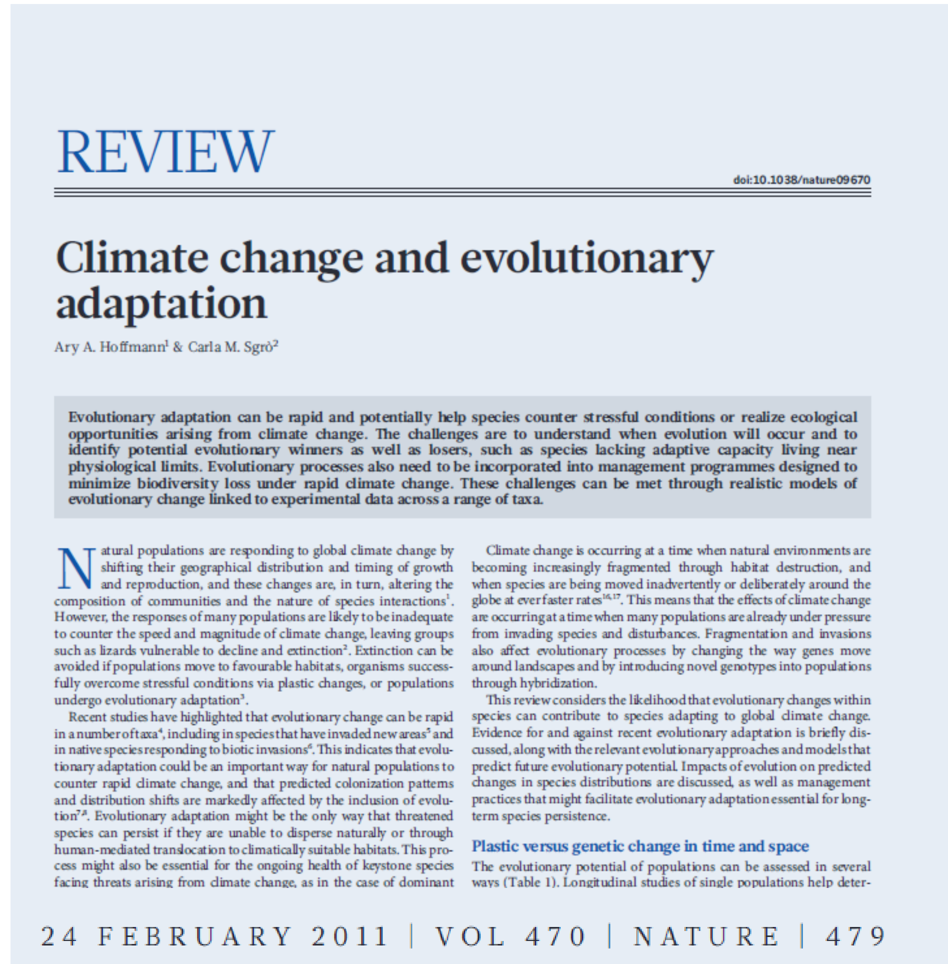
BIOL3110 Conservation & Ecological Genetics

LECTURE 21: CLIMATE CHANGE & ADAPTIVE POTENTIAL

Climate Change and Evolutionary Adaptation

Three options to avoid population extinction:

1. **Move** to favourable habitats
2. Overcome stress through **plasticity**
3. Undergo evolutionary **adaptation**



REVIEW

doi:10.1038/nature09670

Climate change and evolutionary adaptation

Ary A. Hoffmann[1] & Carla M. Sgrò[2]

Evolutionary adaptation can be rapid and potentially help species counter stressful conditions or realize ecological opportunities arising from climate change. The challenges are to understand when evolution will occur and to identify potential evolutionary winners as well as losers, such as species lacking adaptive capacity living near physiological limits. Evolutionary processes also need to be incorporated into management programmes designed to minimize biodiversity loss under rapid climate change. These challenges can be met through realistic models of evolutionary change linked to experimental data across a range of taxa.

Natural populations are responding to global climate change by shifting their geographical distribution and timing of growth and reproduction, and these changes are, in turn, altering the composition of communities and the nature of species interactions[1]. However, the responses of many populations are likely to be inadequate to counter the speed and magnitude of climate change, leaving groups such as lizards vulnerable to decline and extinction[2]. Extinction can be avoided if populations move to favourable habitats, organisms successfully overcome stressful conditions via plastic changes, or populations undergo evolutionary adaptation[3].

Recent studies have highlighted that evolutionary change can be rapid in a number of taxa[4], including in species that have invaded new areas[5] and in native species responding to biotic invasions[6]. This indicates that evolutionary adaptation could be an important way for natural populations to counter rapid climate change, and that predicted colonization patterns and distribution shifts are markedly affected by the inclusion of evolution[7,8]. Evolutionary adaptation might be the only way that threatened species can persist if they are unable to disperse naturally or through human-mediated translocation to climatically suitable habitats. This process might also be essential for the ongoing health of keystone species facing threats arising from climate change, as in the case of dominant

Climate change is occurring at a time when natural environments are becoming increasingly fragmented through habitat destruction, and when species are being moved inadvertently or deliberately around the globe at ever faster rates[16,17]. This means that the effects of climate change are occurring at a time when many populations are already under pressure from invading species and disturbances. Fragmentation and invasions also affect evolutionary processes by changing the way genes move around landscapes and by introducing novel genotypes into populations through hybridization.

This review considers the likelihood that evolutionary changes within species can contribute to species adapting to global climate change. Evidence for and against recent evolutionary adaptation is briefly discussed, along with the relevant evolutionary approaches and models that predict future evolutionary potential. Impacts of evolution on predicted changes in species distributions are discussed, as well as management practices that might facilitate evolutionary adaptation essential for long-term species persistence.

Plastic versus genetic change in time and space

The evolutionary potential of populations can be assessed in several ways (Table 1). Longitudinal studies of single populations help deter-

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Ary A. Hoffmann[1] & Carla M. Sgrò[2]

"…with few exceptions, the importance of evolution tends to be ignored

both in broader discussions about the effects of climate change on biodiversity

and in models for predicting species responses."

Evolutionary adaption: Evolvability

Described in one generation by:

$$R = h^2 S$$

Rate of adaptation depends on:

- Selection differential (what will *S* be?)
- Generation time
- Population size (tough for small pops)
- h^2 and V_A

New selection pressures

- Increased climatic variability:
  - incidence of extreme events and extremes (e.g. cold – hot)
  - Increasing periods of thermal stress and drought
- Directional selection on stress traits

Critical For Prediction:

Stress trait variances (as well as means)

Mean:

Heat tolerance **HIGH**

Desicc resistance **HIGH**

Variance: ??

V_P & V_E	Plastic responses
V_G & V_A	Heritability & Evolvability

Emerging insights from Quant Genetics

Australian *Drosophila* as a model system for adaptive potential for stress:

- Cold & heat tolerance
- Desiccation resistance

REPORTS

Low Potential for Climatic Stress Adaptation in a Rainforest *Drosophila* Species

A. A. Hoffmann,* R. J. Hallas, J. A. Dean, M. Schiffer

The ability of sensitive rainforest species to evolve in response to climate change is largely unknown. We show that the Australian tropical rainforest fly *Drosophila birchii* exhibits clinal variation in desiccation resistance, but the most resistant population lacks the ability to evolve further resistance even after intense selection for over 30 generations. Parent-offspring comparisons indicate low heritable variation for this trait but high levels of genetic variation for

REPORTS

Fundamental Evolutionary Limits in Ecological Traits Drive *Drosophila* Species Distributions

Vanessa Kellermann,[1]* Belinda van Heerwaarden,[1,2] Carla M. Sgrò,[2] Ary A. Hoffmann[3]

Species that are habitat specialists make up much of biodiversity, but the evolutionary factors that limit their distributions have rarely been considered. We show that in *Drosophila*, narrow and wide ranges of desiccation and cold resistance are closely associated with the distributions of specialist

PROCEEDINGS OF THE ROYAL SOCIETY B

Proc. R. Soc. B (2009) 276, 1517–1526
doi:10.1098/rspb.2008.1288
Published online 25 February 2009

Testing evolutionary hypotheses about species borders: patterns of genetic variation towards the southern borders of two rainforest *Drosophila* and a related habitat generalist

Belinda van Heerwaarden[1,*], Vanessa Kellermann[1], Michele Schiffer[2], Mark Blacket[1], Carla M. Sgrò[3] and Ary A. Hoffmann[1]

PNAS

Upper thermal limits of *Drosophila* are linked to species distributions and strongly constrained phylogenetically

Vanessa Kellermann[a,1,2], Johannes Overgaard[a], Ary A. Hoffmann[b], Camilla Fløjgaard[a], Jens-Christian Sv
and Volker Loeschcke[a]

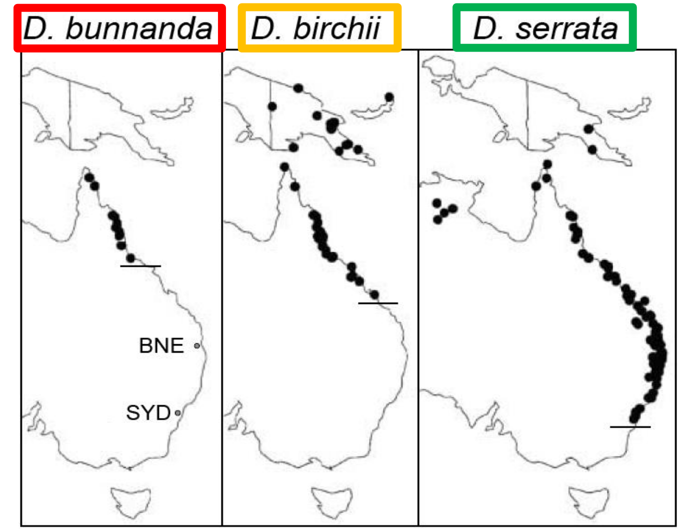
[a]Department of Bioscience, Aarhus University, DK-8000 Aarhus C, Denmark; and [b]Department of Genetics, Bio21 Institute, University
Melbourne, Victoria 3010, Australia

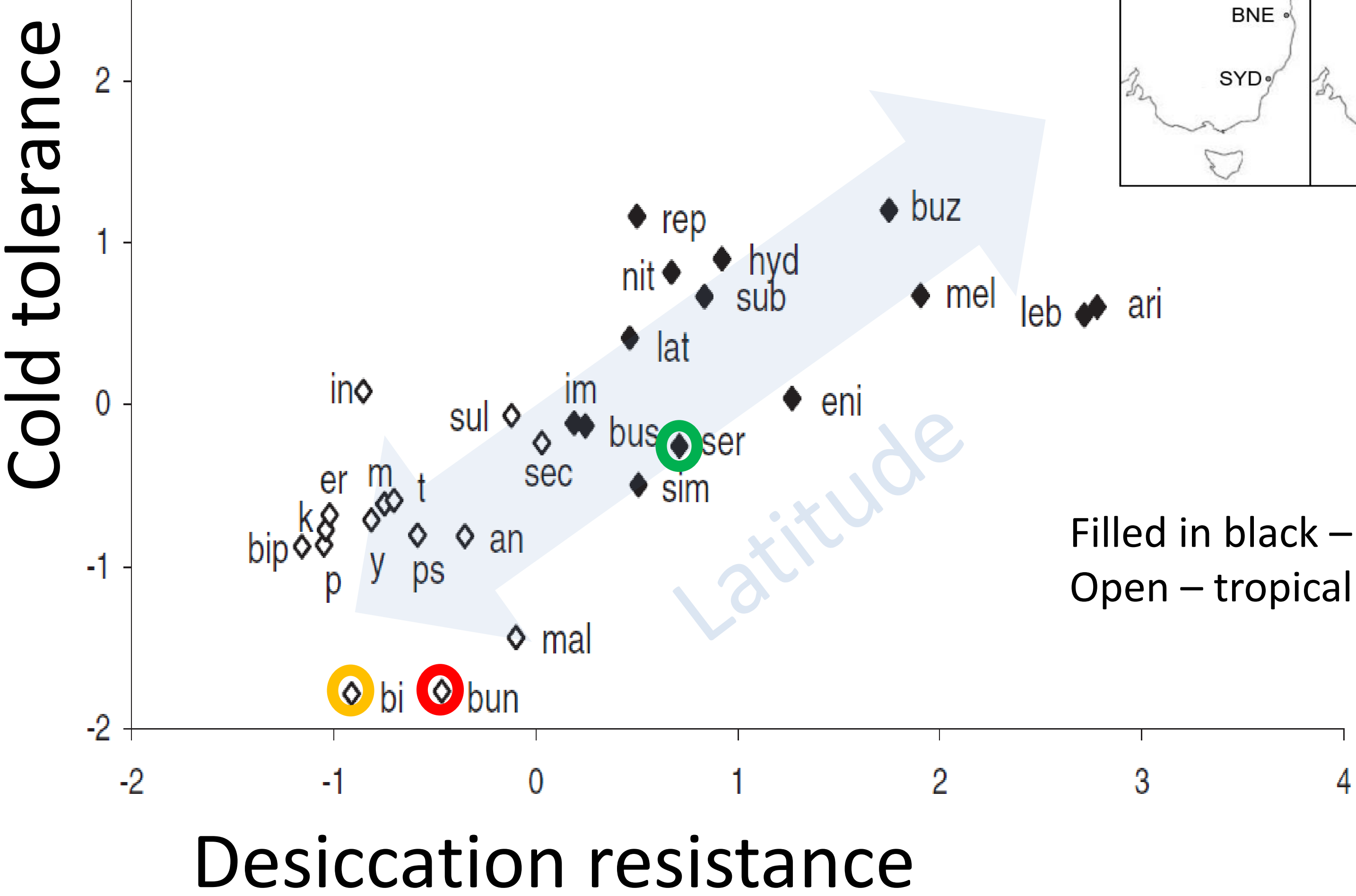
Edited by David L. Denlinger, Ohio State University, Columbus, OH, and approved August 24, 2012 (received for review May 8, 2012)

Upper thermal limits vary less than lower limits among related species of terrestrial ectotherms. This pattern may reflect weak or uniform

to climate change (13, 14). In the past phyloger
mainly aimed to control for the effects of phy

The Biogeography of Stress Tolerance

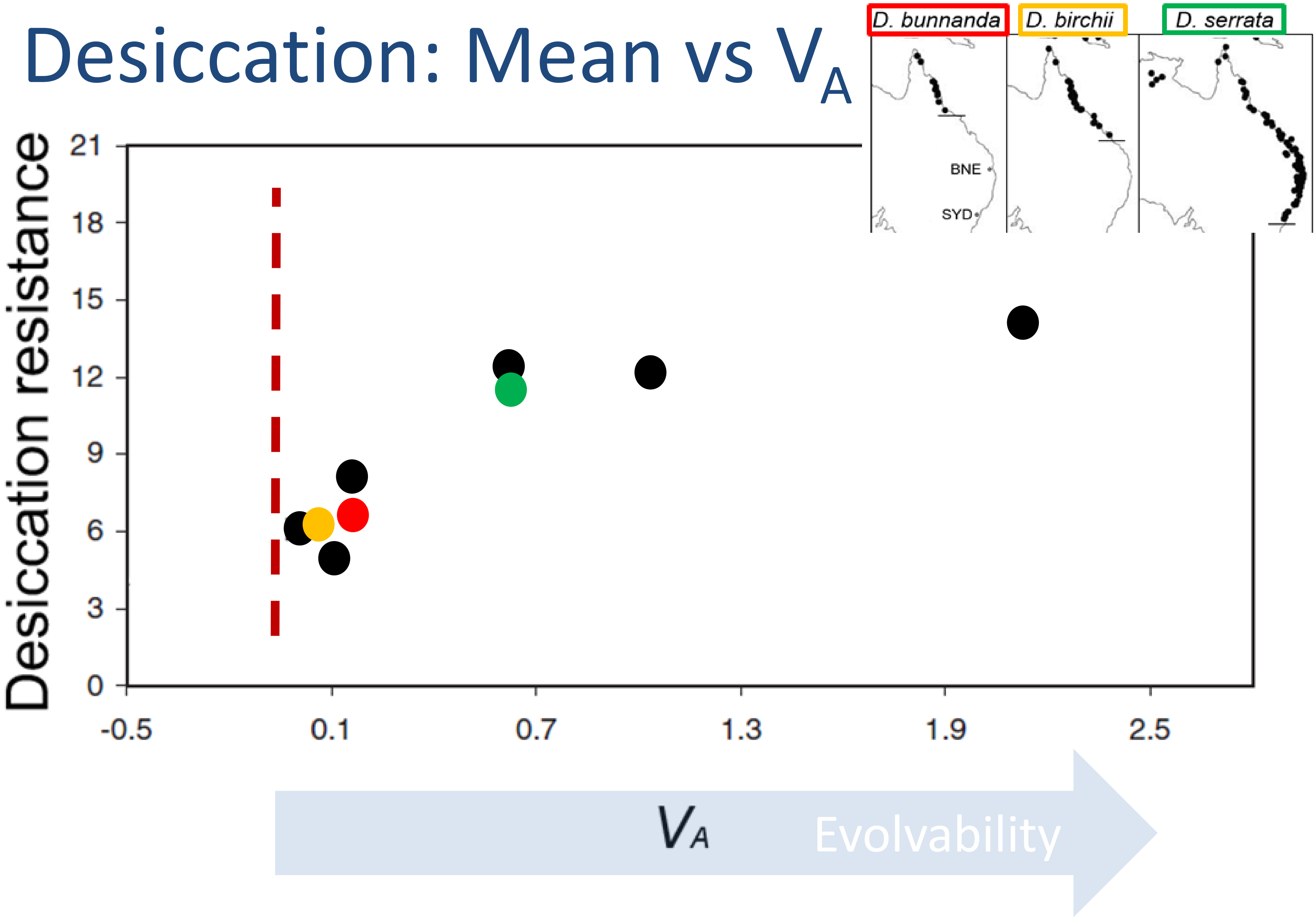




Filled in black – widespread species
Open – tropical species

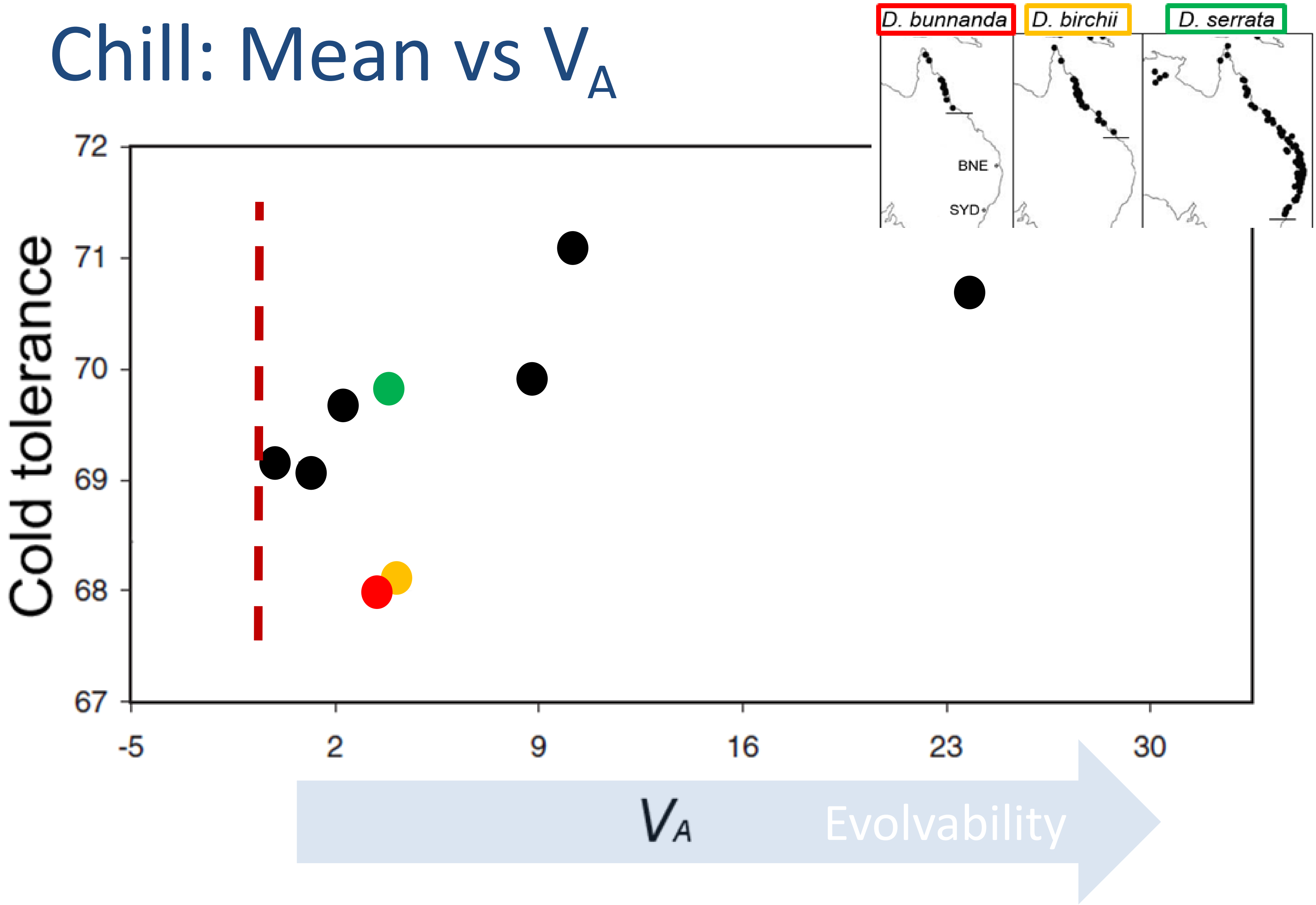
van Heerwaarden *et al.* (2009) *Science*

Desiccation: Mean vs V_A



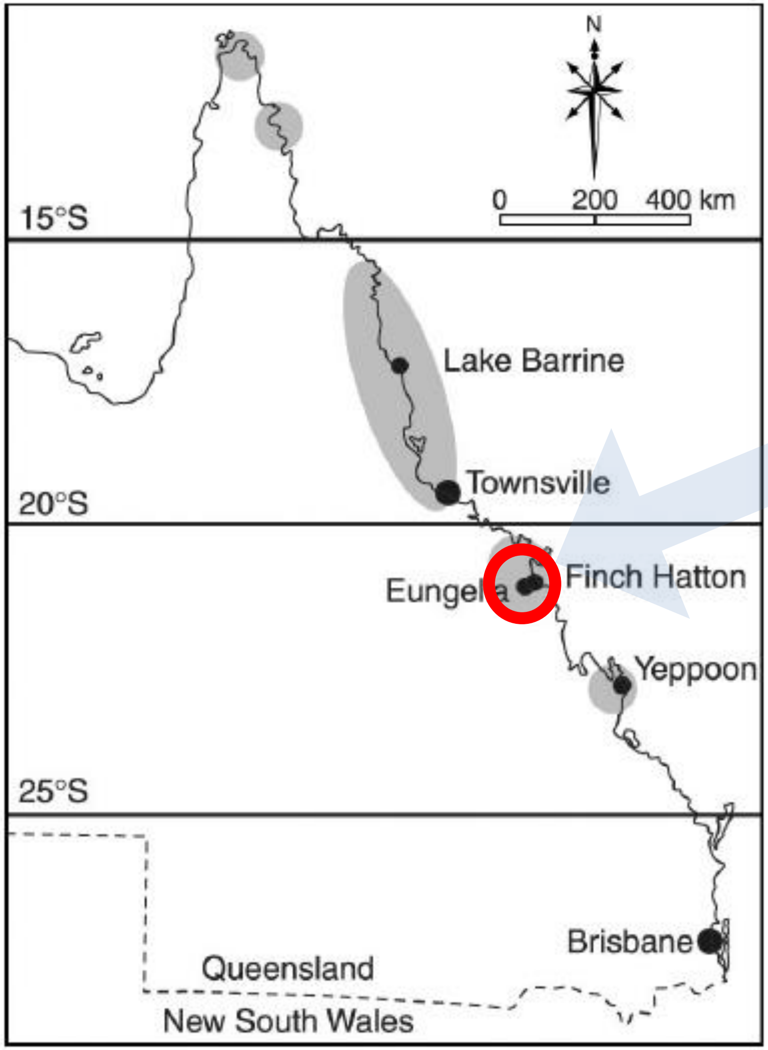
van Heerwaarden *et al.* (2009) *Science*

Chill: Mean vs V_A



van Heerwaarden *et al.* (2009) *Science*

Drosophila birchii



h^2 estimated from parent-offspring regression:

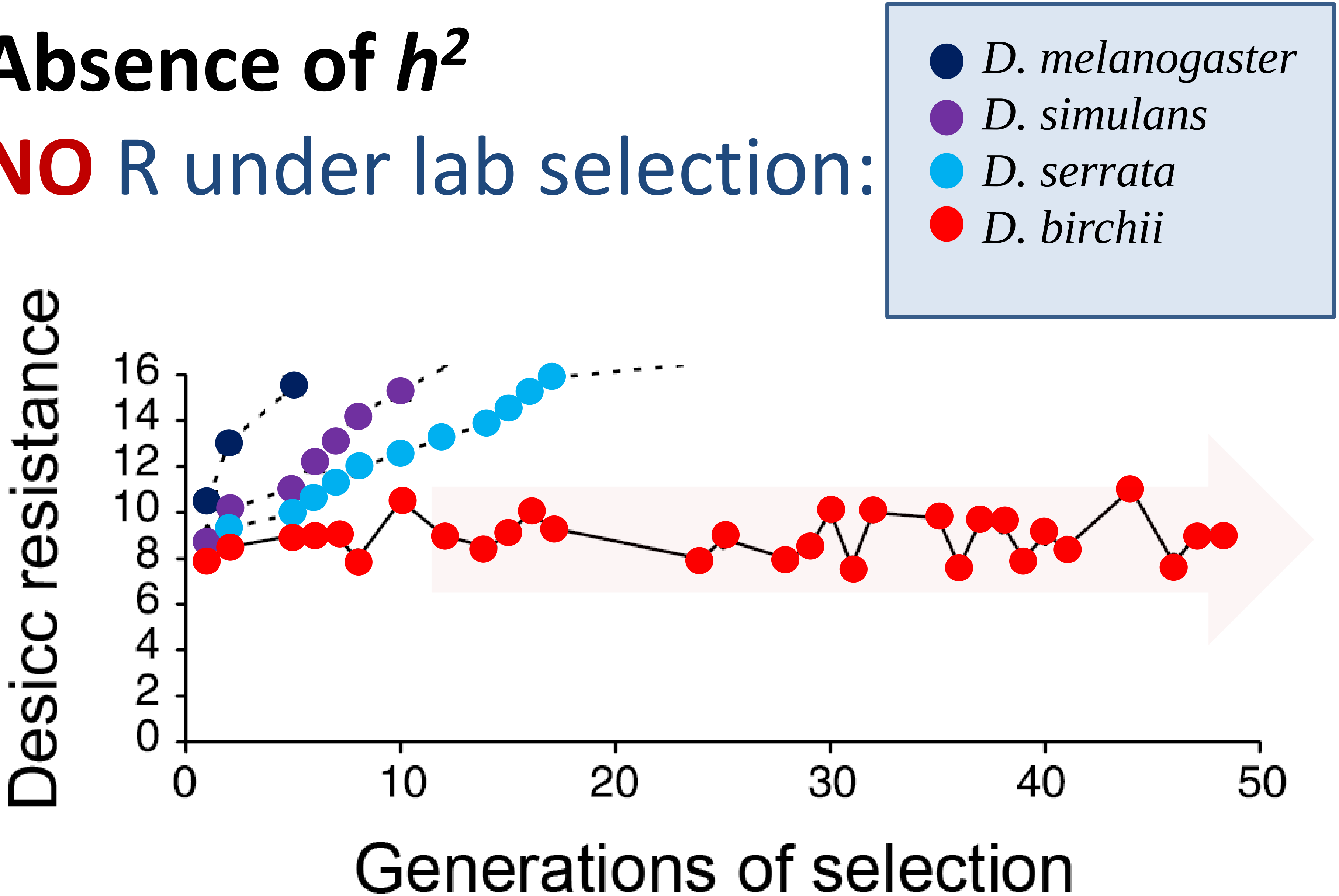
	Number of families	Narrow-sense heritability	Standard error of heritability
Desicc resistance	122	0	0.090
	121	0	0.154
	113	0	0.095
Wing size	66	0.706	0.230
	66	0.386	0.108
Wing aspect	66	0.821	0.198
	66	0.680	0.158

Least stress-tolerant tropical population

Hoffmann *et al*. (2003) *Science*

Absence of h^2

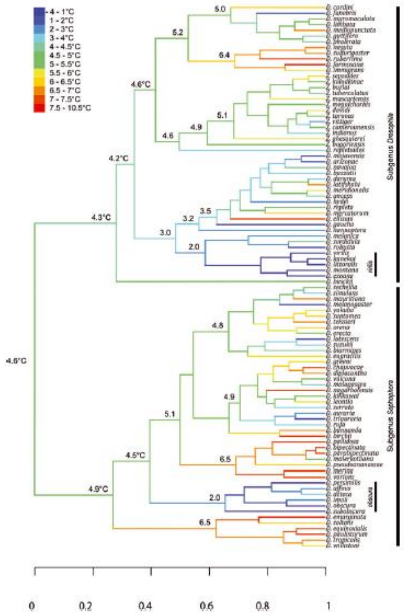
NO R under lab selection:

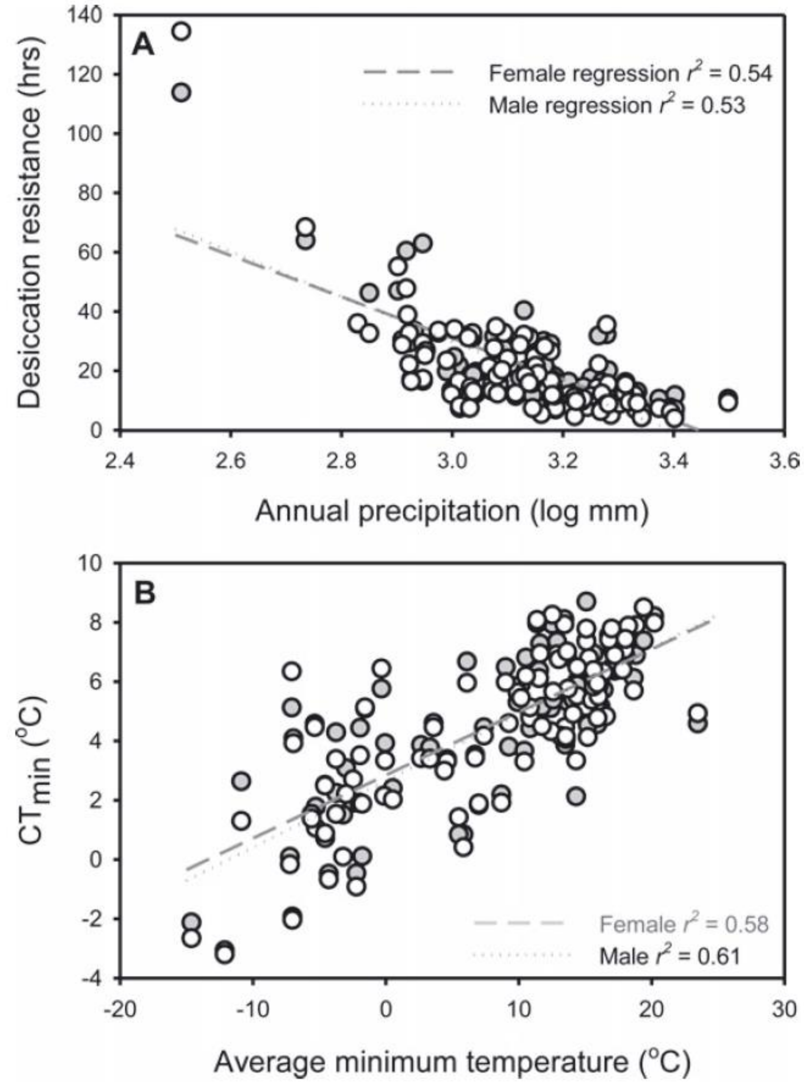


Hoffmann *et al.* (2003) *Science*

Big robust tropical pops that lack V_A for handling stress: **Why?**

- Localised adaptation?
- Disentangle phylogenetic inertia





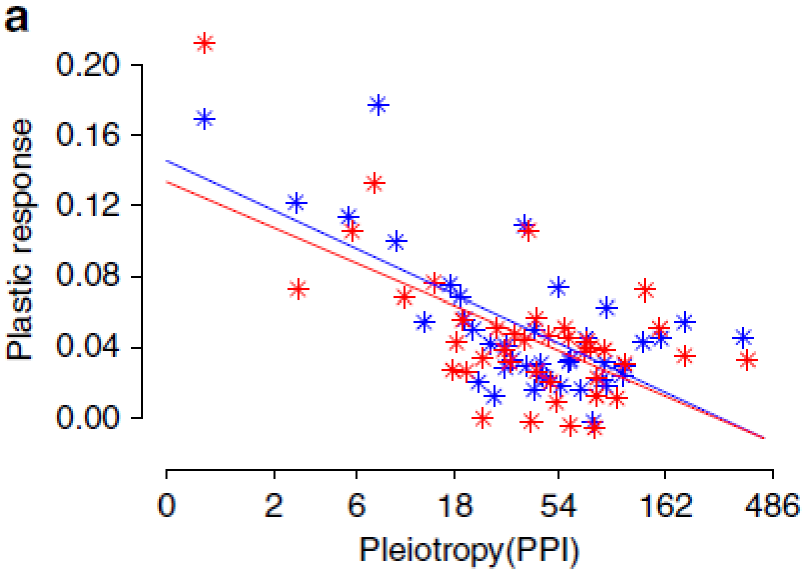
Kellermann *et al.* (2012) *Evolution*

Big robust tropical pops that lack V_A for handling stress:

Why?

- Localised adaptation?
- Pleiotropy?

= (selection against costly adaptations for handling extremes)



Also – in general pleiotropy constrains protein expression (less plasticity). Papakostic, Nat comm 2014

Big robust tropical pops that lack V_A for handling stress: **Why?**

Temperate zone

- Localised adapt
- Pleiotropy
- DNA decay?

Individuals do better
@ heat extremes

Population
variants @
thermal
tolerance
loci:

1. ATGCGCAT
2. CGCCCTCT
3. TAGCTGGT
4. TAGGAGAT
5. ATGCATCG
6. CGGCTACG
7. ATATAGCTA

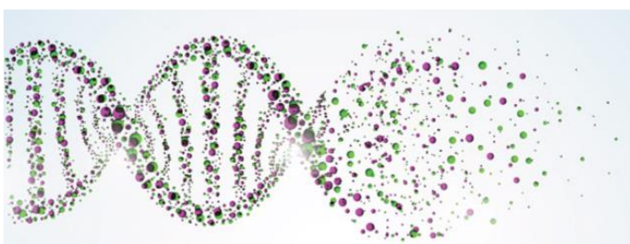
Individuals do better
@ cold extremes

Big robust tropical pops that lack V_A for handling stress:

Why?

Temperate zone

- Localised adaptation?
- Pleiotropy?
- DNA decay?



Population variants @ thermal tolerance loci:

1. ATGCGCAT
2. CGCCCTCT
3. TAGCTGGT
4. TAGGAGAT
5. ATGCATCG
6. CGGCTACG
7. ~~ATATAXCTA~~

Deleterious mutation

Big robust tropical pops that lack V_A for handling stress:

Why?

Temperate zone

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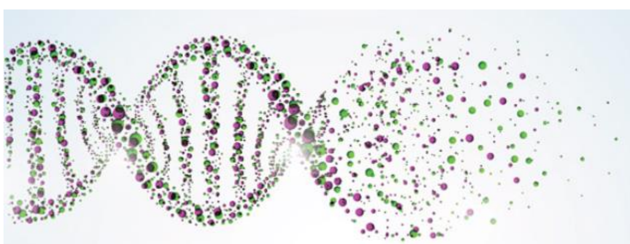
- Pleiotropy?
- DNA decay?



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Big robust tropical pops that lack V_A for handling stress:

Why?

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- Pleiotropy?
- DNA decay?

e.g: Thermal tolerance loci:

1. **ATGCGCAT**
2. **CGCCCTCT**
3. **TAGCTGGT**
4. **TAGGAGAT**
5. **ATGCATCG**
6. **CGGCTACG**
7. **ATATAGCTA**

Tropics

Less selective pressure in the Tropics

Big robust tropical pops that lack V_A for handling stress:
Why?

- Localised adaptation?
- Pleiotropy?
- DNA decay?

Mutation
but not deleterious!

e.g: Thermal tolerance loci:

1. **ATGCXCAT**
2. **CGCCCTCT**
3. **TAGCTGGT**
4. **TAGGAGAT**
5. **ATGCATCG**
6. **CGGCTACG**
7. **ATATAGCTA**

Tropics

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Why?

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- Pleiotropy?
- DNA decay?

e.g: Thermal tolerance loci:

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7. **ATATAXCTA**

Tropics

Big robust tropical pops that lack V_A for handling stress:

Why?

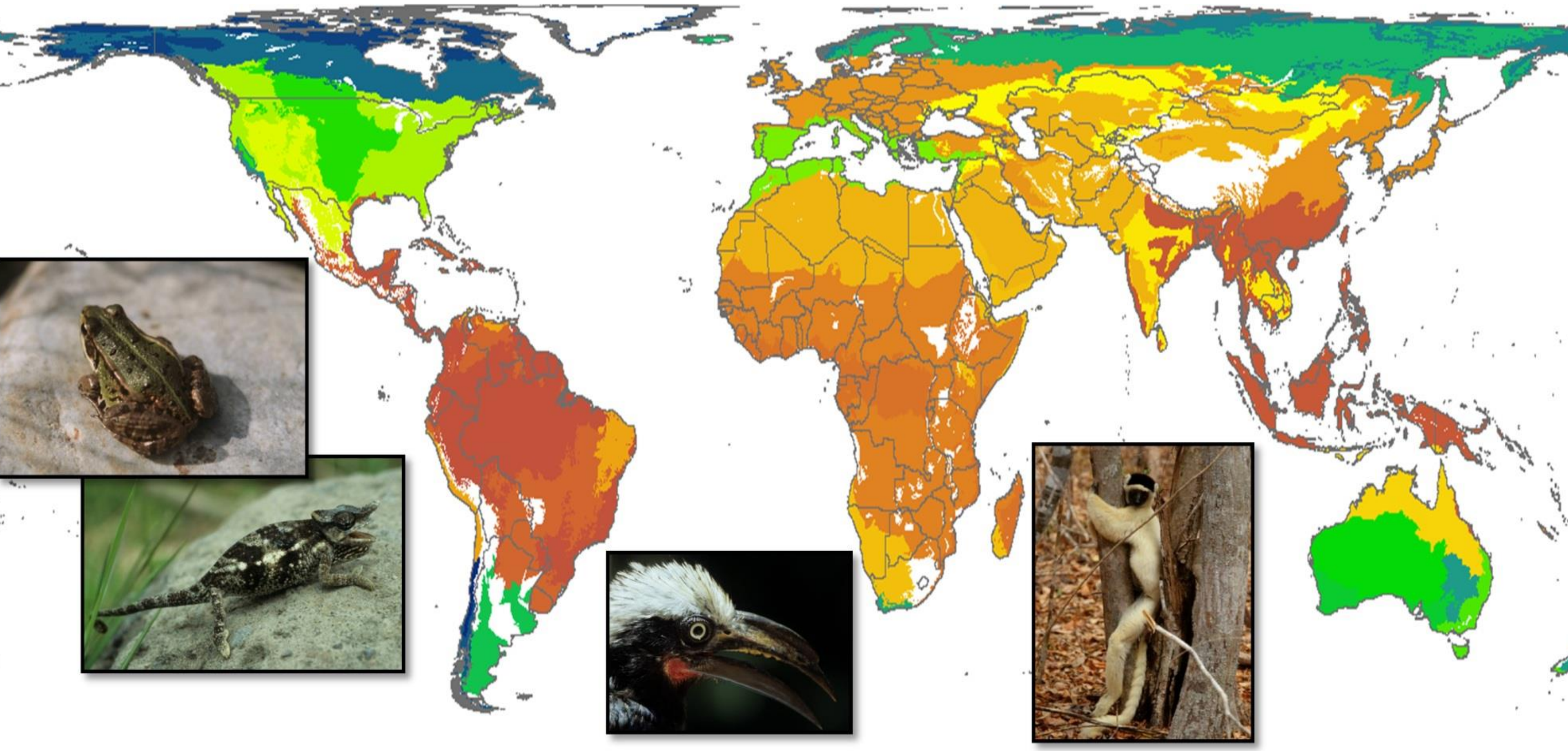
- Localised adaptation?
- Pleiotropy?
- DNA decay?

e.g: Thermal tolerance loci:

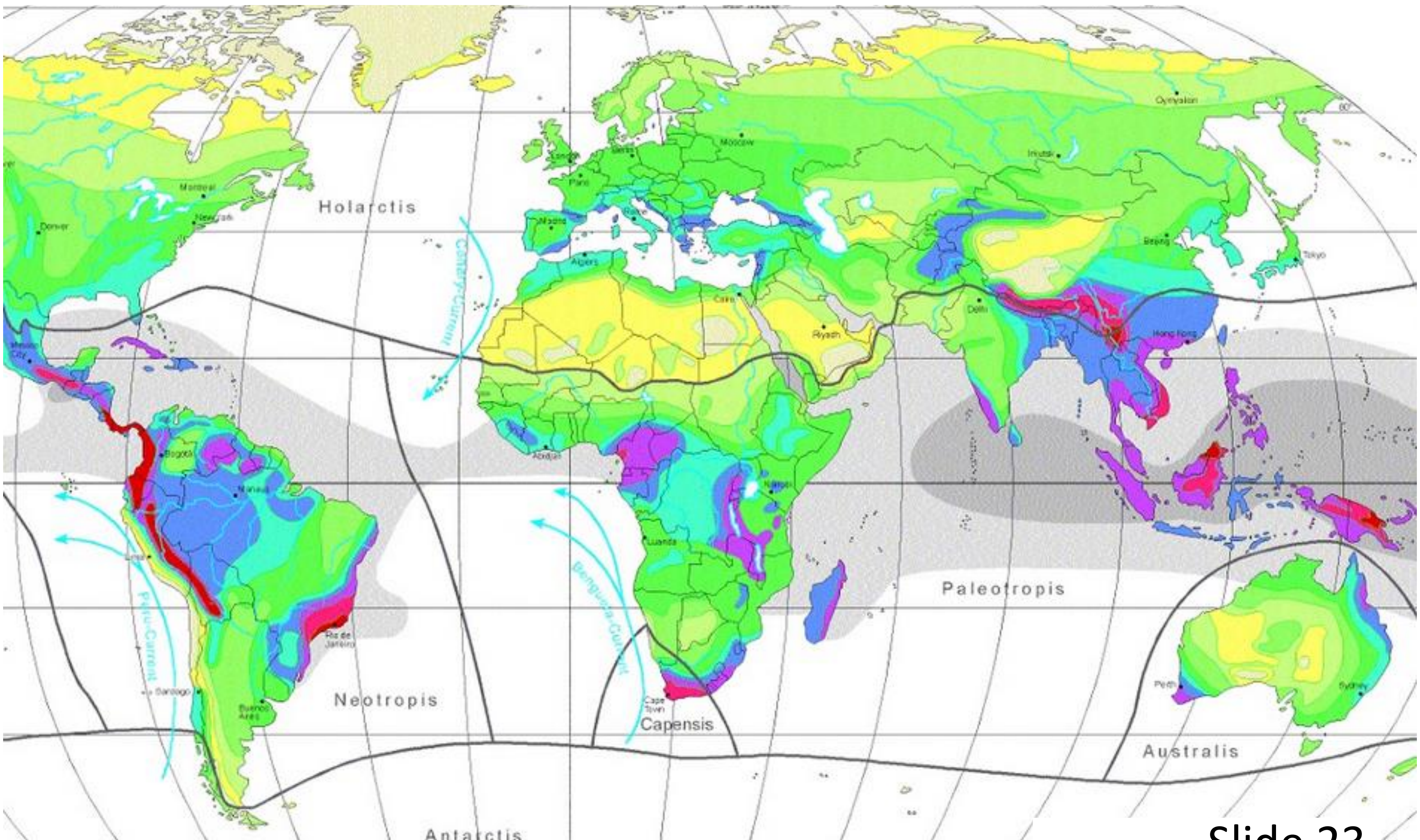
1. XTGCXCAT
2. CGCCCTCT
3. TAGCTGGT
4. TAGGAGAT
5. ATGXATCG
6. CGGCXXCG
7. ATATAXCTA

Tropics

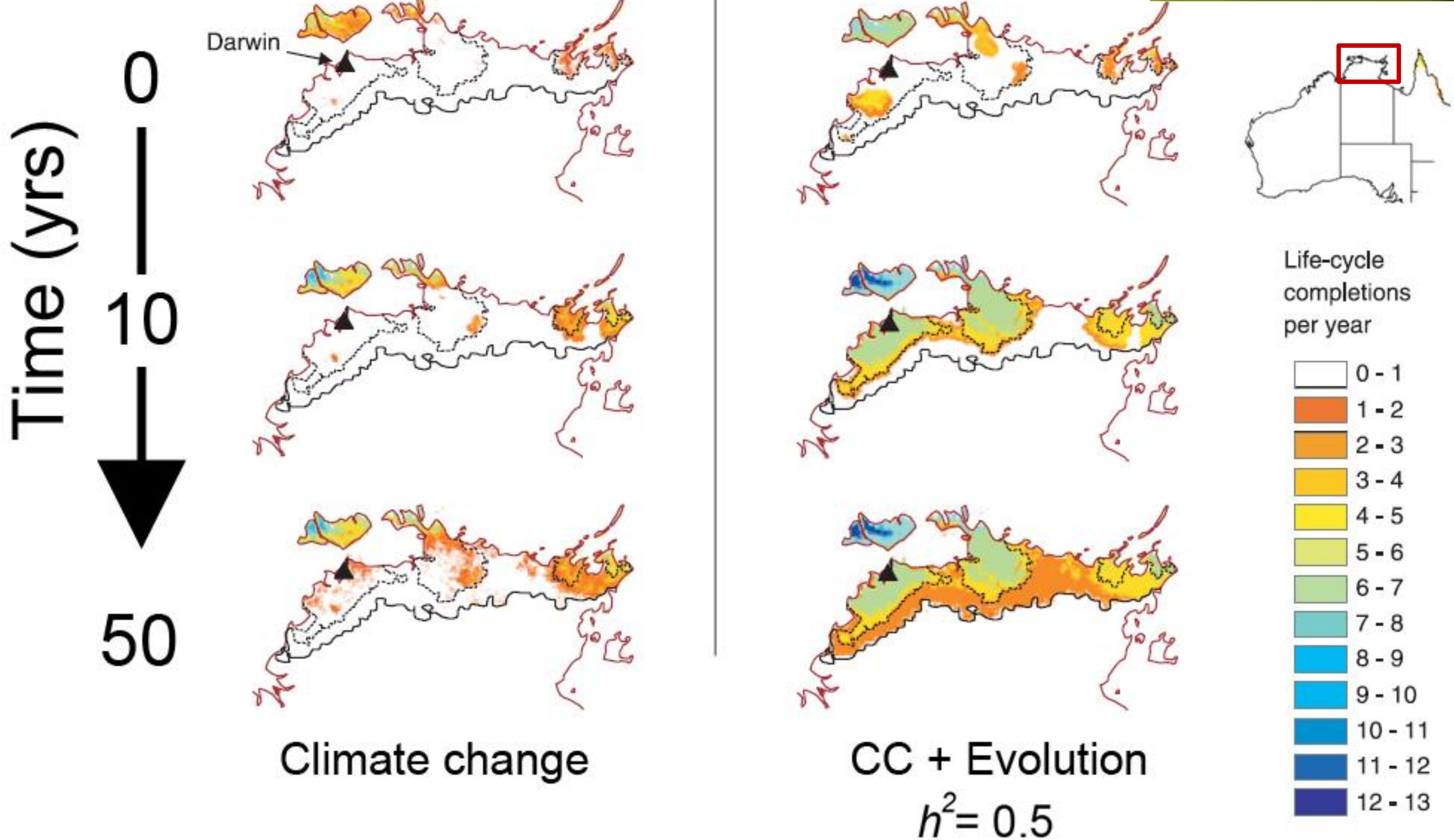
Global biodiversity: vertebrates



Global biodiversity: Vascular plants



Consequences for prediction…



Kearney *et al.* (2018) *Functional Ecology*

Next Lecture: Genetic Rescue