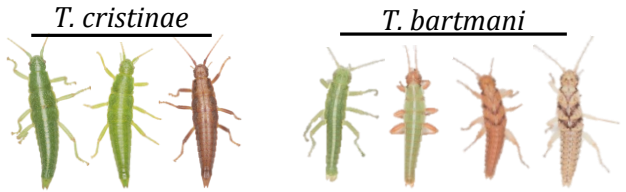
Expected genetic basis of colour in *Timema* sp.

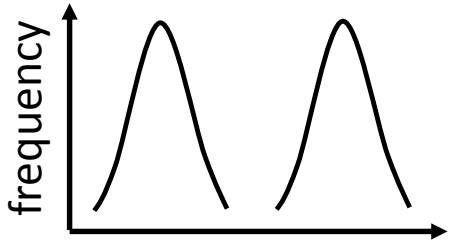


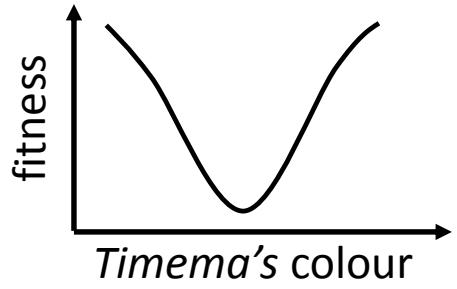




Multiple loci

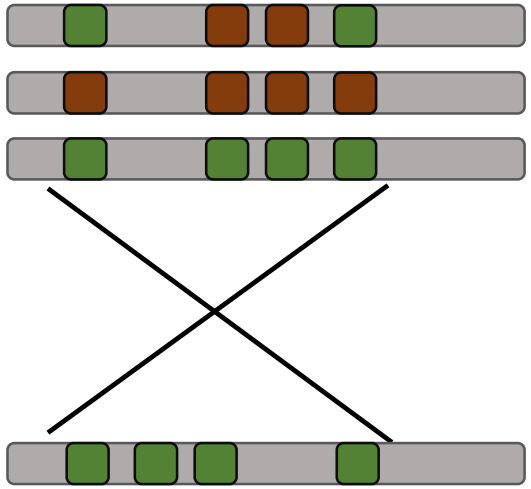






Single locus
(supergenes)

Why do supergenes evolve?

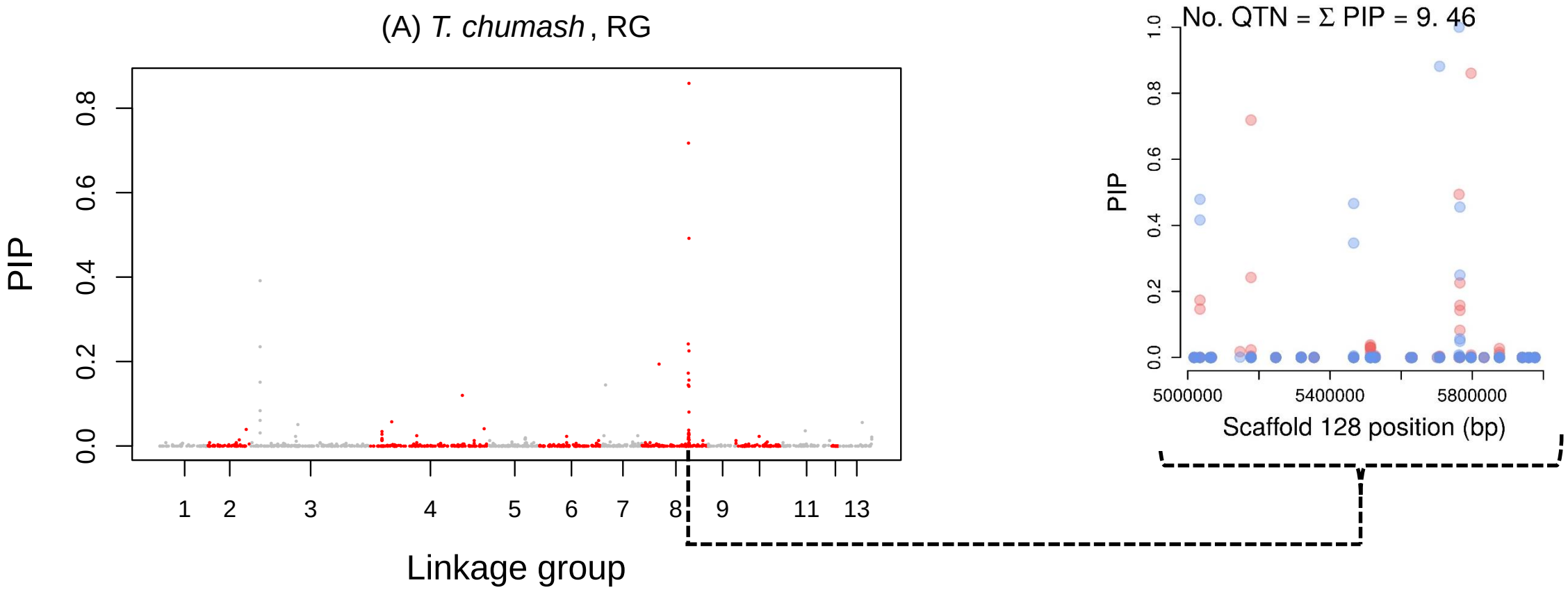


- Expected outcome of disruptive selection on a trait controlled by multiple loci located on the same chromosome (Charlesworth & Charlesworth 1976, Kirkpatrik & Barton 2006)

- Strongly reduce recombination in heterozygotes at this particular locus (Sturtevant 1921, Hoffmann & Rieseberg 2008, Stump et al. 2007).

Avoid the cost of producing offspring with ‘unfit’ allelic combinations
Reduce the effect of gene flow
Region segregates as a single locus

Colour is polygenic in *T. chumash*

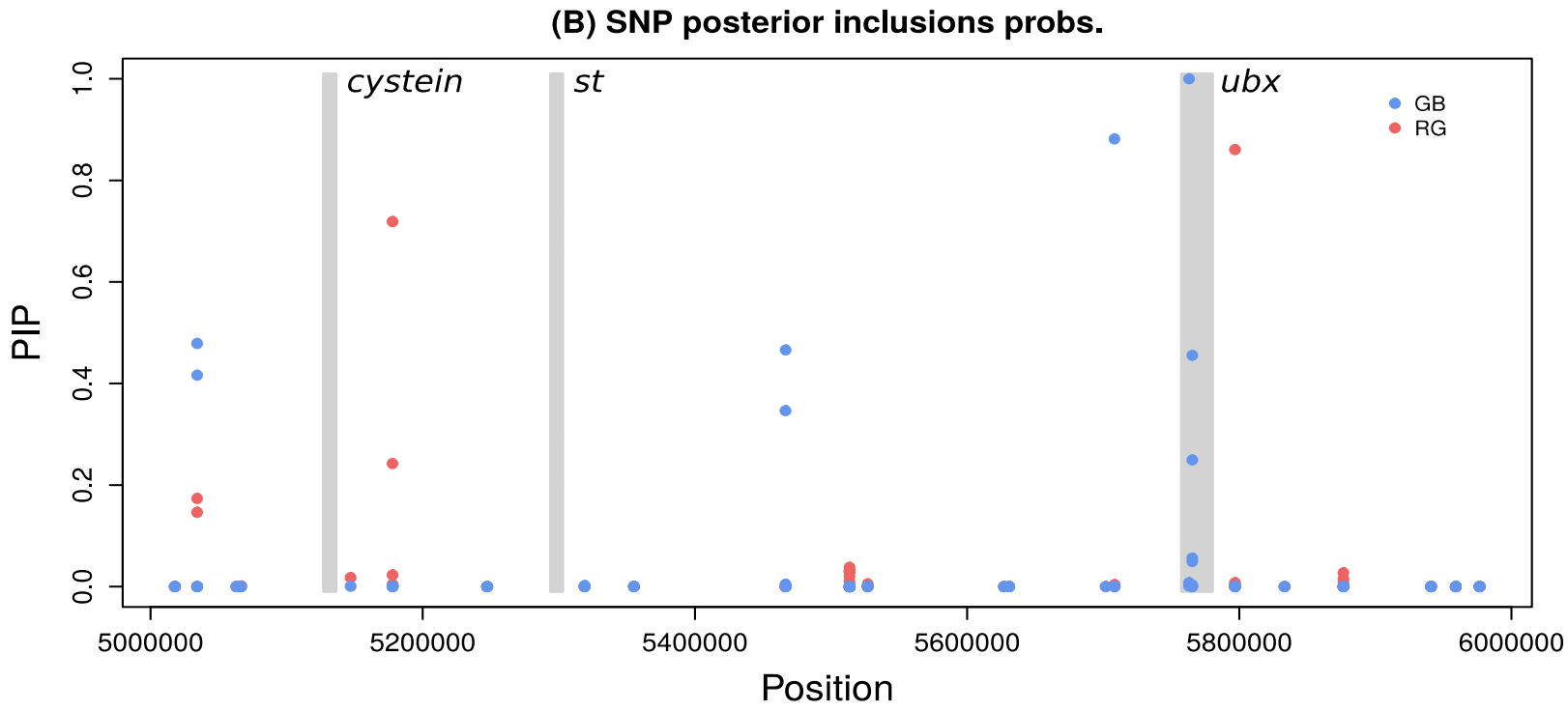


LD is low among top SNPs

~8-10 variants controlling color in *T. chumash*

Villoutreix *et al.* 2020

Colour is primarily associated with one region in *T. chumash*



st: homolog of *st* gene in drosophila (scarlet membrane transporter)

cystein: Tyrosine kinase. Cell communication process. (*Haplochromini* cichlids)

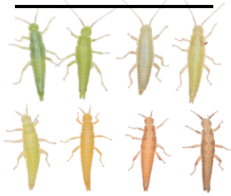
ubx: Protein activation. Activated by *cortex* (Heliconius and Biston betularia)

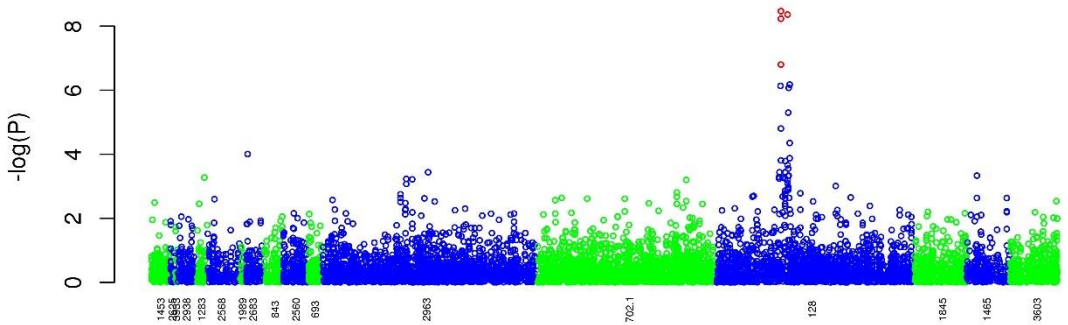
Villoutreix *et al.* 2020

Colour morph discontinuity is enhanced by structural variation…

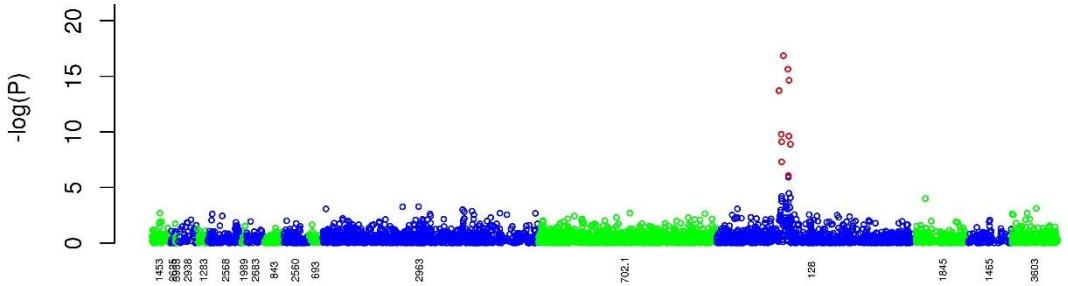
… in all species studied but *T. chumash.*

T. chumash

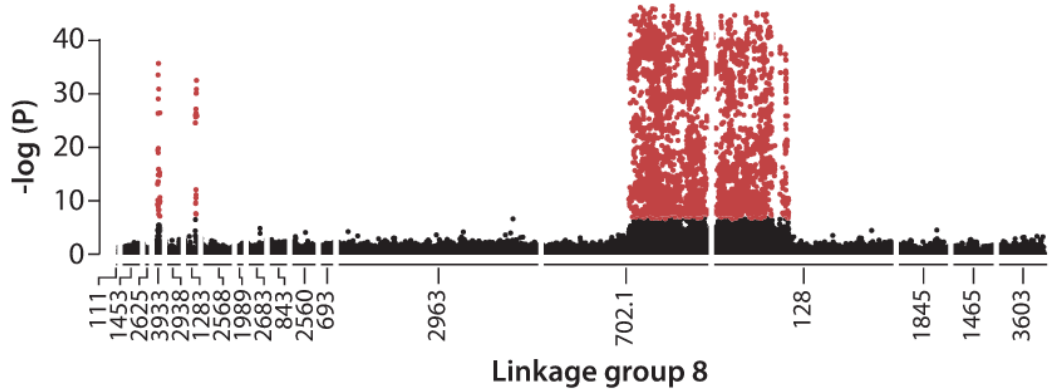




T. bartmani

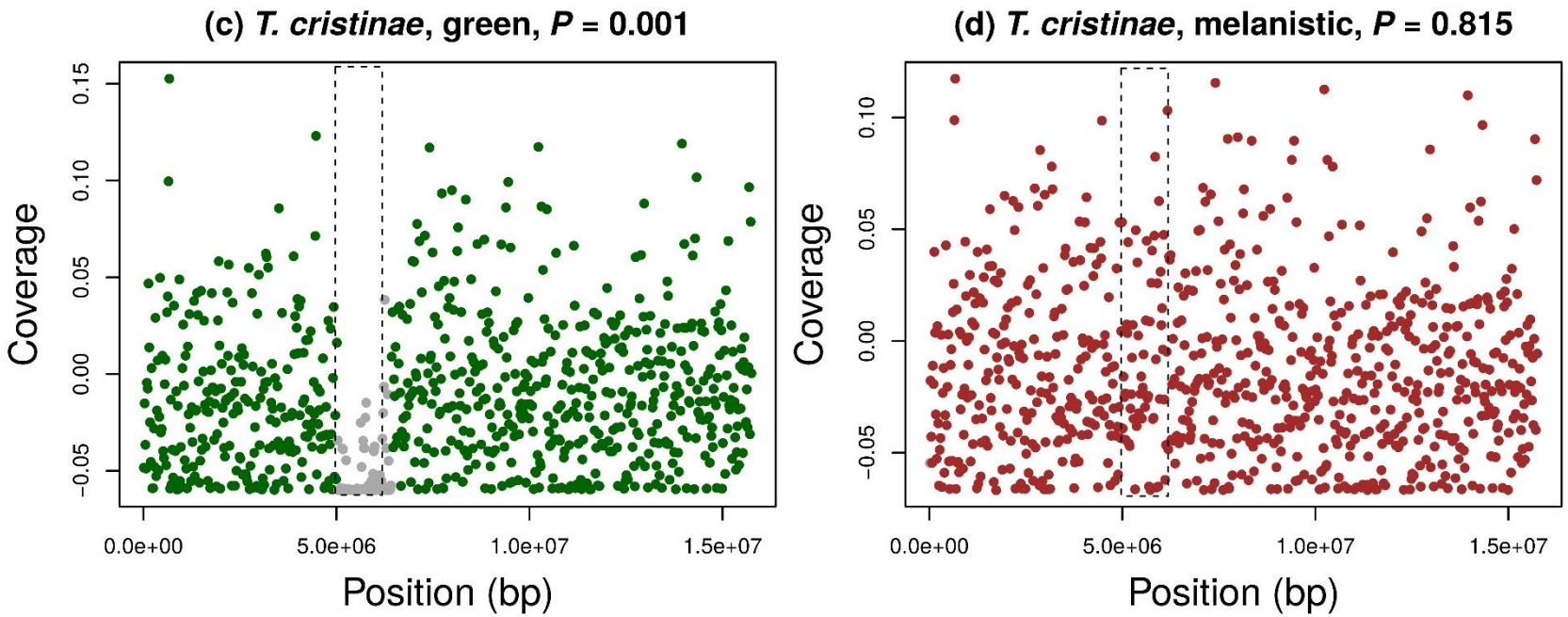


T. cristinae



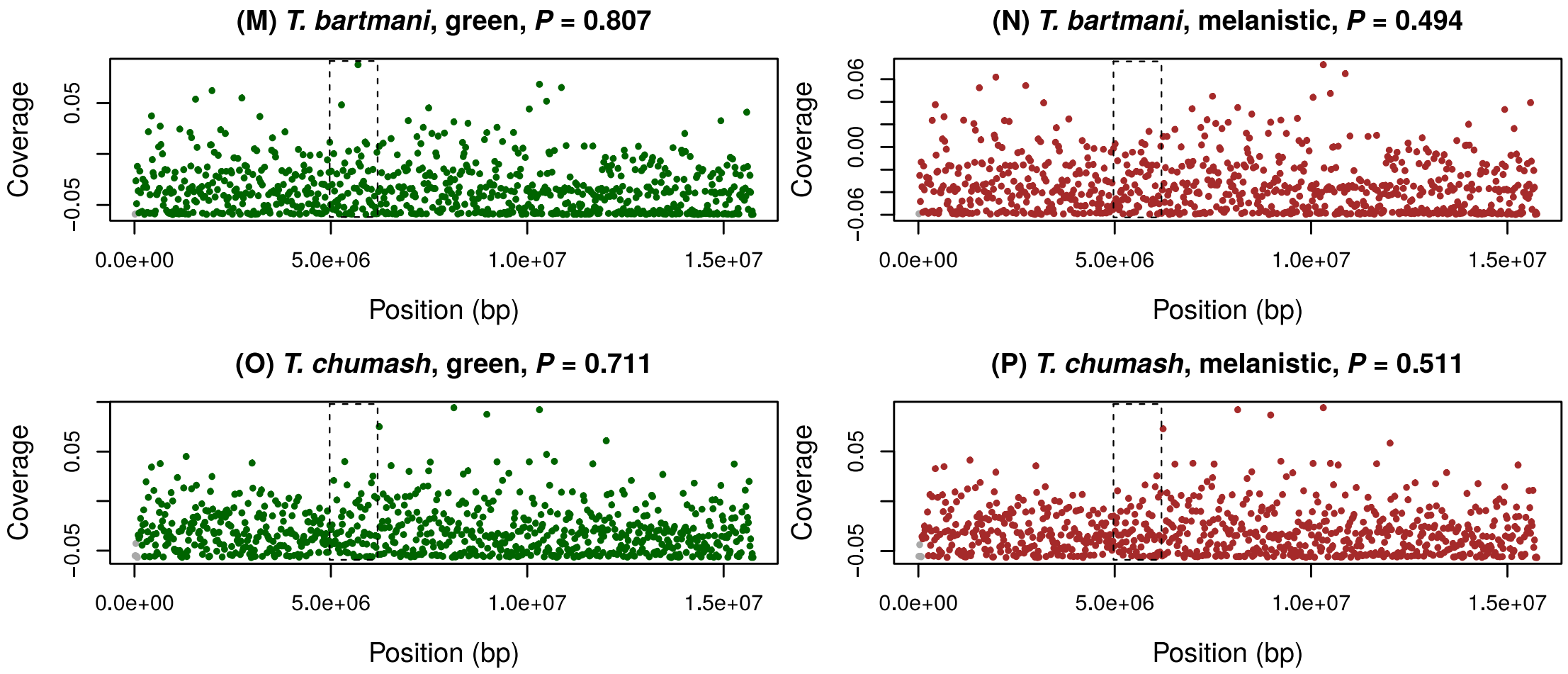
Villoutreix *et al.* 2020

Breakpoint mutation in *T. cristinae*



Villoutreix *et al.* 2020

Breakpoint mutation in *T. cristinae*



Villoutreix *et al.* 2020

In conclusion

Host plant leaves and stems discontinuity drives colour morph discontinuity by generating disruptive selection

Host plant colouration likely drives the evolution of supergene(s) in *Timema* sp..

Plausibility of large or sudden evolutionary changes remains unclear.

Developmental biology: developmental switches involving gene regulation.

Here: conversion of polygenic variation into discrete phenotypic categories by **supergene evolution**.

Reconcile ideas about **large evolutionary shifts** (**Punctuated equilibria** and **hopeful monsters**) with **polygenic adaptation** and **neo-darwinian gradualism**.

Thanks!

Lab/fieldwork assistant:

Óscar Mira Pérez

Undergraduate students:

Lucy Lloyd
Josh Thakrar

Help with libraries:

Anamaria Štambuk

IT support:

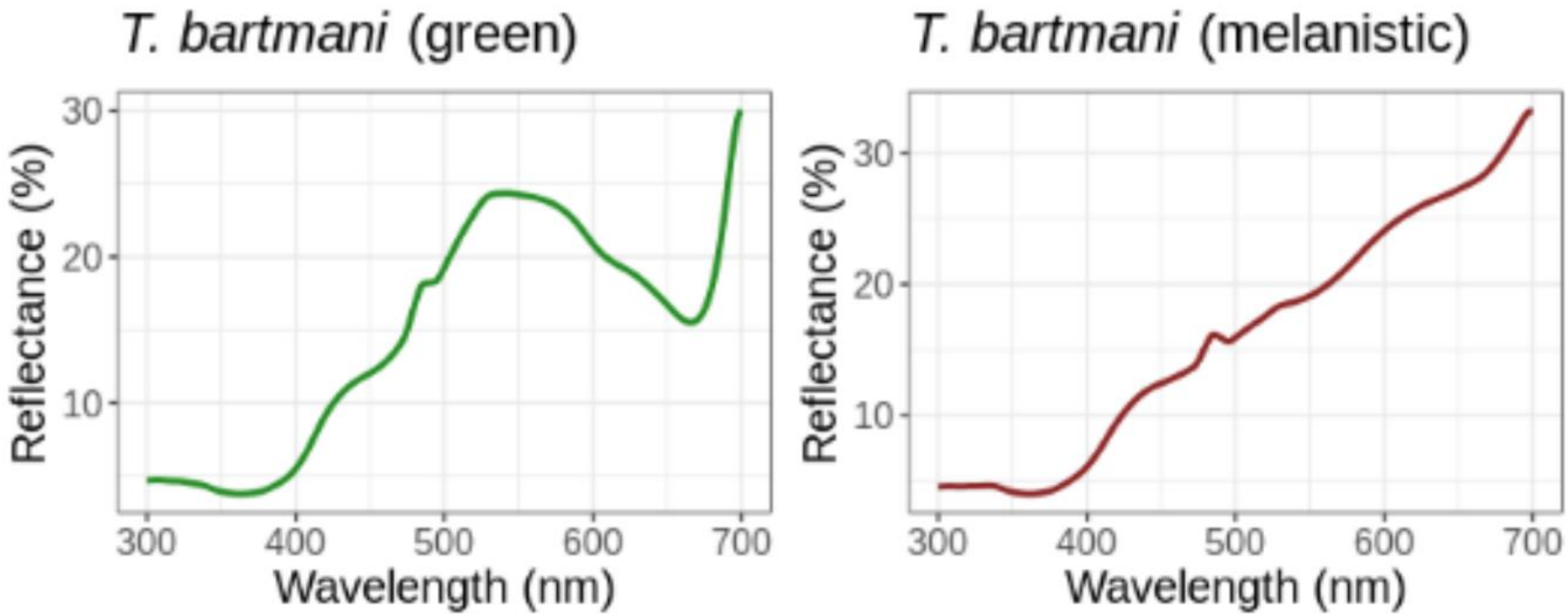
CICs – University of Sheffield
HPC team (Iceberg)

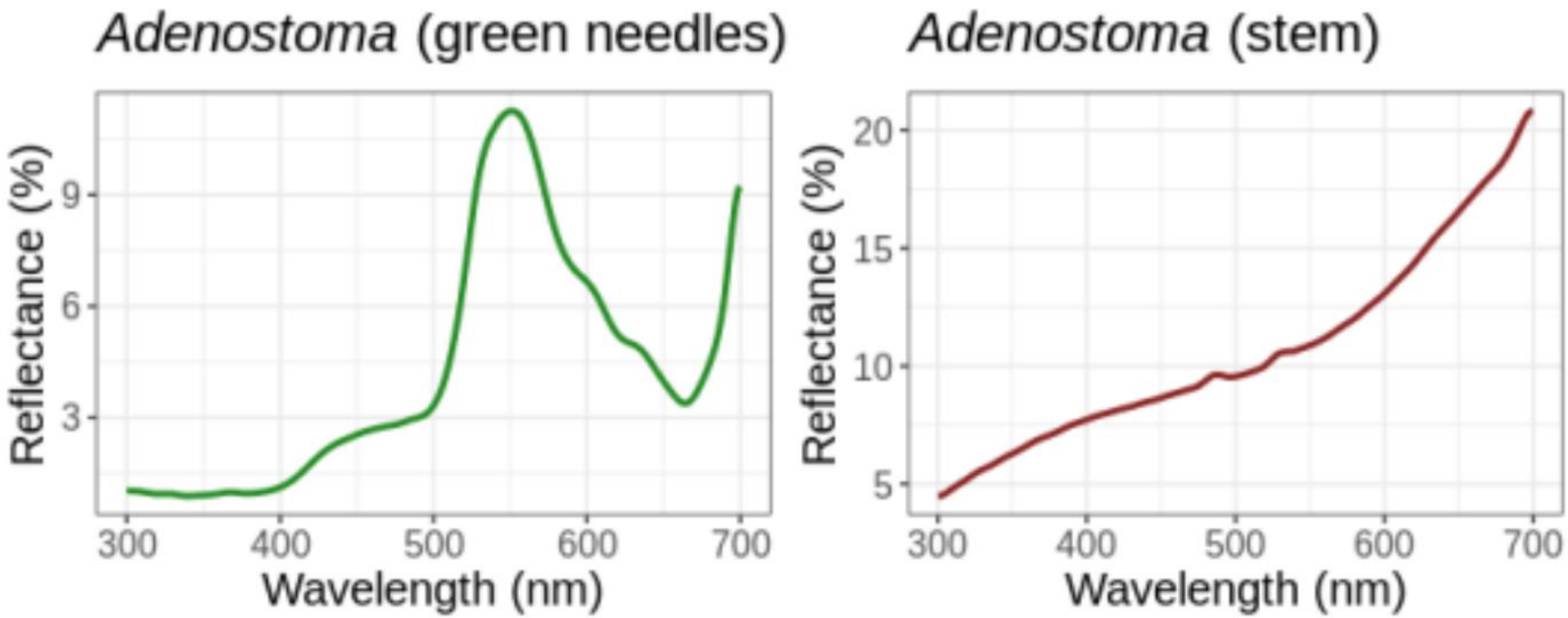
Access to a lab during fieldwork:

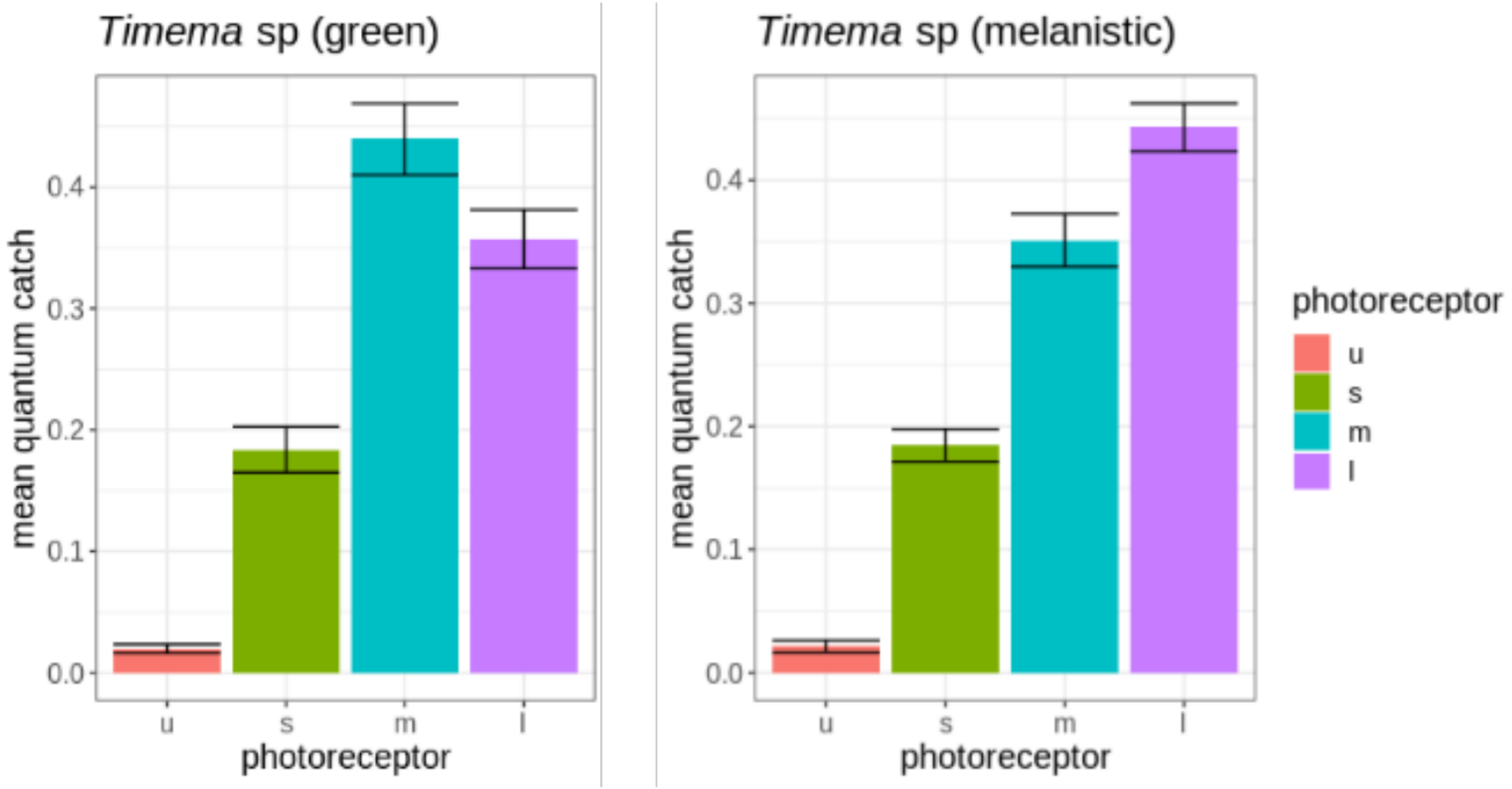
Todd Oakley
Emily Ellis
Morris Aguilar

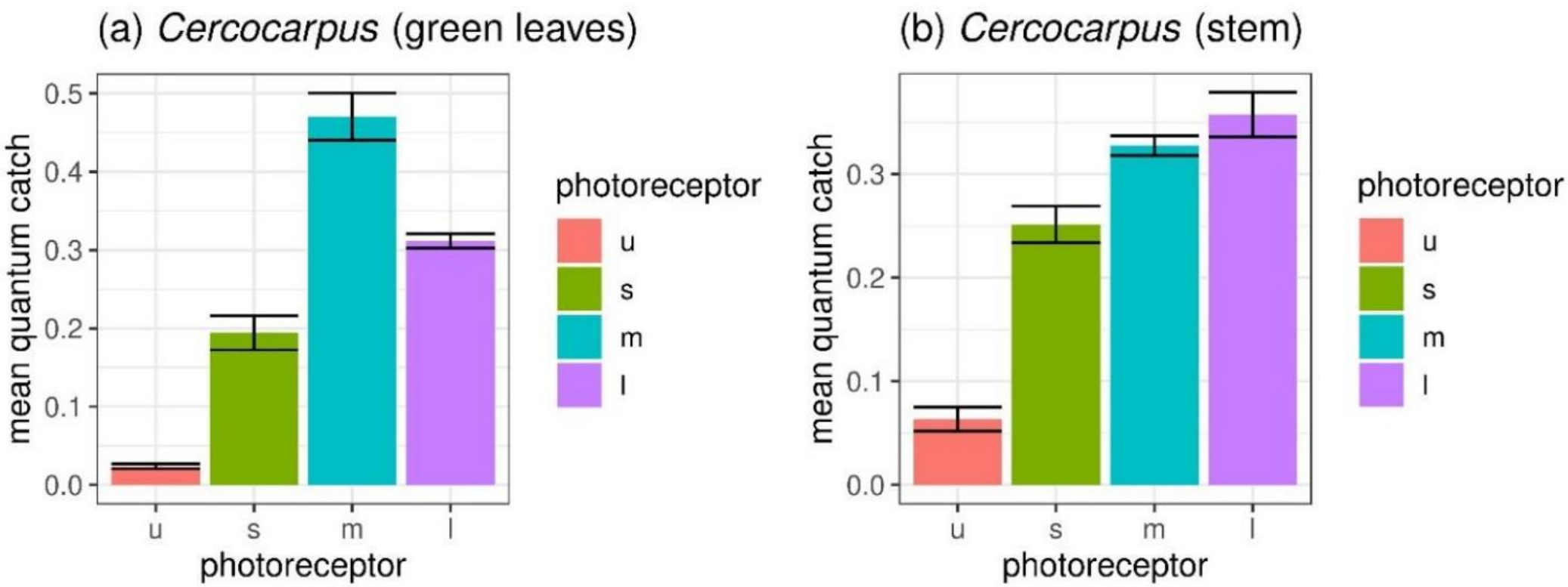
Funding bodies:

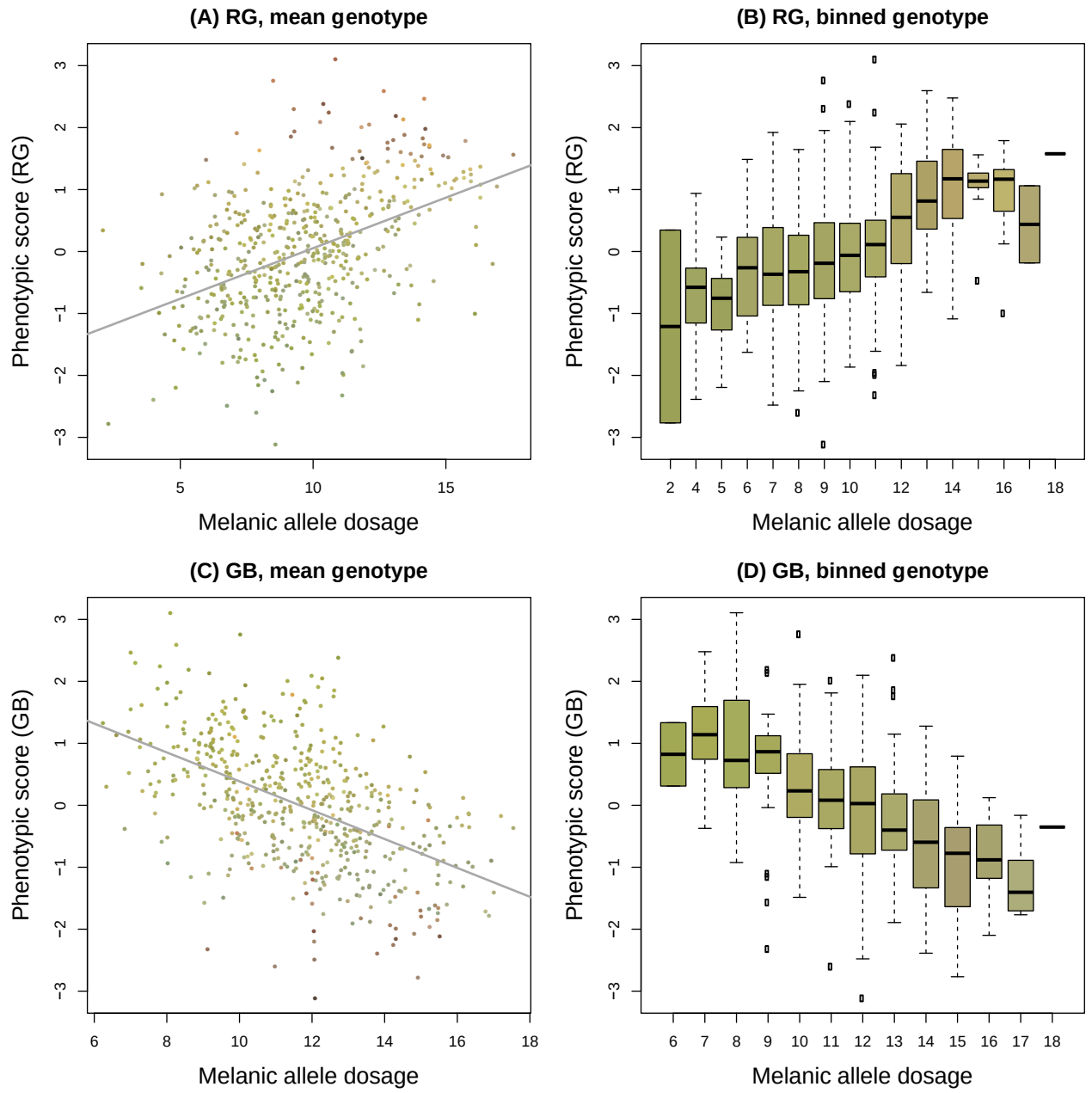
European research council


T. bartmani (green)
Reflectance (%)
30
20
10
300
400
500
600
700
Wavelength (nm)
T. bartmani (melanistic)
Reflectance (%)
30
20
10
300
400
500
600
700
Wavelength (nm)


Adenostoma (green needles)
Reflectance (%)
3
6
9
300
400
500
600
700
Wavelength (nm)
Adenostoma (stem)
Reflectance (%)
5
10
15
20
300
400
500
600
700
Wavelength (nm)


Timema sp (green)
Timema sp (melanistic)
mean quantum catch
0.0
0.1
0.2
0.3
0.4
u
s
m
l
photoreceptor
photoreceptor
u
s
m
l


(a) *Cercocarpus* (green leaves)
mean quantum catch
0.0
0.1
0.2
0.3
0.4
0.5
u
s
m
l
photoreceptor
photoreceptor
u
s
m
l
(b) *Cercocarpus* (stem)
mean quantum catch
0.0
0.1
0.2
0.3
u
s
m
l
photoreceptor
photoreceptor
u
s
m
l


(A) RG, mean genotype
Phenotypic score (RG)
Melanic allele dosage
(B) RG, binned genotype
Phenotypic score (RG)
Melanic allele dosage
(C) GB, mean genotype
Phenotypic score (GB)
Melanic allele dosage
(D) GB, binned genotype
Phenotypic score (GB)
Melanic allele dosage

Color map primarily to one region in *T. chumash* but is polygenic