

Concepts, islands & continuums: a perspective on speciation genomics

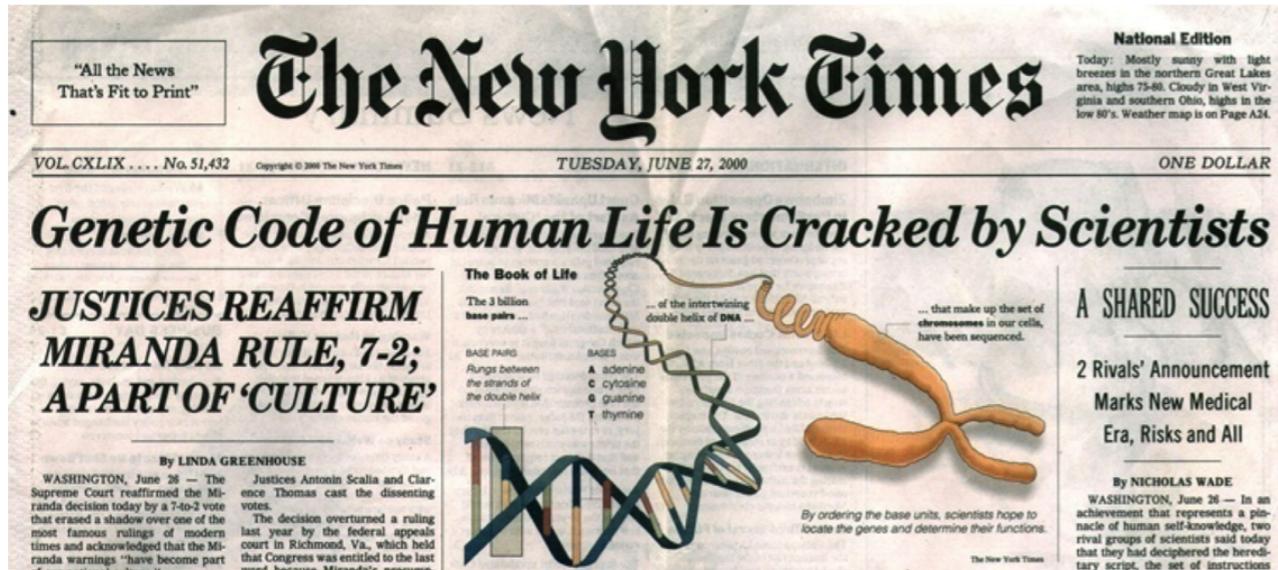


Mark Ravinet

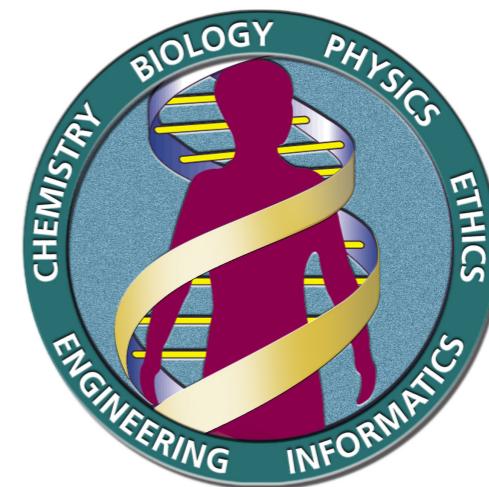
University of Nottingham, UK

@mark_ravinet mark.ravinet@nottingham.ac.uk

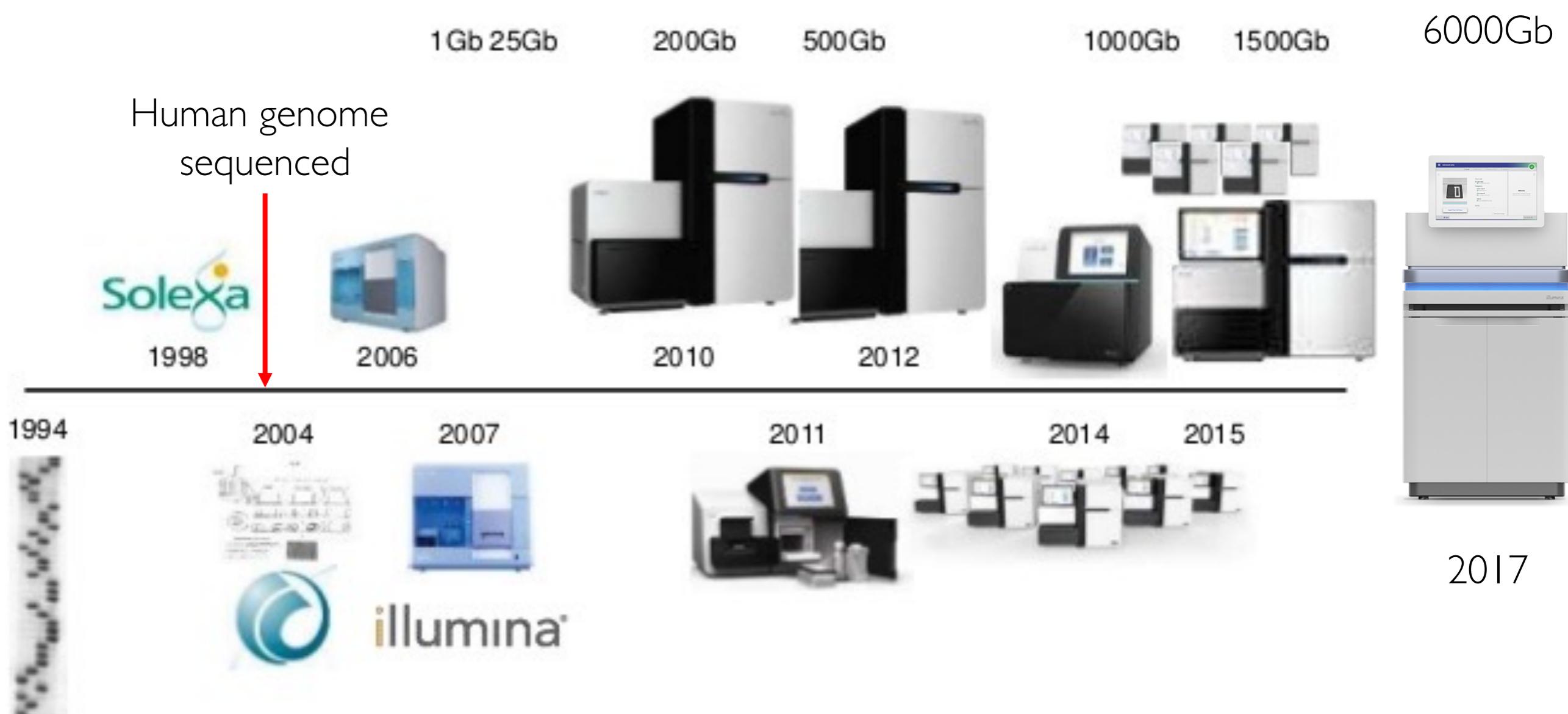
The Human Genome Project



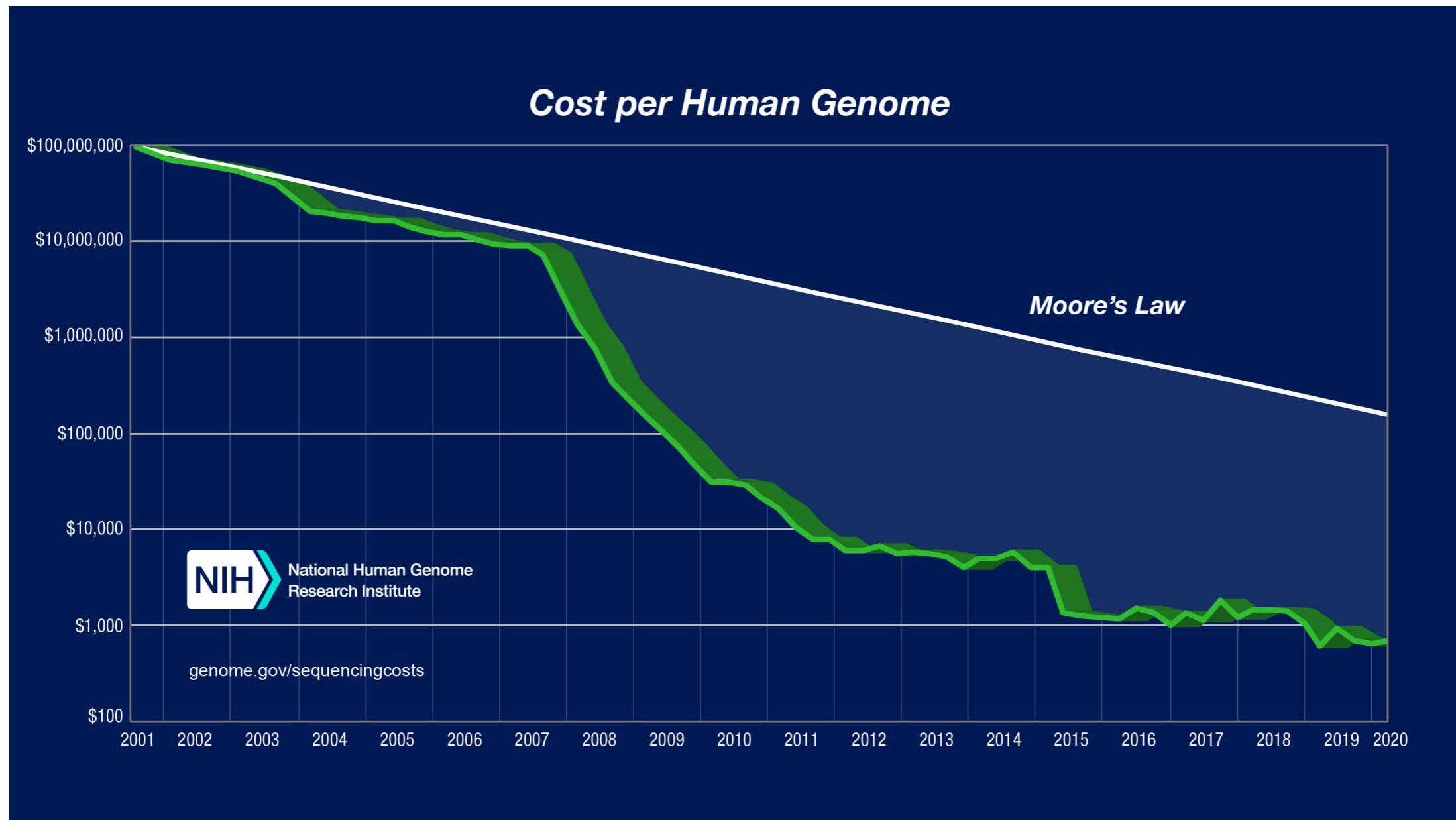
- Human genome project – started in 1990; draft sequence announced in June 2000; completed in 2003
- Sequenced across ~20 institutions worldwide
- Cost an approximate \$5 billion US dollars
- Put in place the methodological and computational infrastructure for large-scale sequencing projects



Rapid rise of sequencing methods

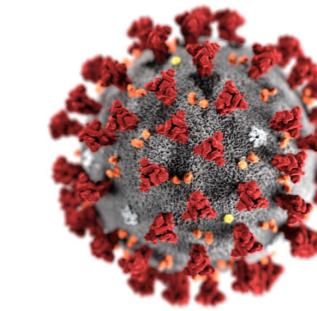
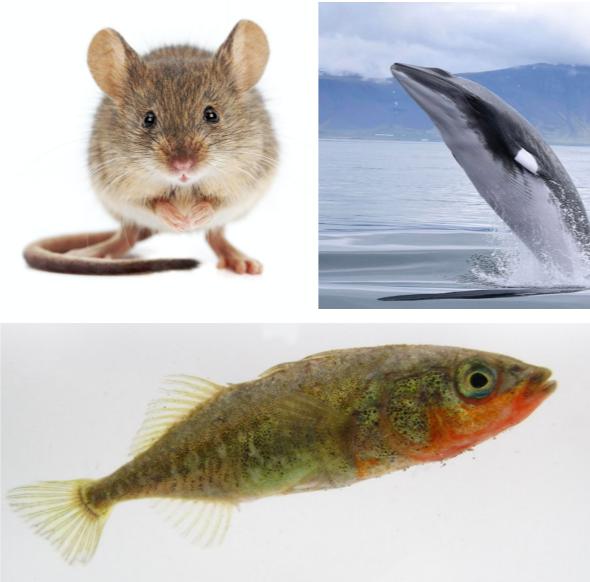


Approaching the \$1000 genome



The genomic era in biology

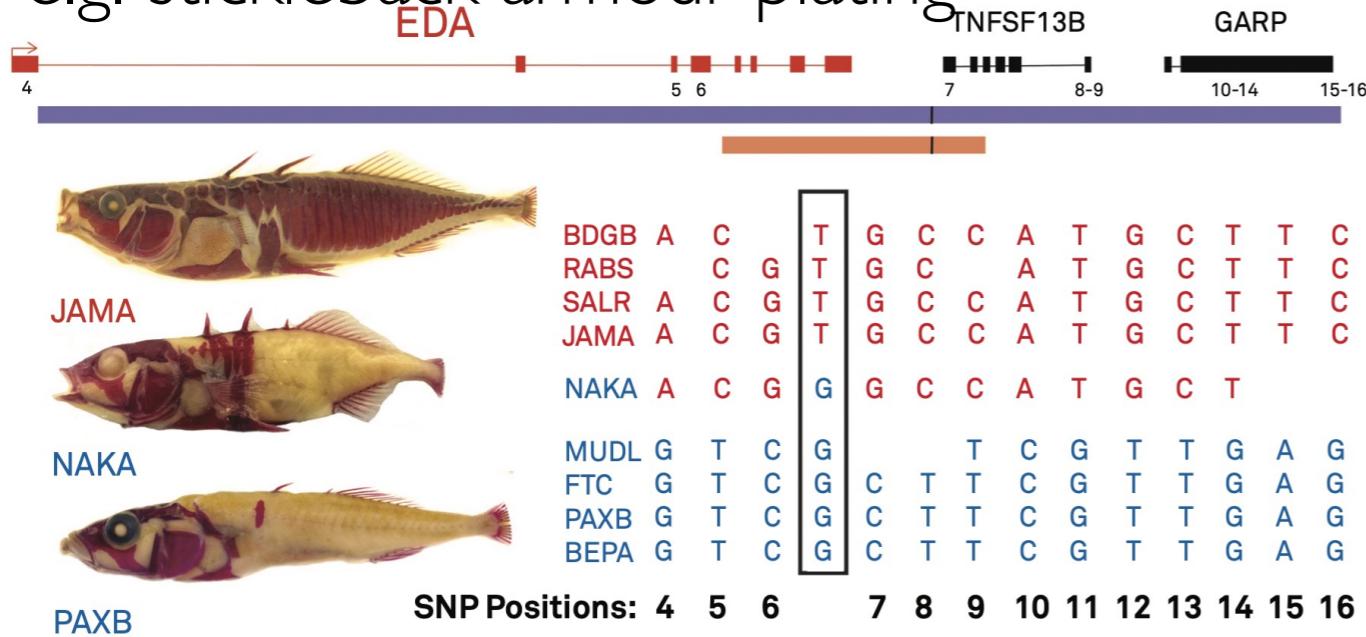
- A huge number of genomes now sequenced:
 - 362, 483 sequencing projects (Genomes Online Database)



A new look at old thinking

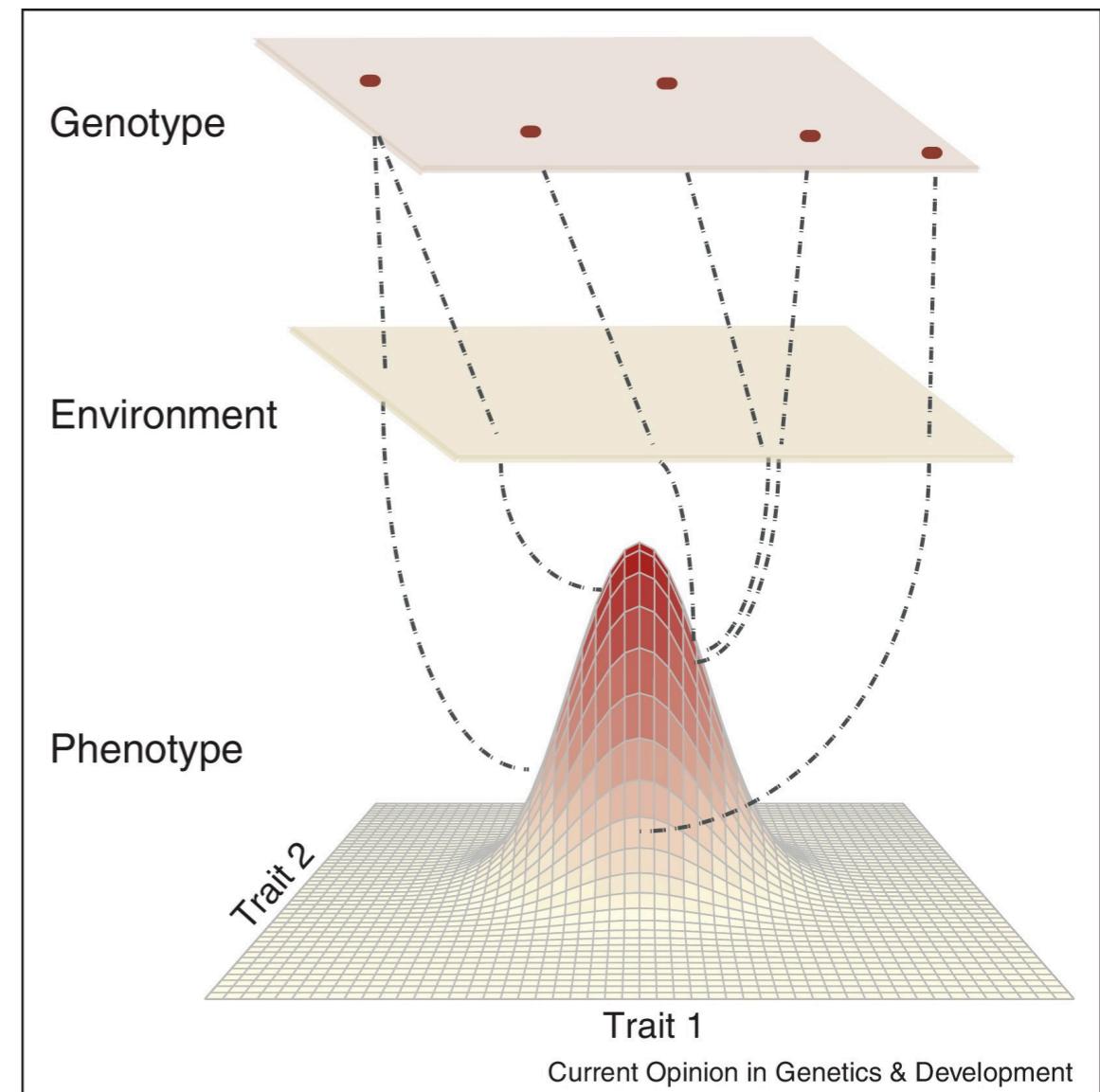
Genetic basis of phenotypic traits

e.g. stickleback armour plating

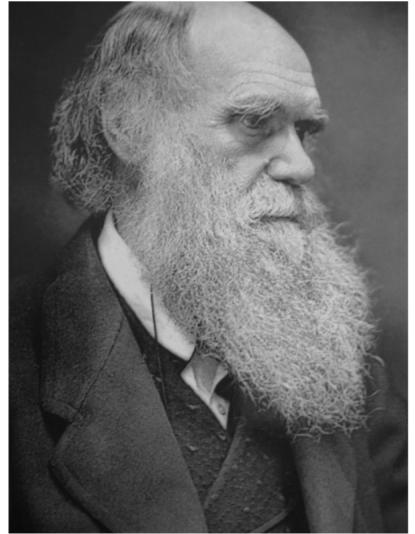


A need for balance & caution

- Genomics has helped our understanding but it cannot solve all problems
- Challenges and limits to our knowledge:
 - Distribution of effect sizes
 - The genomic architecture of complex traits
 - The genetic basis of reproductive isolation



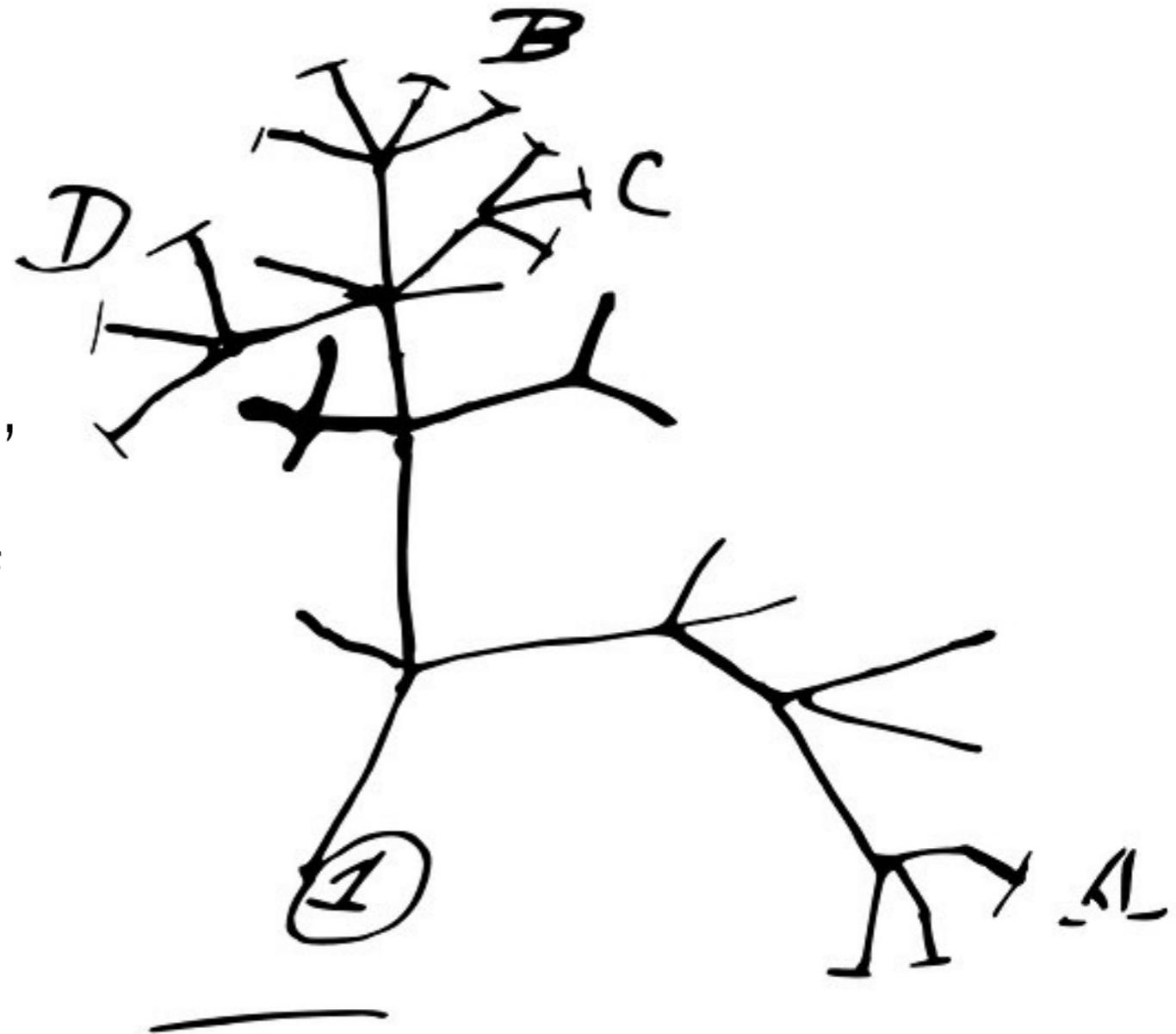
Darwin and the origin



“...that mystery of mysteries...”

Charles Darwin (1859) *The Origin of Species*

I think



Species concepts and the modern synthesis

“Species are groups of interbreeding natural populations... reproductively isolated from other such groups”

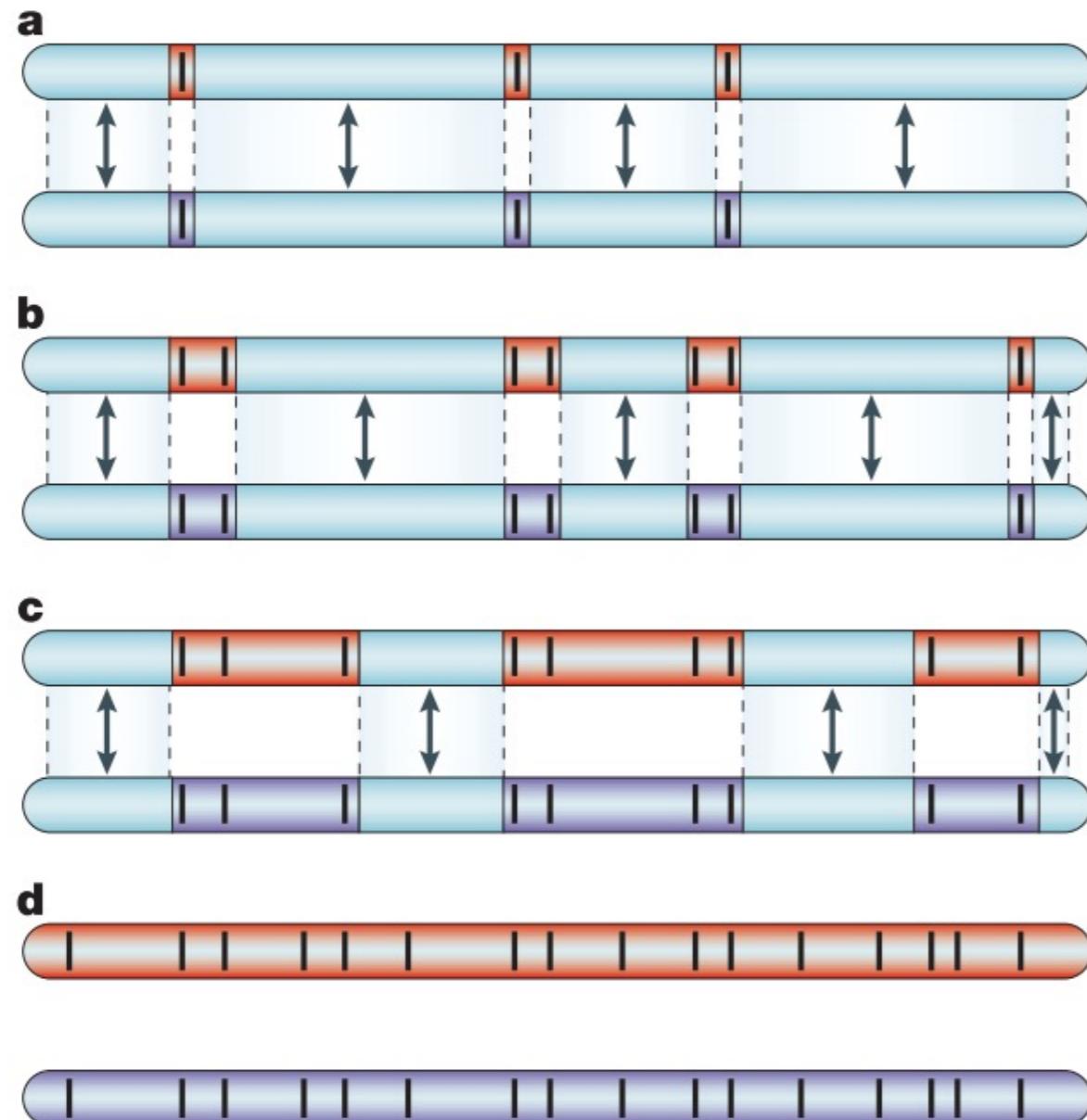
Ernst Mayr (1942) *Systematics and the Origin of Species*



“[The] existence of discrete groups... constitutes evidence that some mechanisms... [isolate] them”

Theodosius Dobzhansky (1937) *Genetics and the Origin of Species*

The genic concept of speciation



Divergent loci resist gene flow

Gene flow continues but linkage builds and divergent regions grow

Complete reproductive isolation evolves

Hybrid zones and gene flow

“Narrow regions in which genetically distinct organisms meet, mate and produce hybrids”

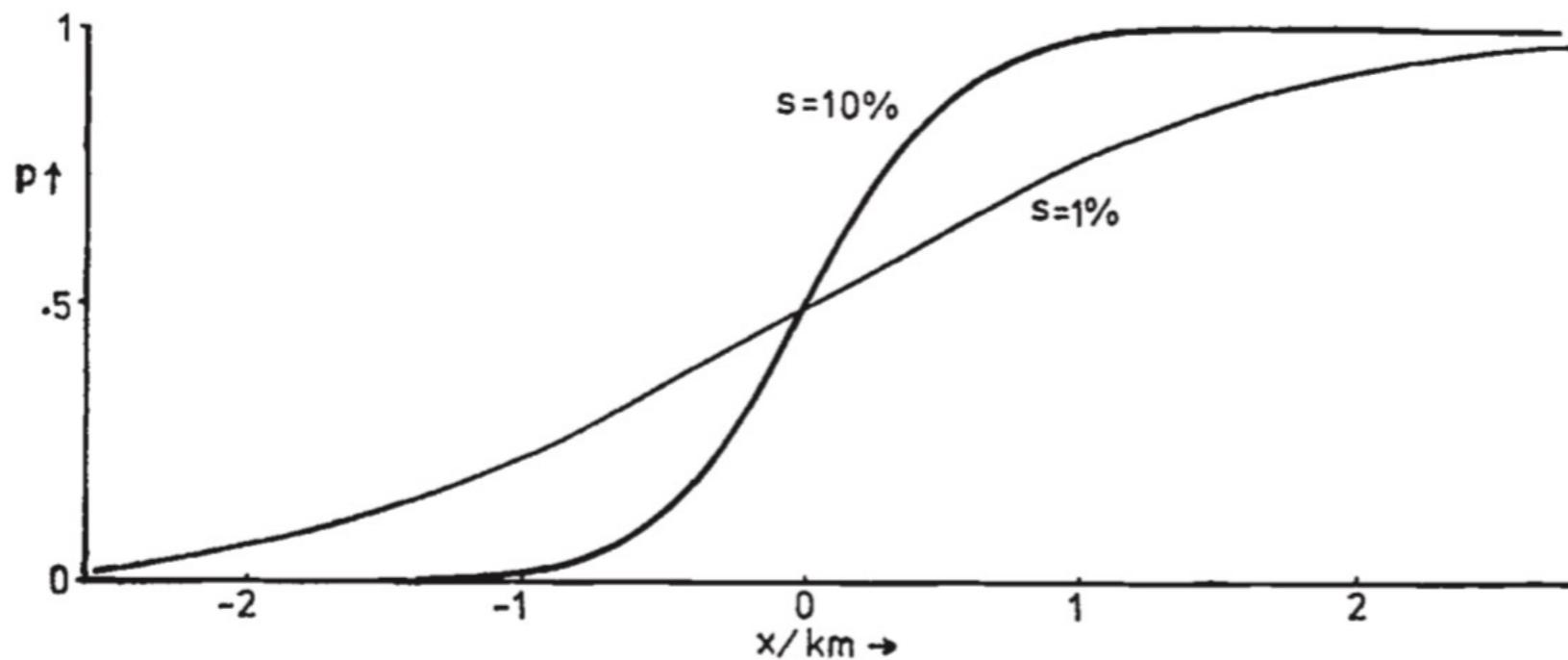


FIG. 1.—Hybrid zones produced by selection against heterozygotes;
dispersal $\sqrt{m} = 112 \text{ m.gen.}^{-\frac{1}{2}}$

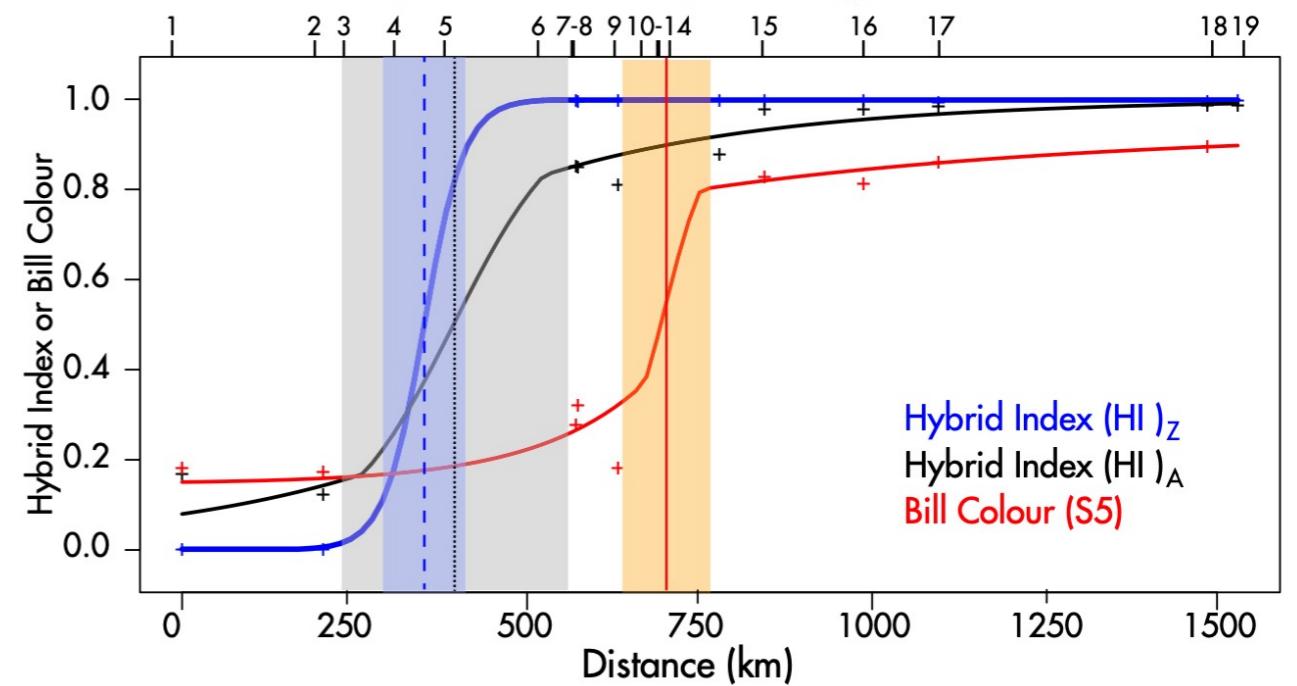
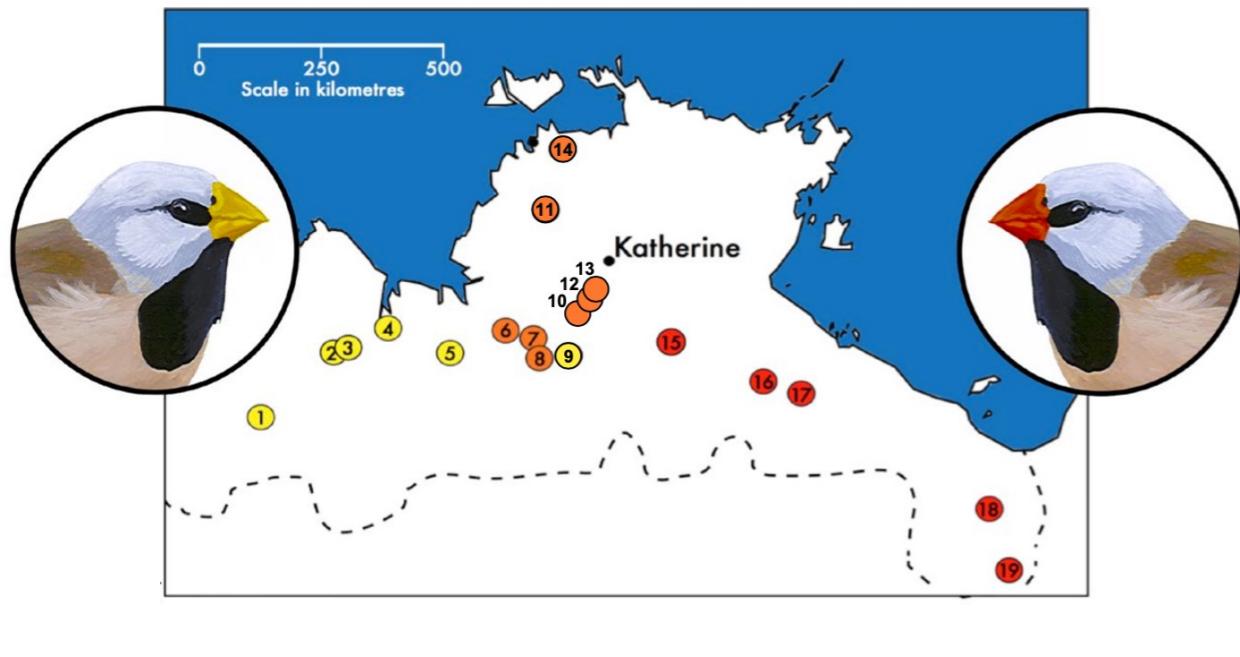
Barton (1979) **Heredity**

“Maintained by a balance between dispersal and selection against hybrids”

Barton & Hewitt (1989) **Nature**

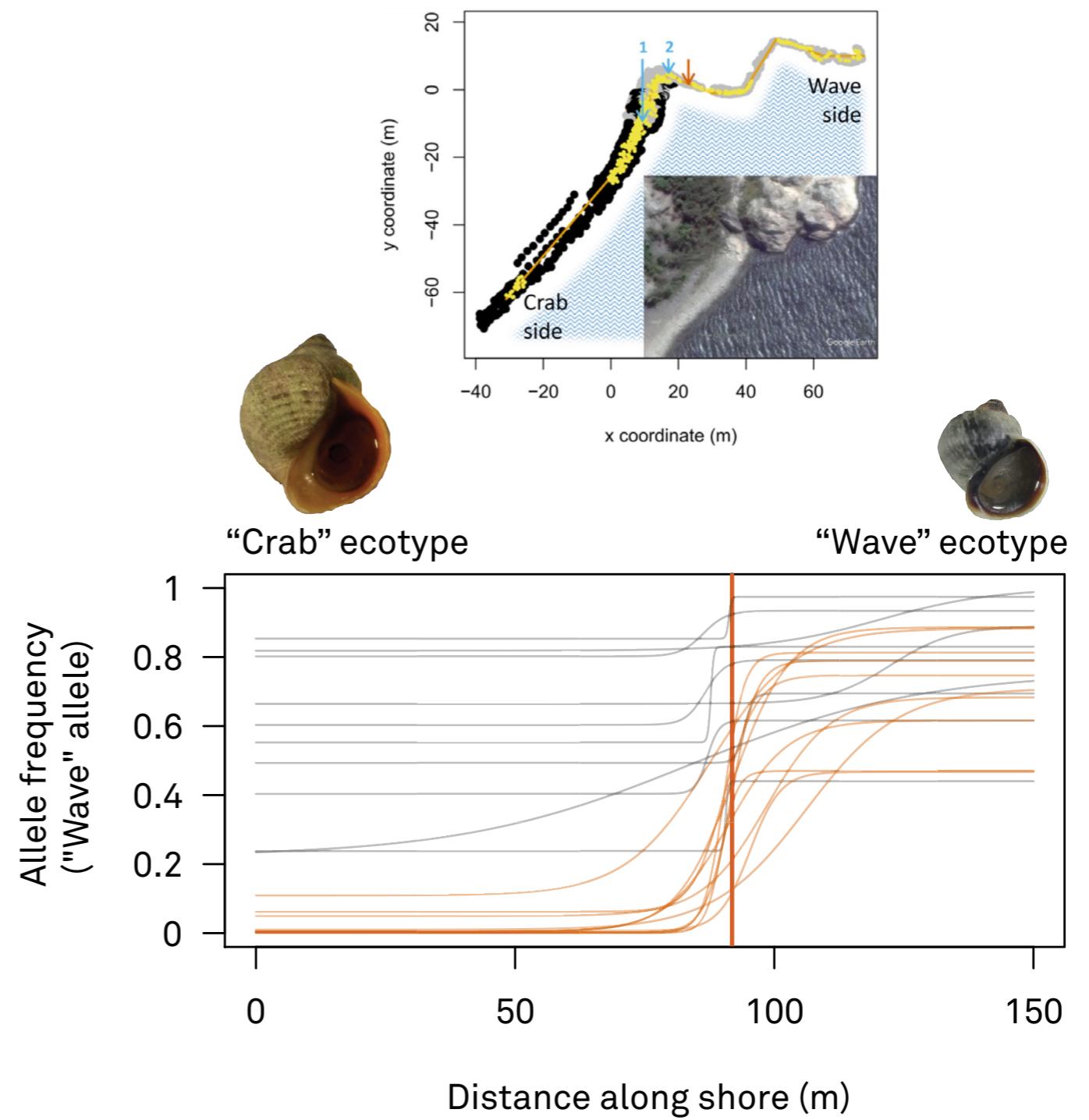
Hybrid zones: natural laboratories

- Contact zones between species
- Context on how some genes move across barriers



Hybrid zones: natural laboratories

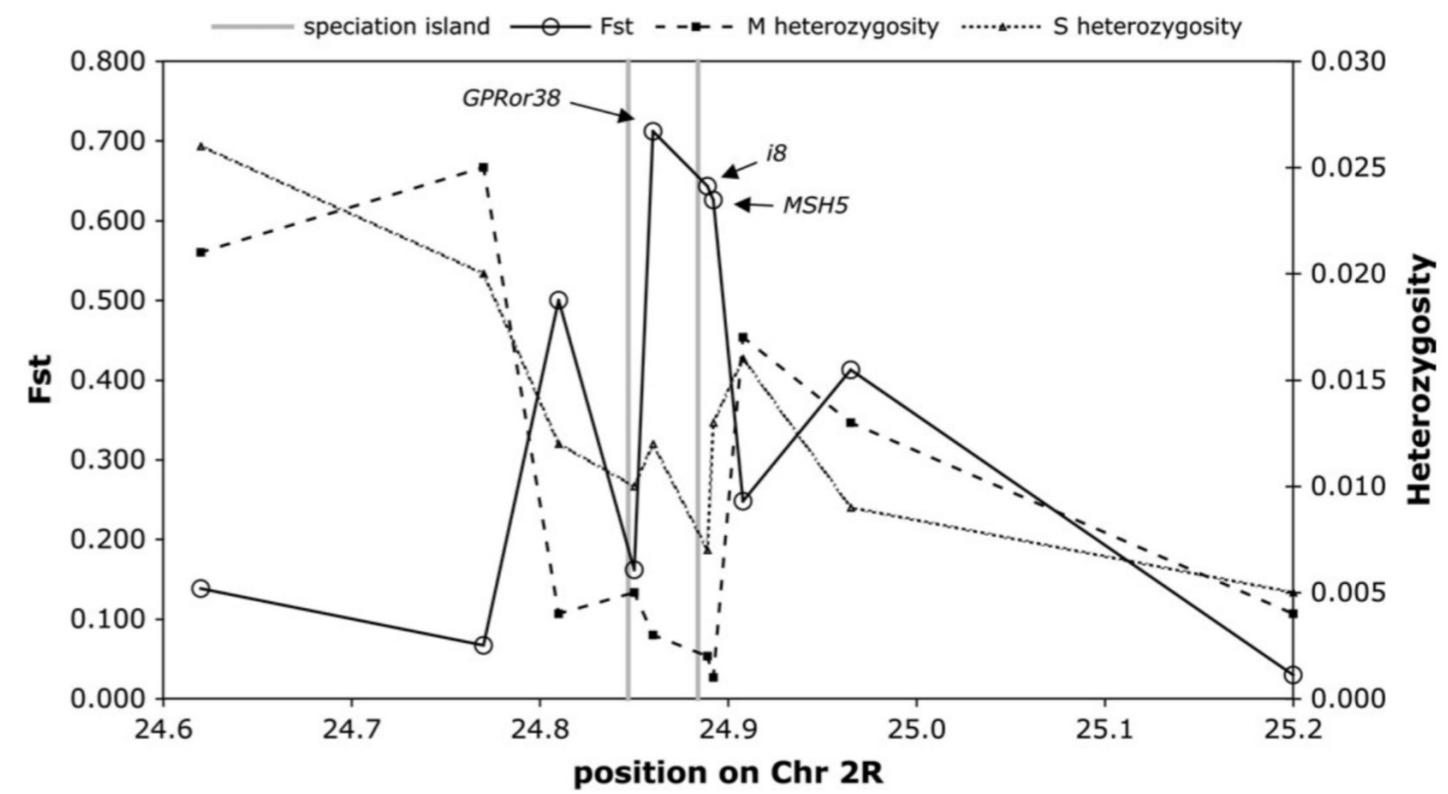
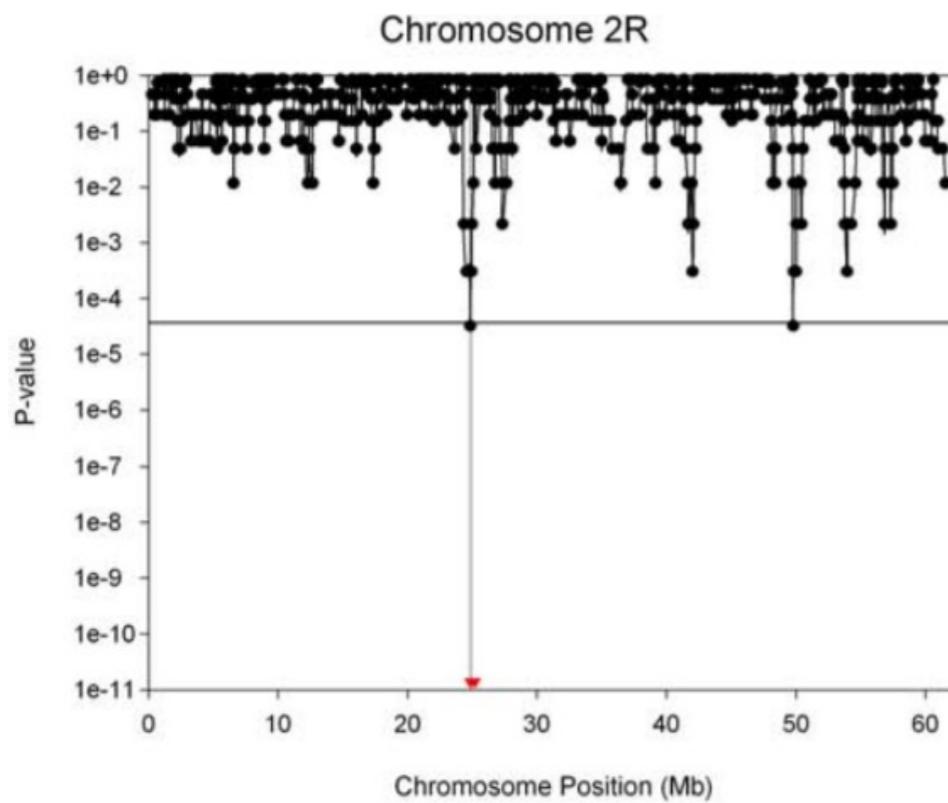
Littorina saxatilis
Western Sweden



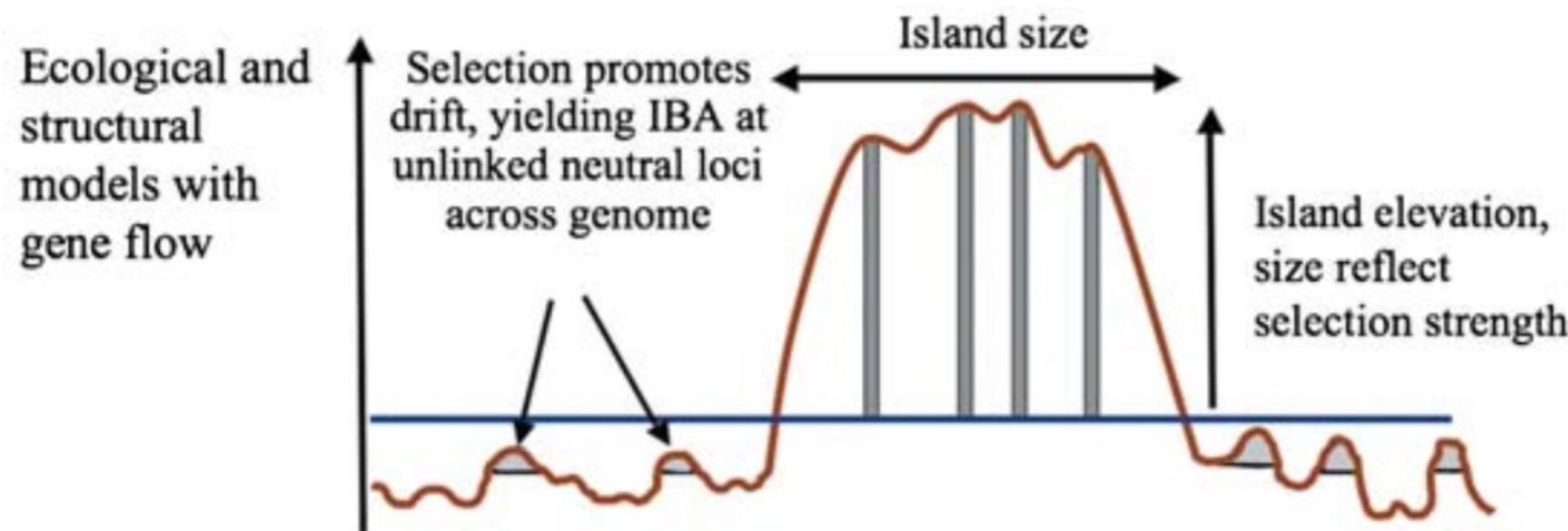
The rise of speciation islands



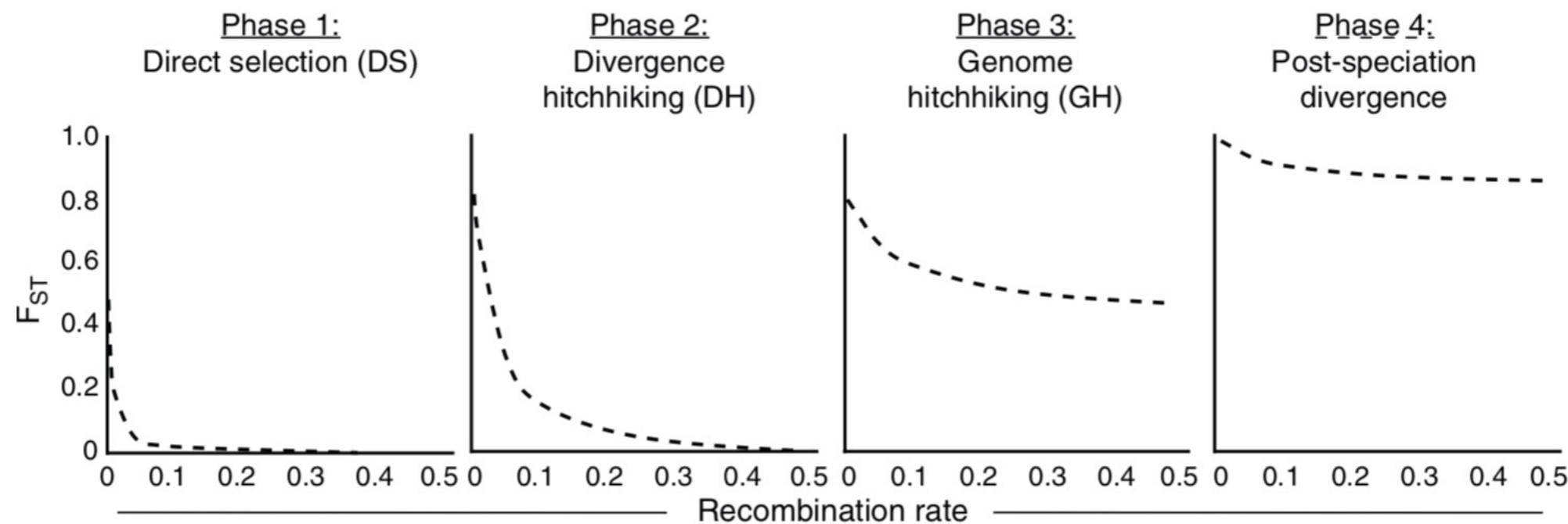
Anopheles gambiae
M + S forms



Speciation islands and processes

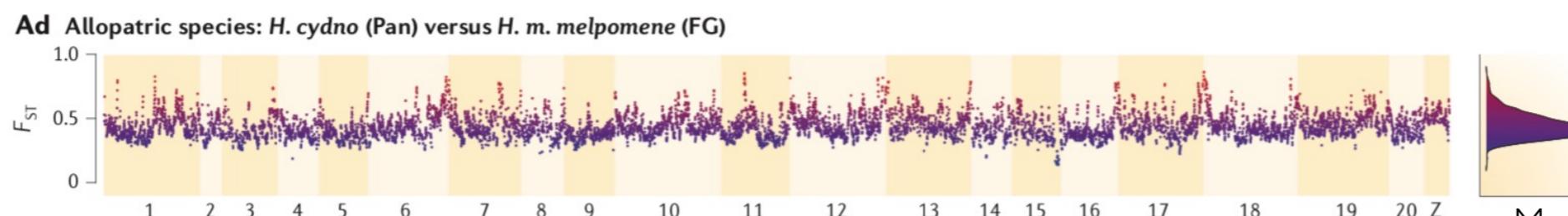
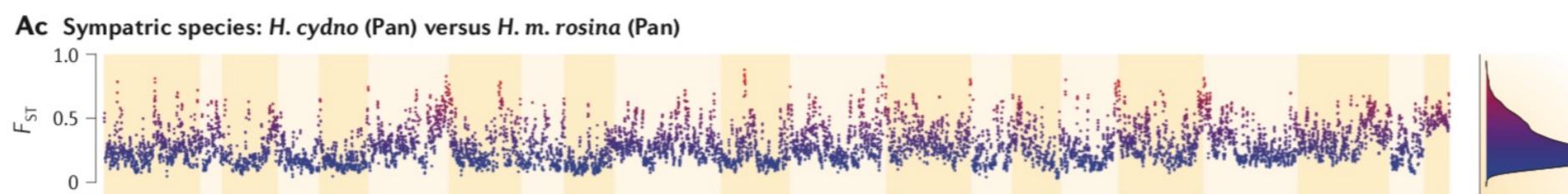
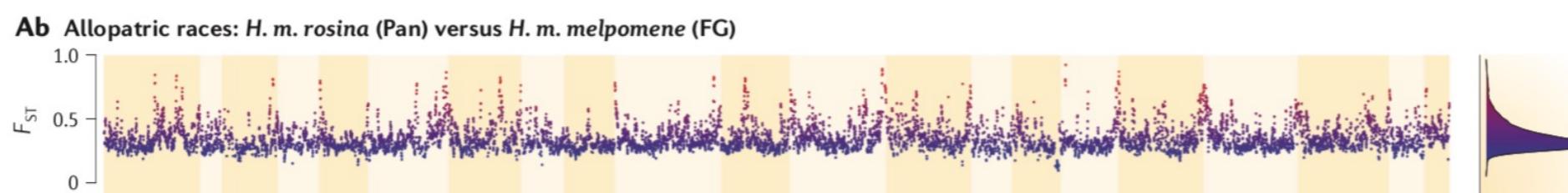
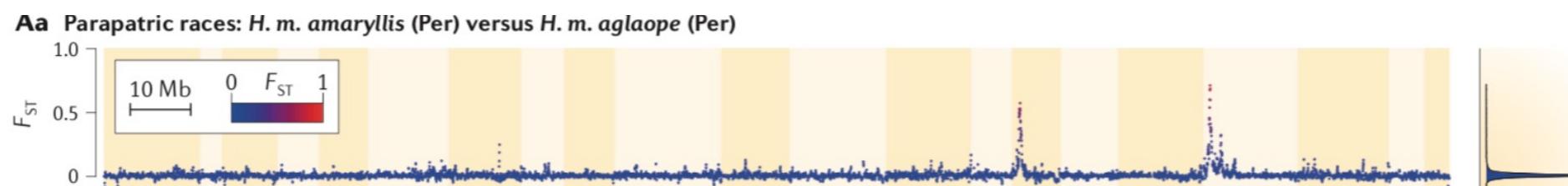
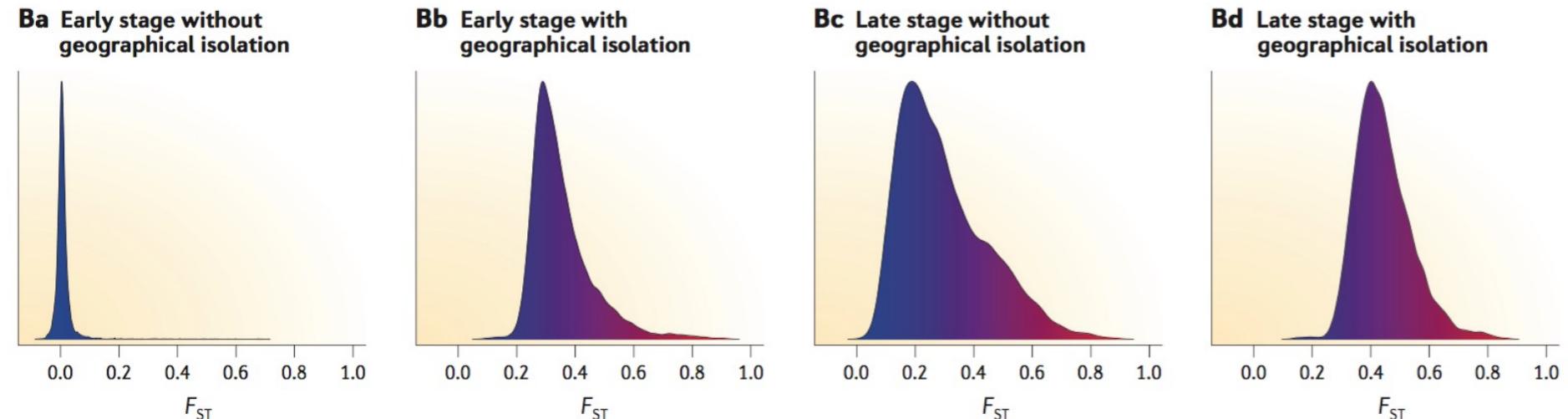


Nosil et al (2009) **Mol Ecol**



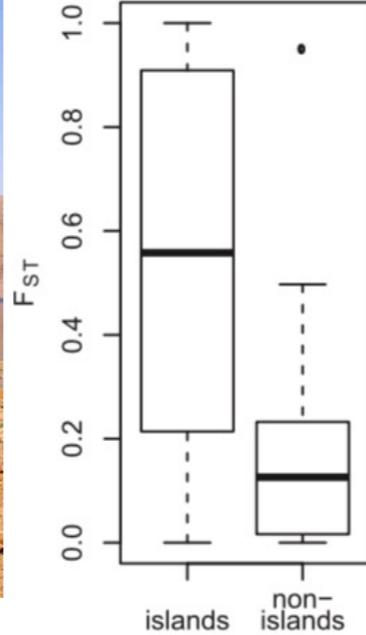
Feder et al (2012) **Trends in Genetics**

Continuums and islands

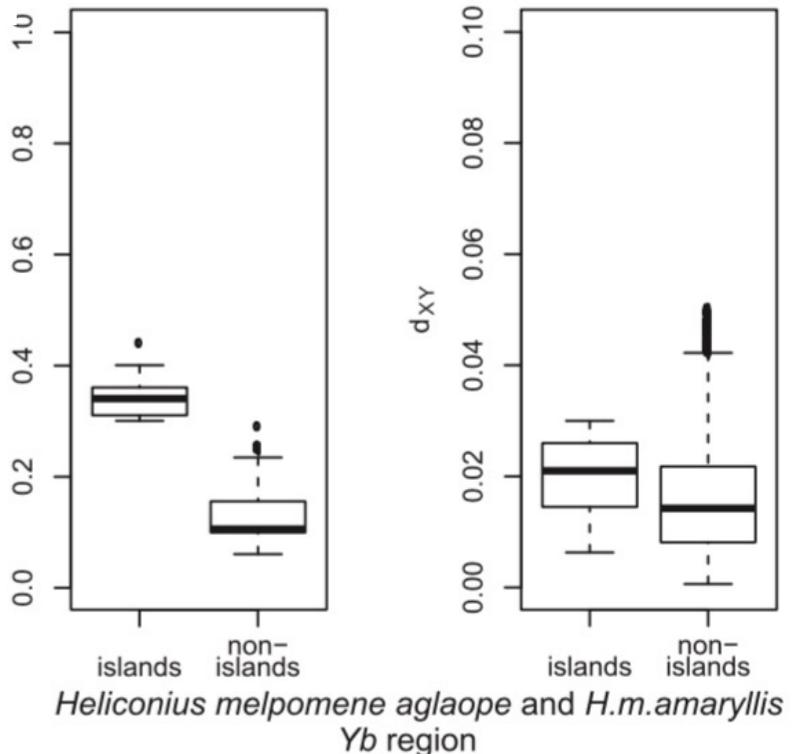
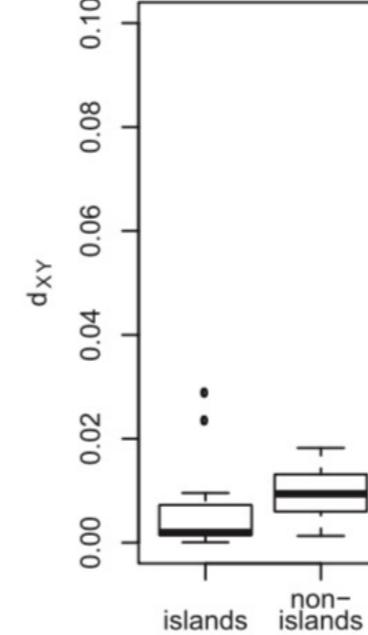


Martin et al. (2013) **Genome Research**
Seehausen et al (2014) **Nat. Rev. Gen**

Mirages and alternative explanations



Anopheles coluzzii and *A. gambiae*

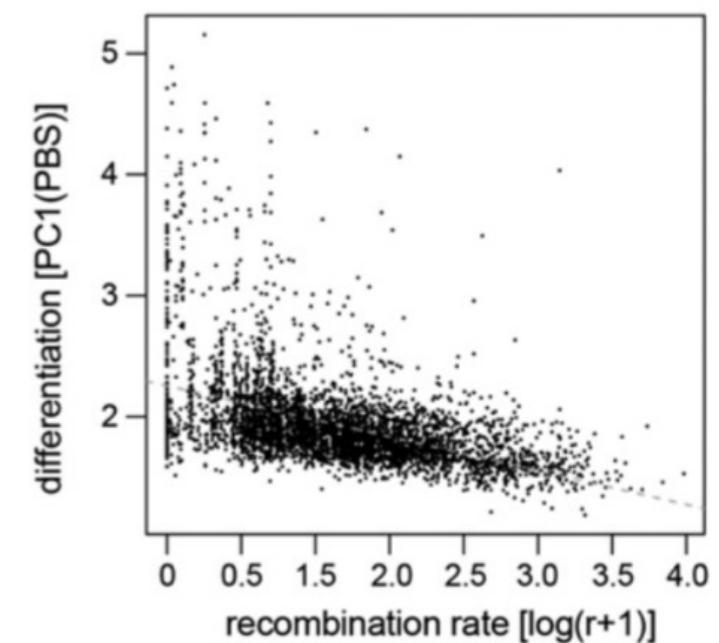
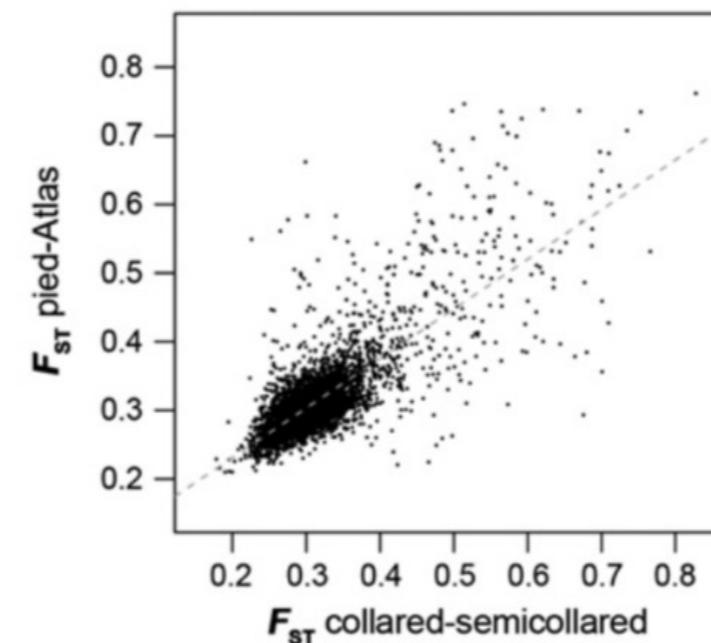
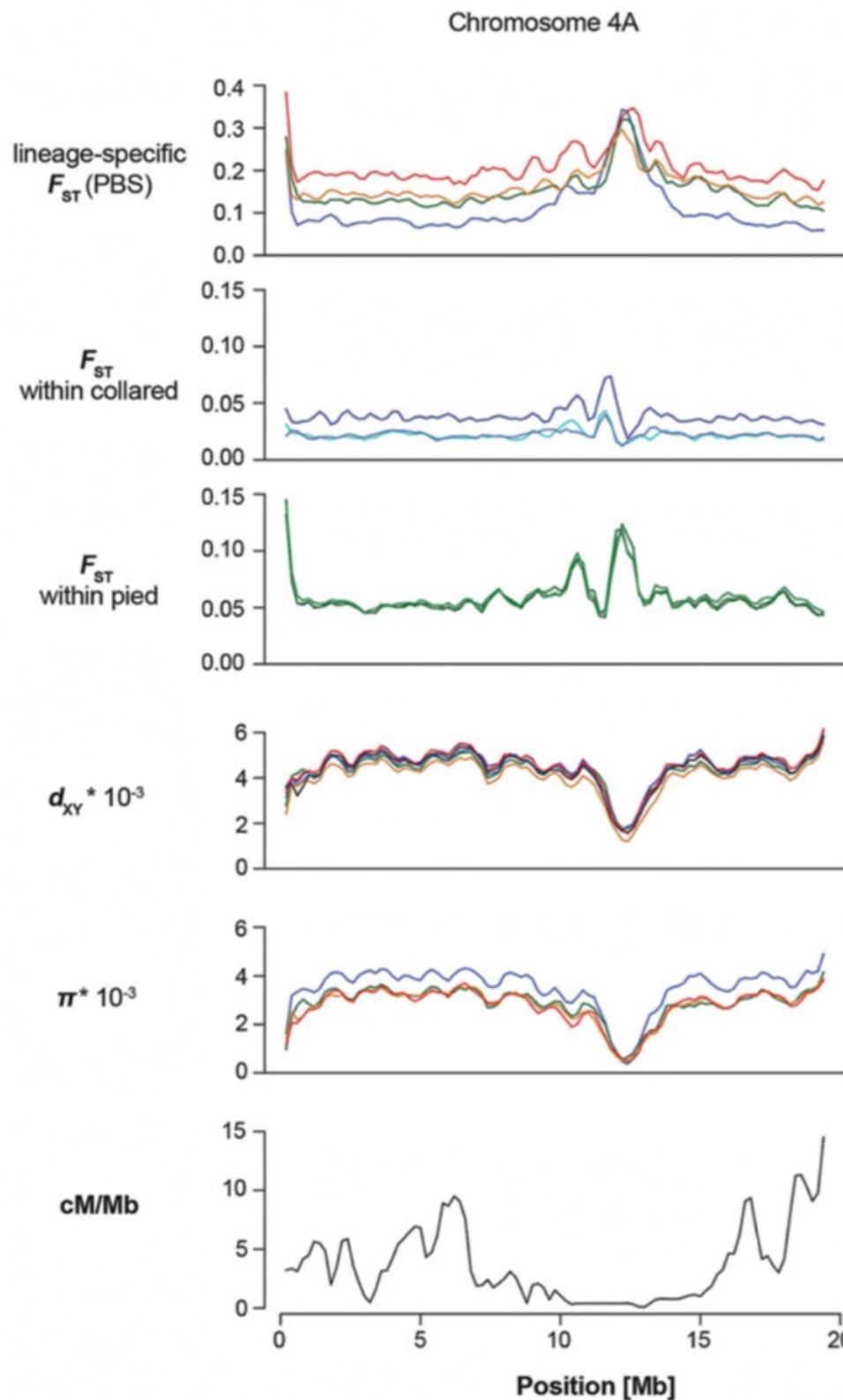


Heliconius melpomene aglaope and *H.m. amaryllis*
Yb region

- Background selection
- Local adaptation after isolation
- Shared ancestral polymorphism

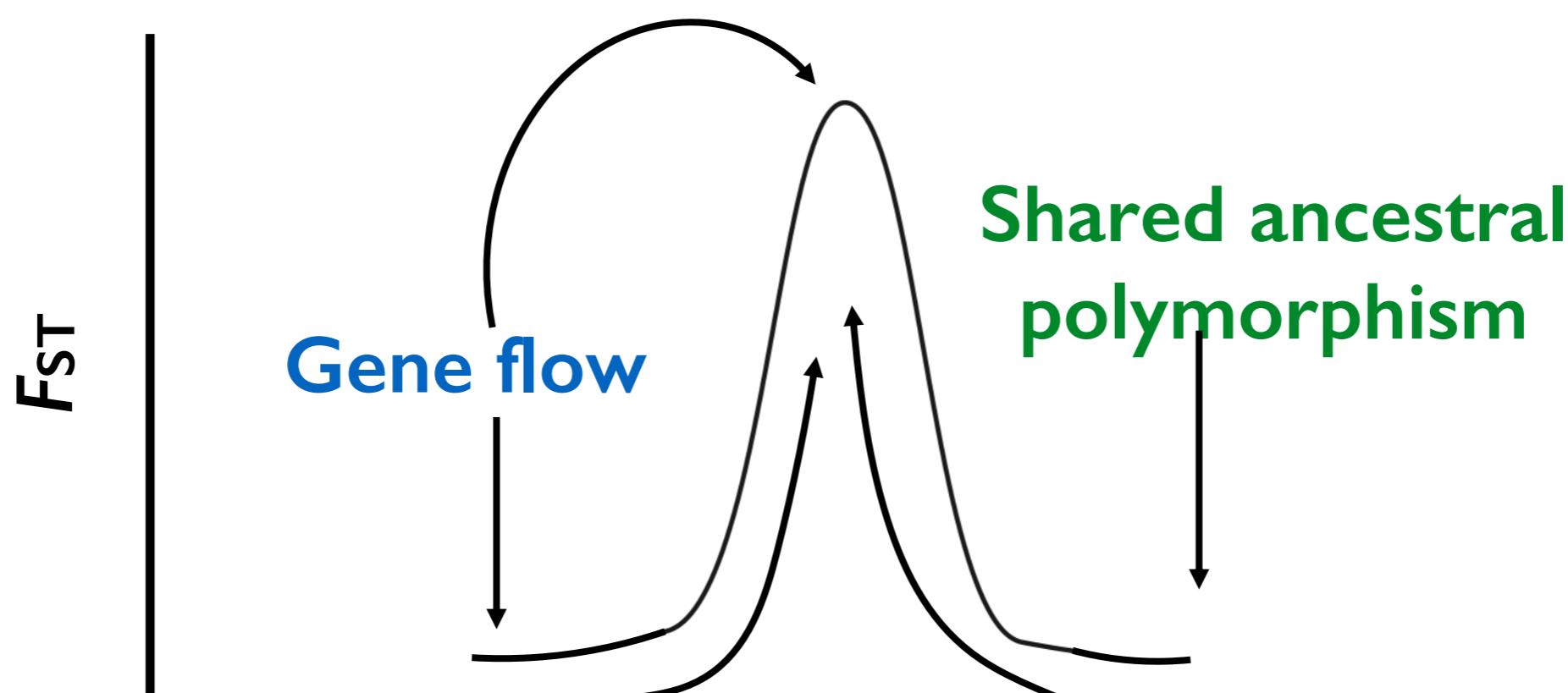
Noor & Bennett (2008) **Heredity**
Cruickshank & Hahn (2014) **Mol Ecol**

Linked selection and recombination



Confounding factors

Demographic history



Background selection

Shared ancestral polymorphism

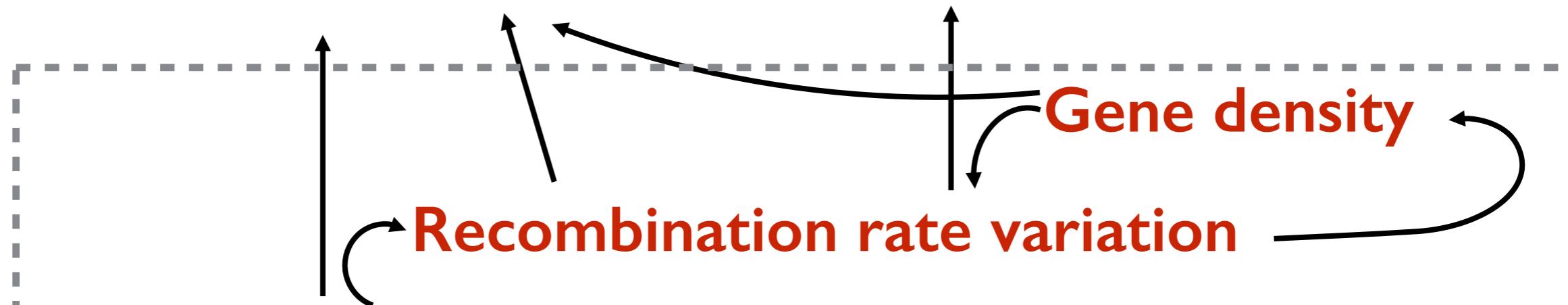
Divergent selection

Mutation rate variation

Genome features

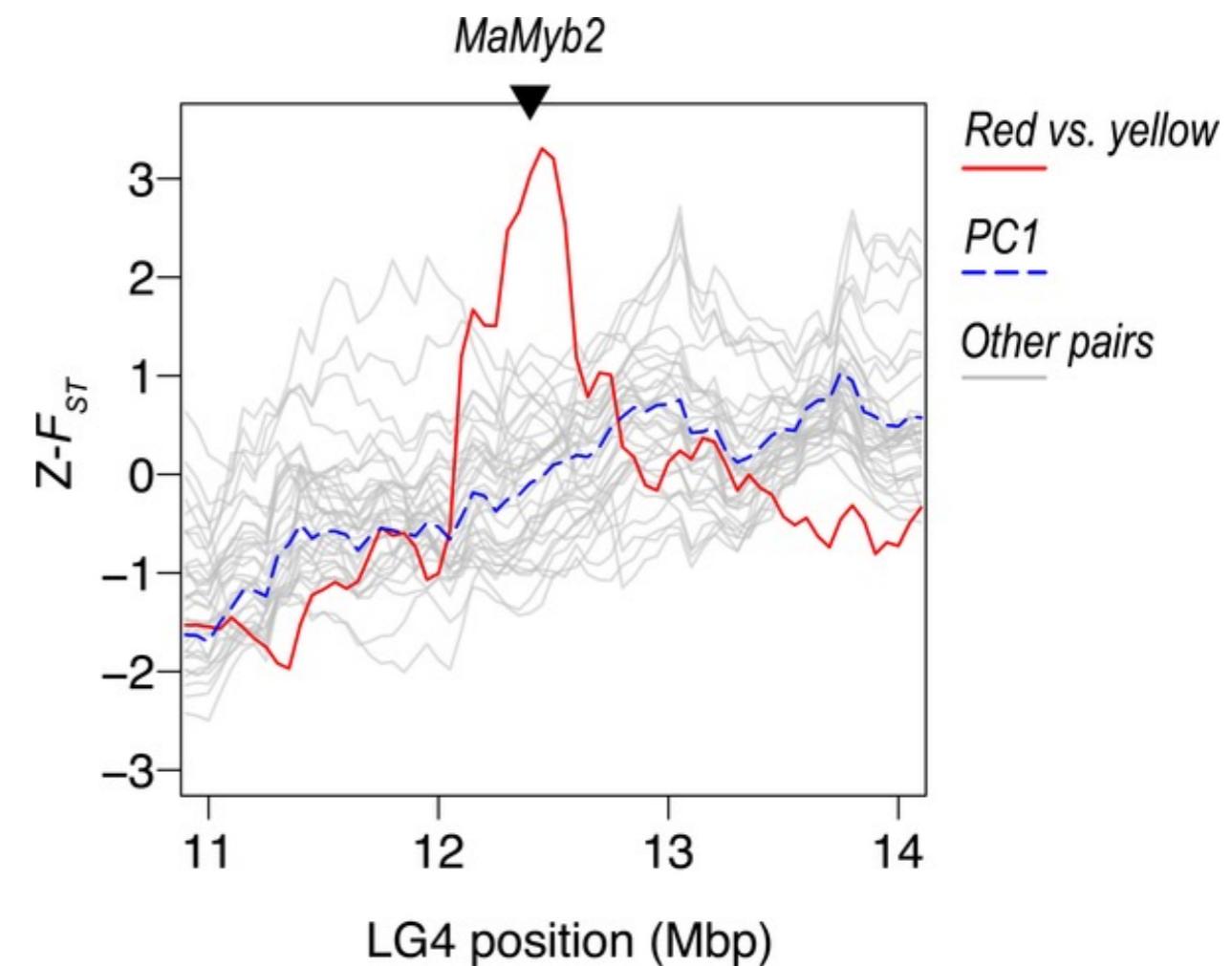
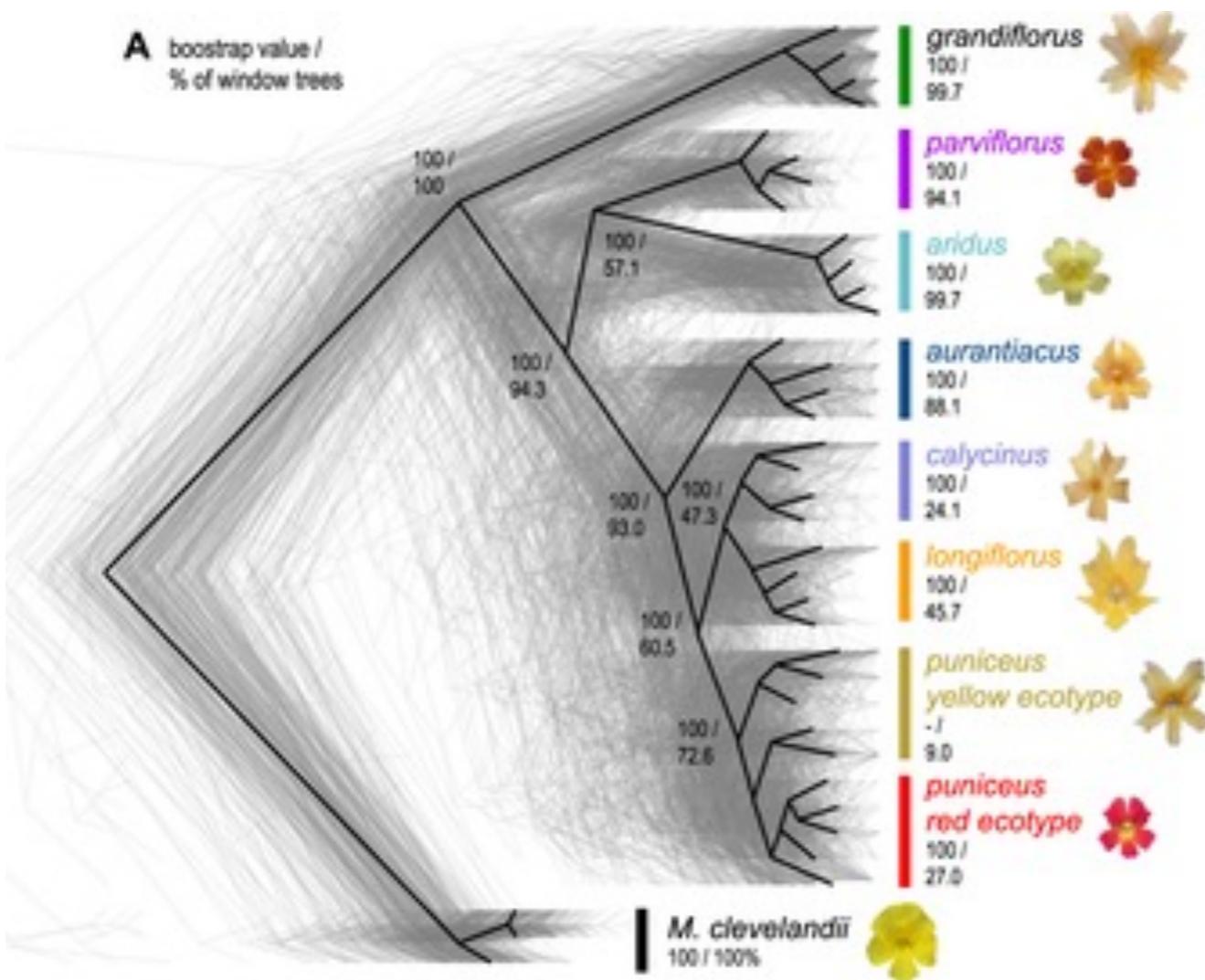
Recombination rate variation

Gene density

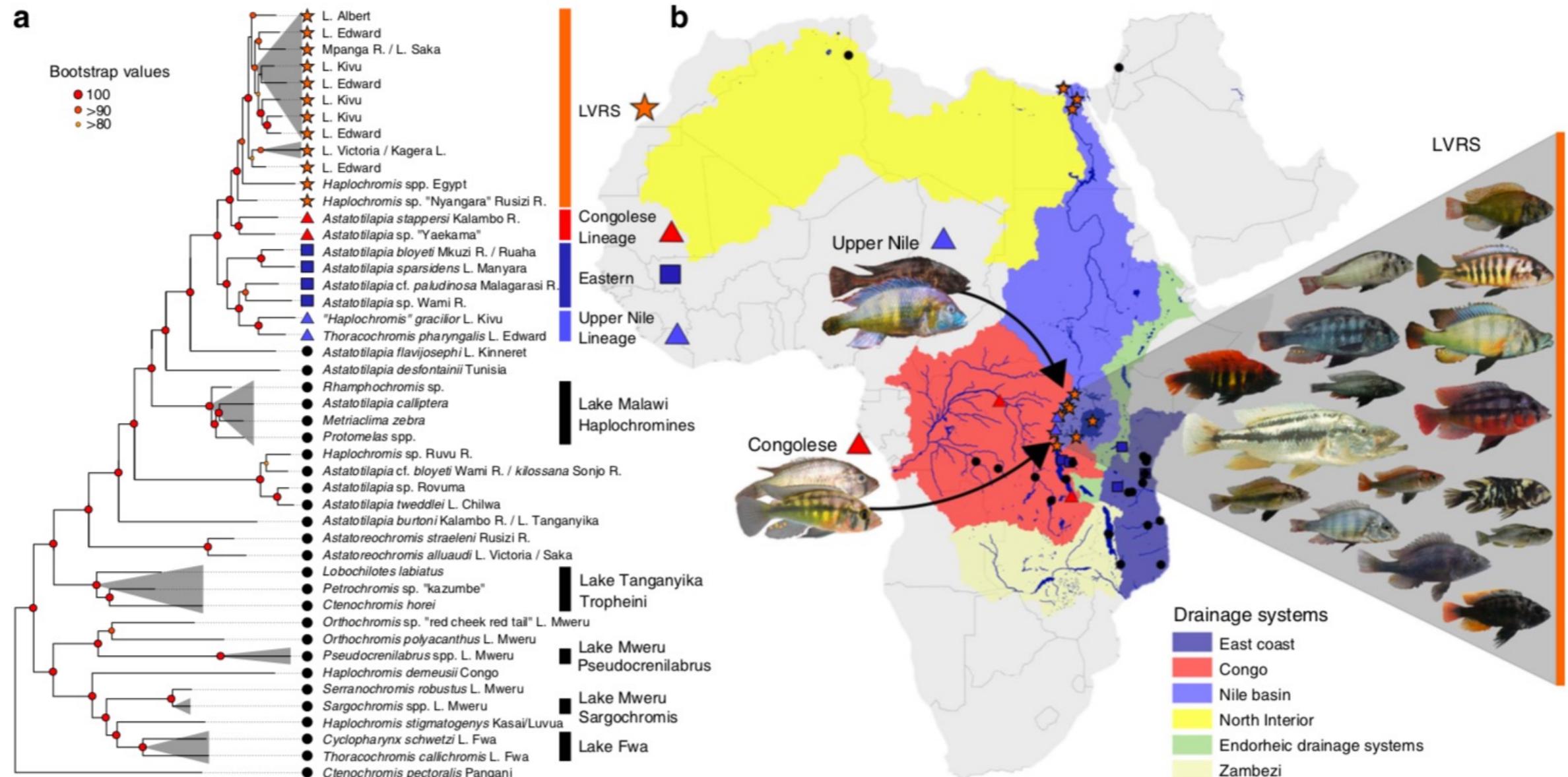


Evidence for speciation-with-gene-flow

- *Mimulus* monkeyflowers

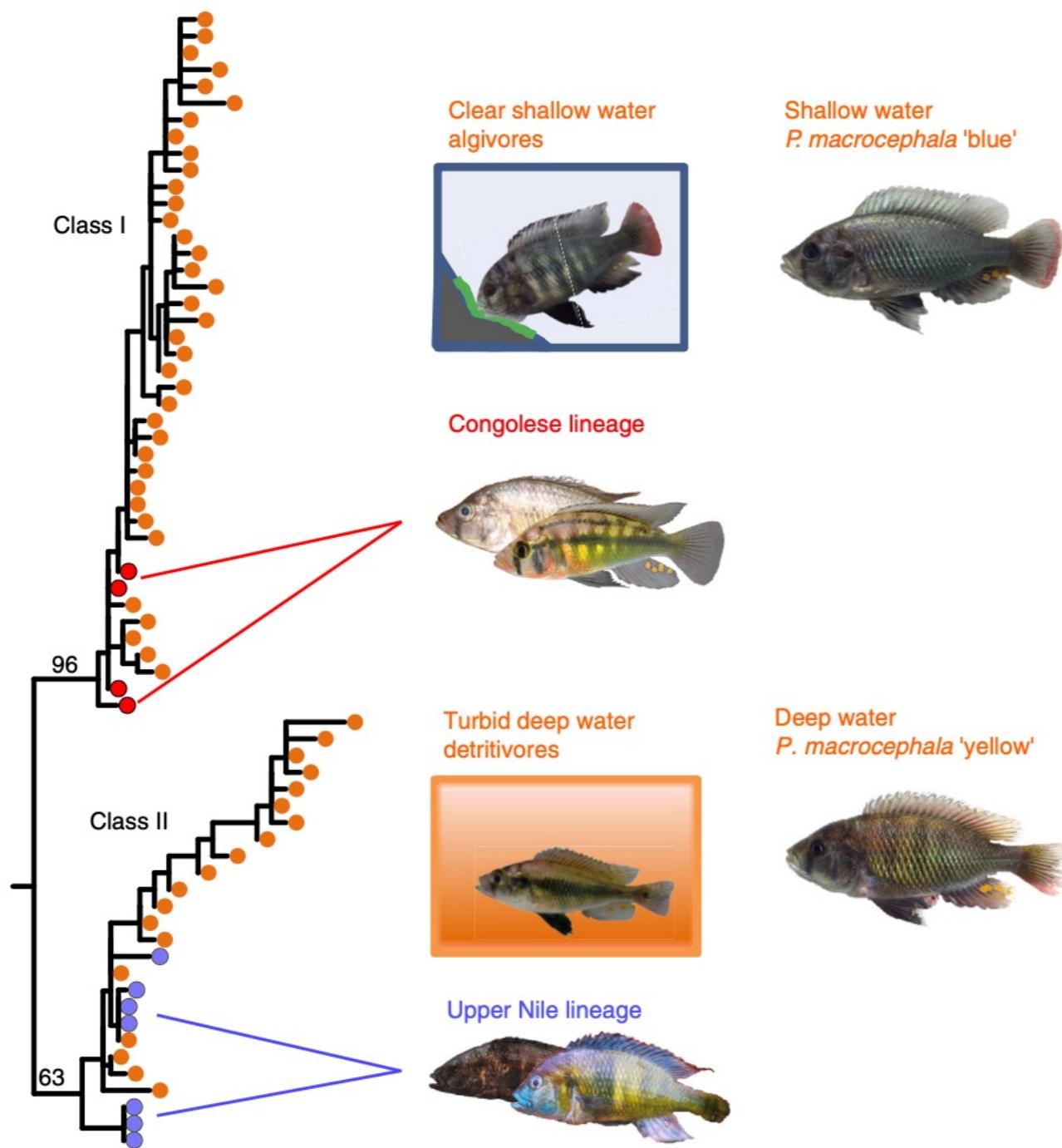


The Lake Victoria cichlid radiation



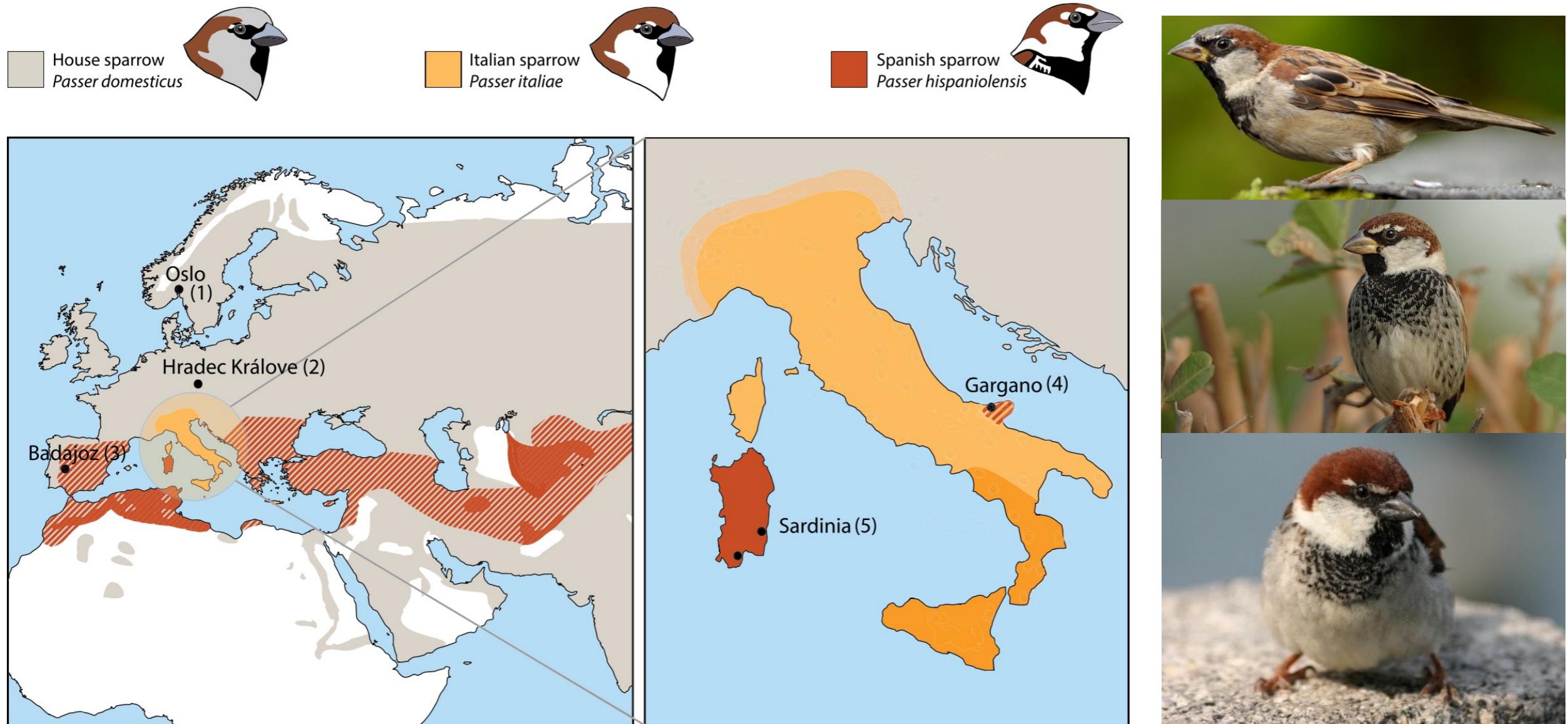
The importance of hybridization

- Opsin genes in Lake Victoria fish

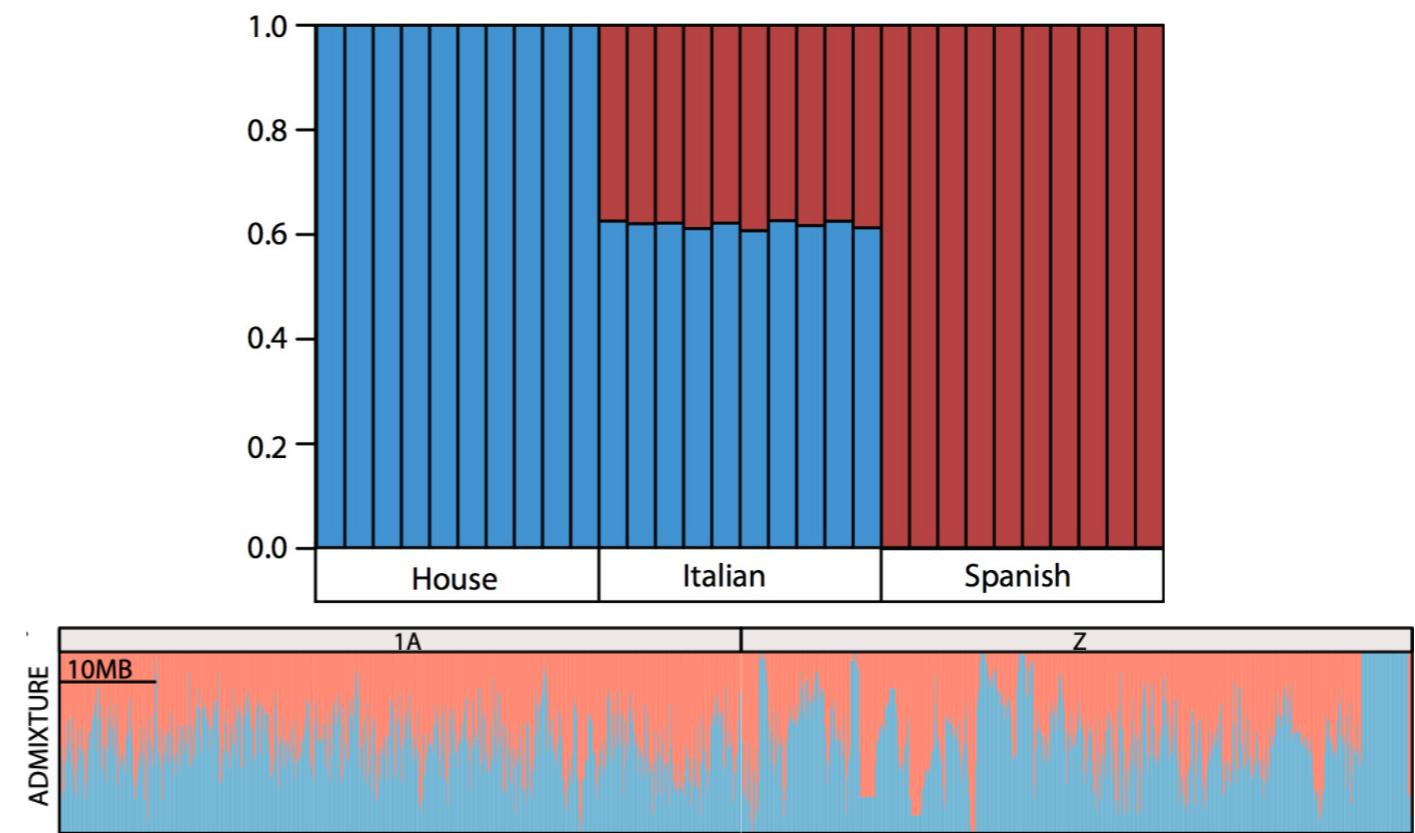
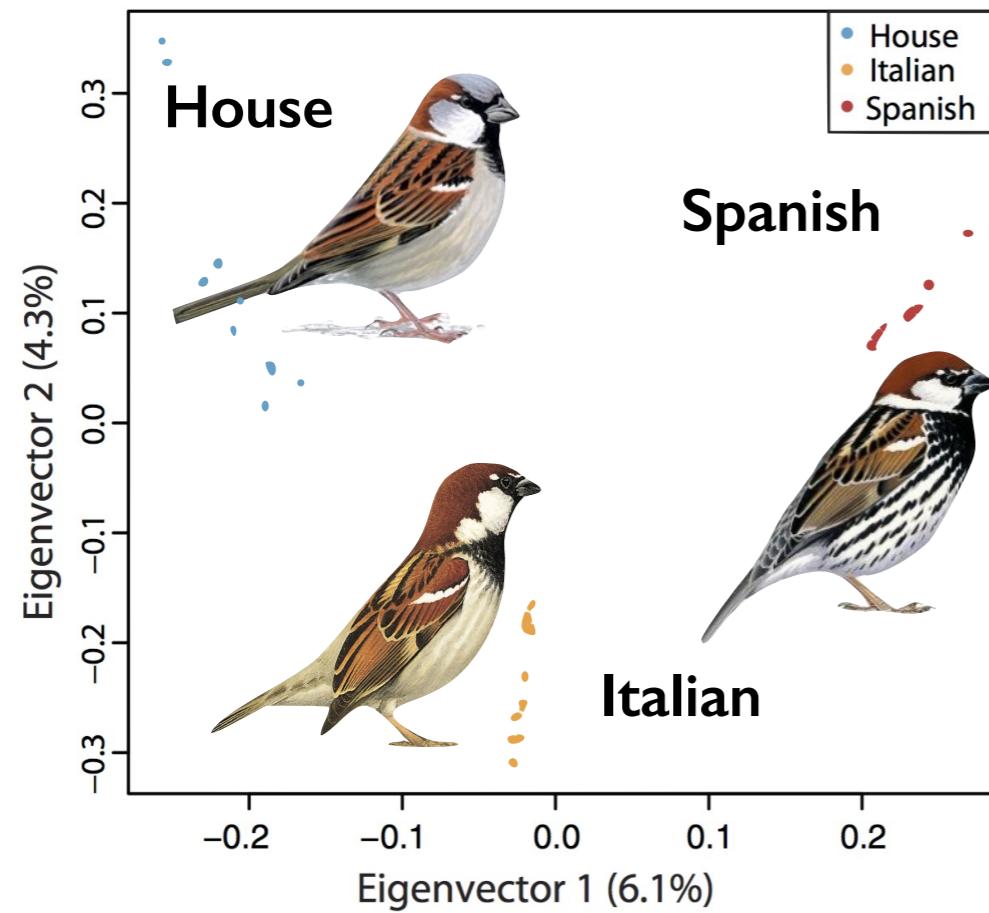


Hybridization and speciation

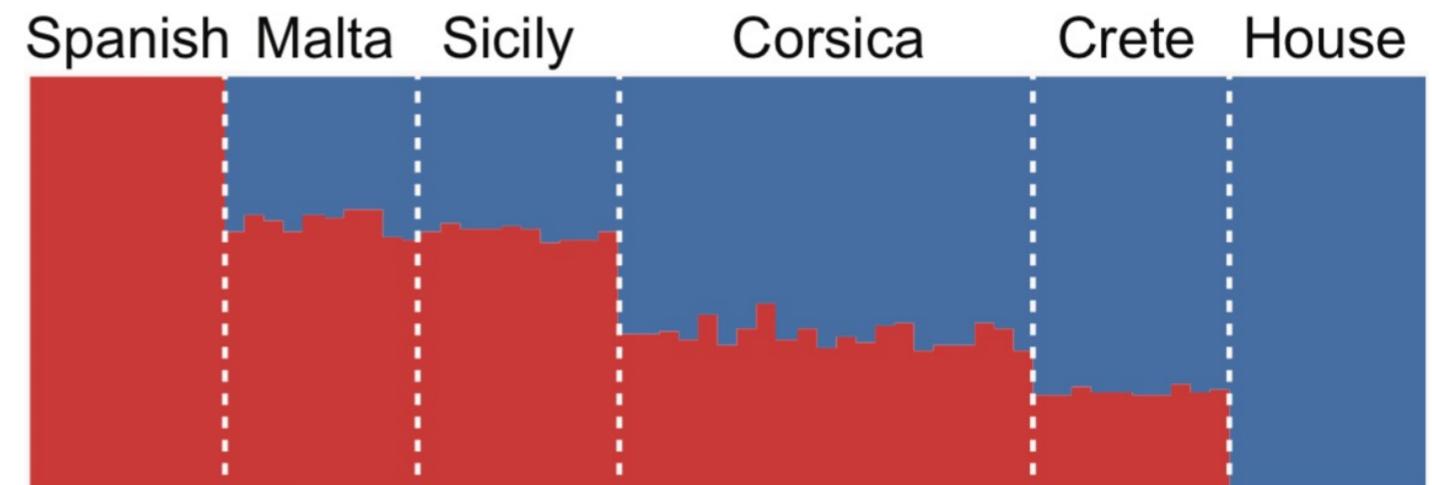
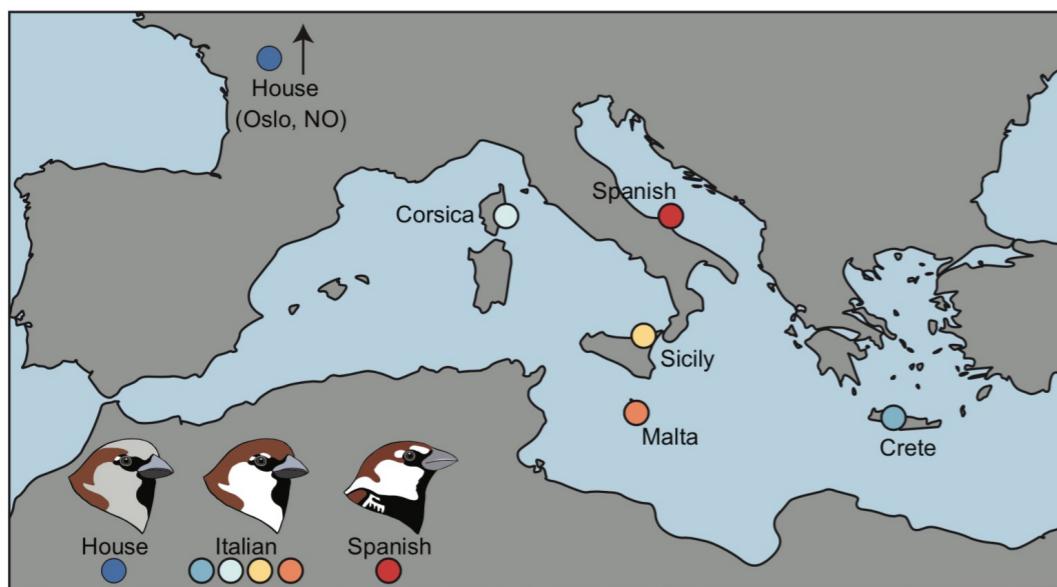
- Creative power of gene flow – resulting in new species



Hybridization and speciation



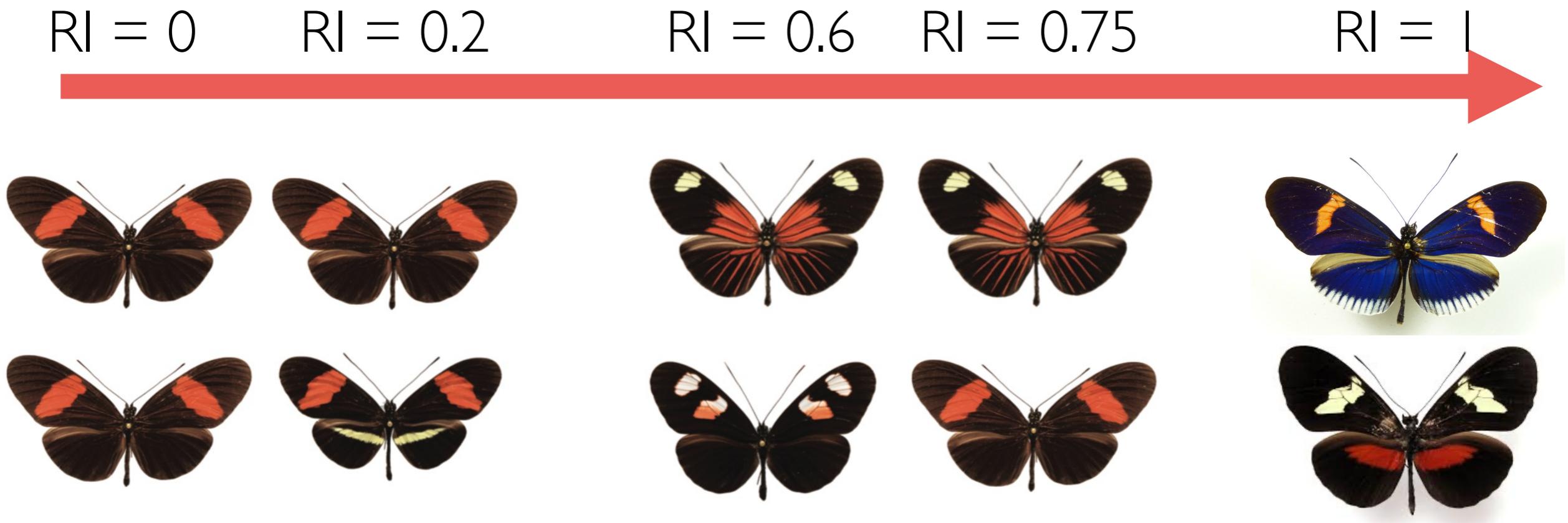
Elgvin et al (2017) Science Advances



Runemark et al (2018) Nat Ecol Evol

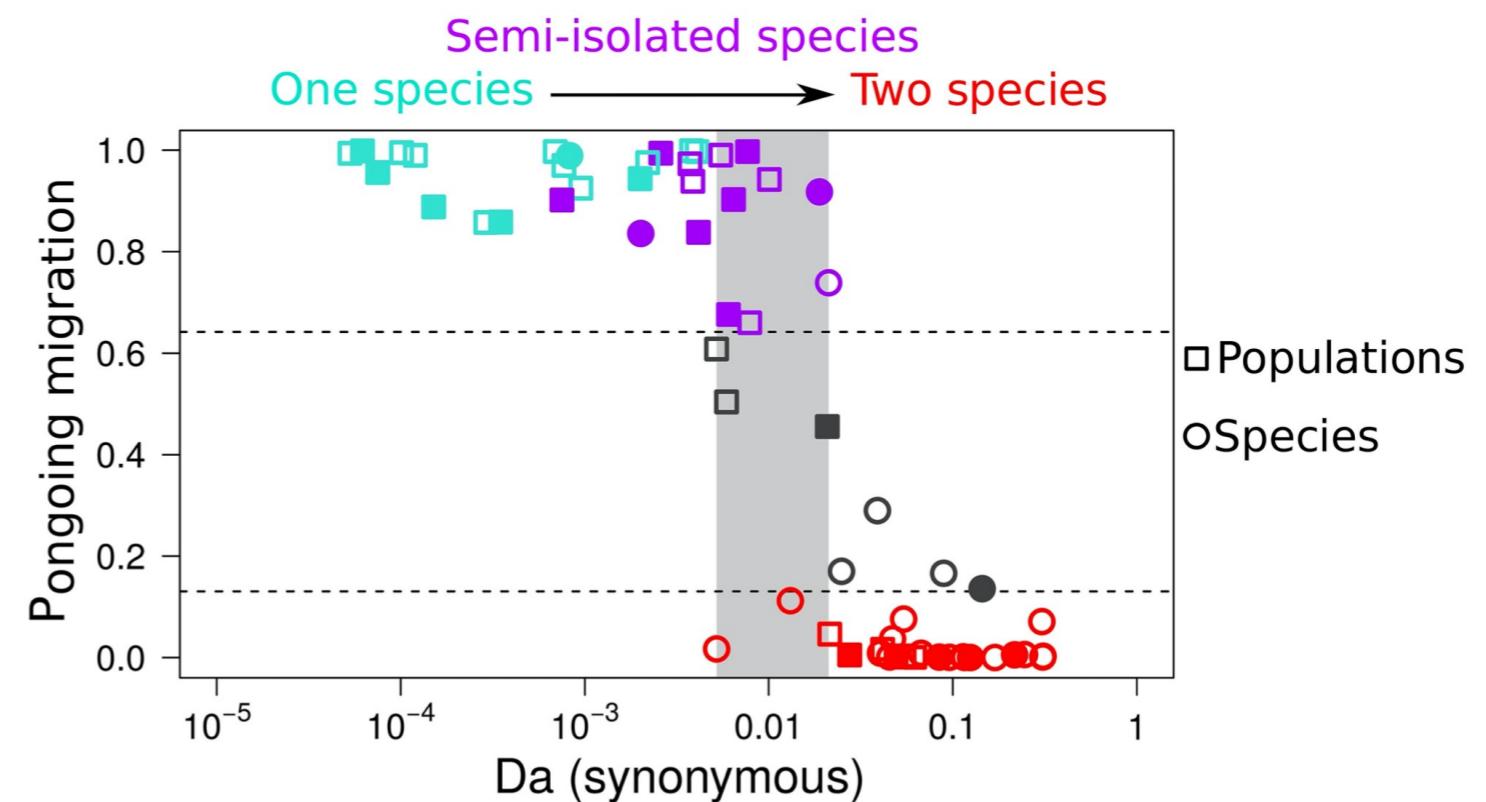
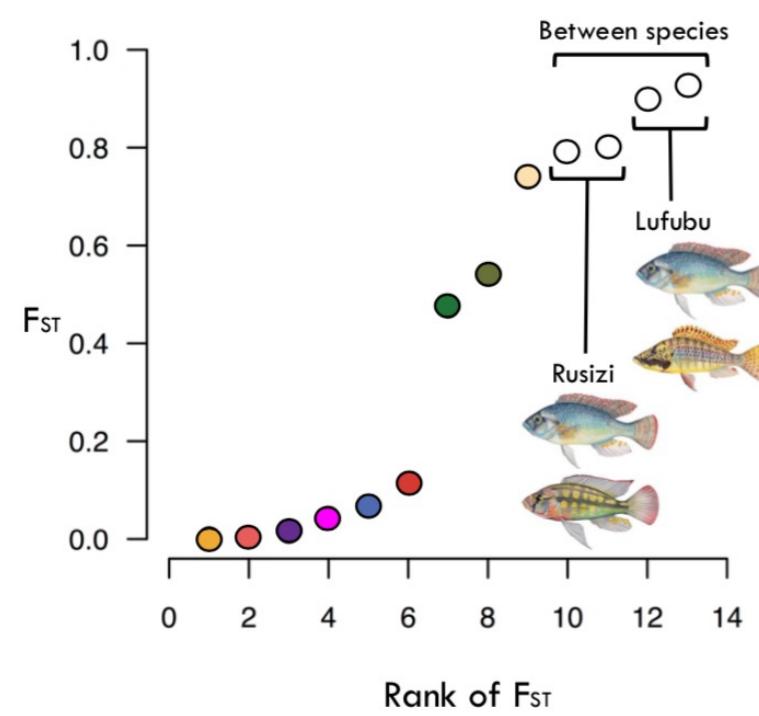
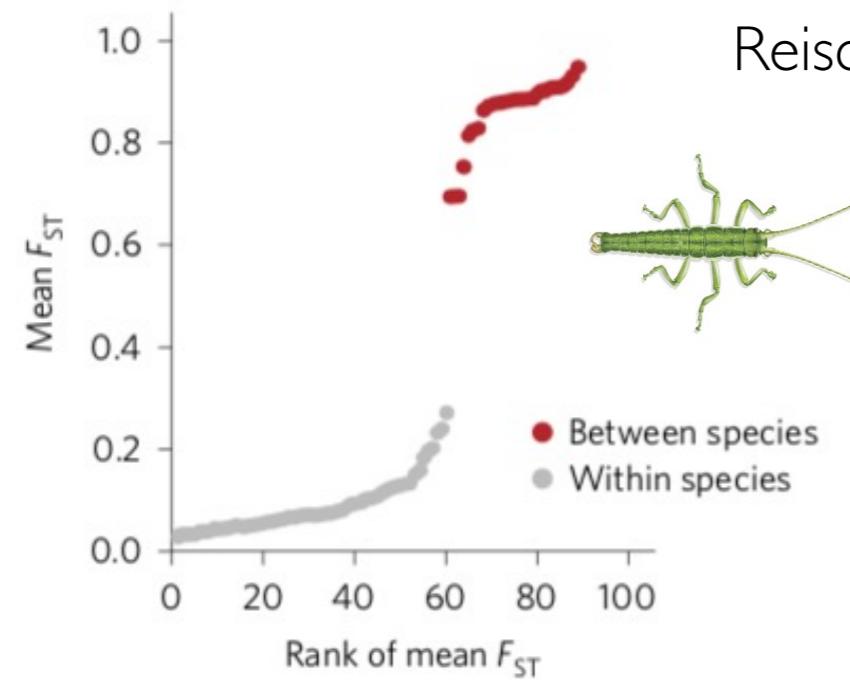
The speciation continuum

The speciation continuum is a *continuum of reproductive isolation*



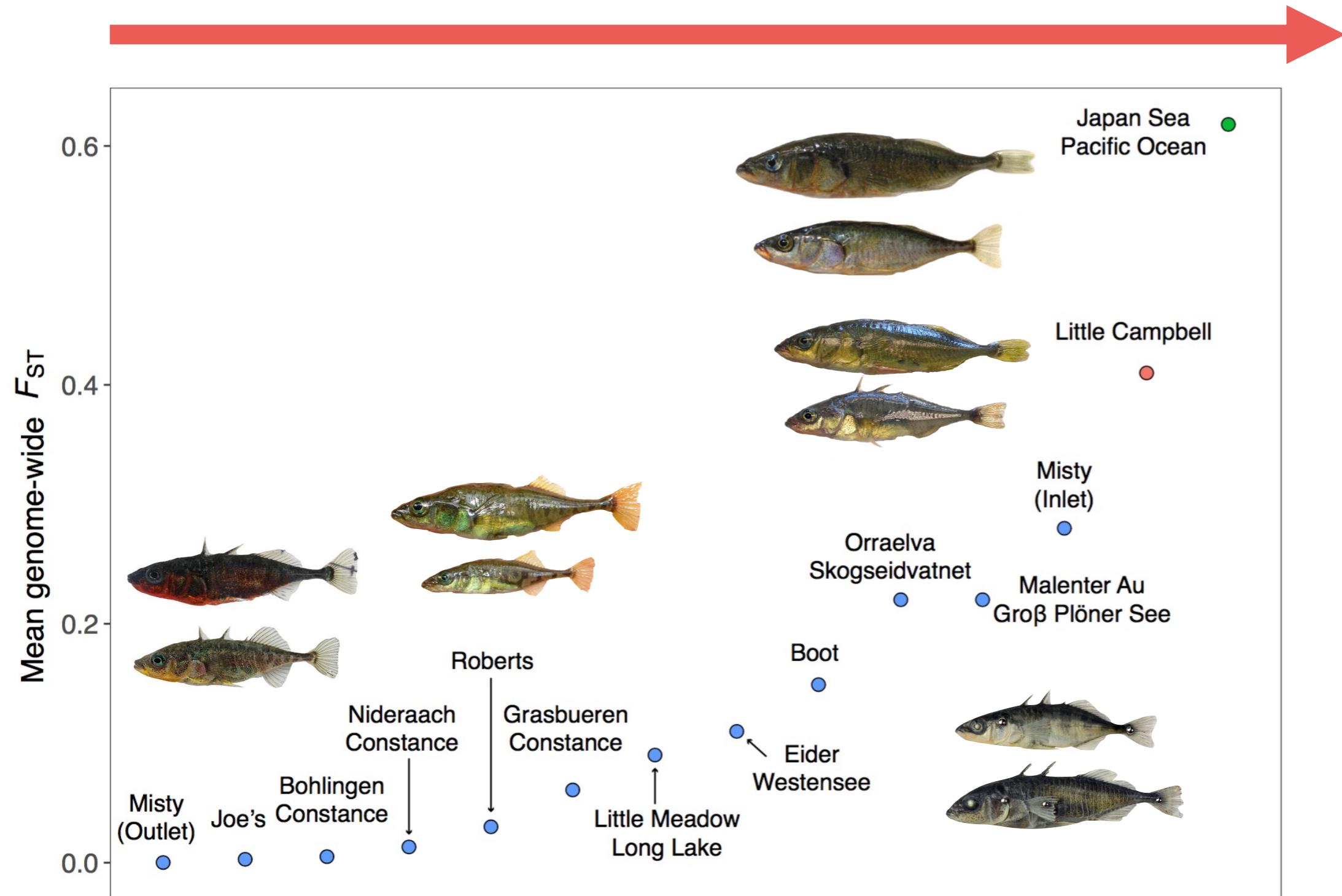
Other axes of the continuum?

Divergence time and genetic divergence



Weber et al 2021 **bioRxiv**

The stickleback speciation continuum



Roesti et al (2012) **Mol Ecol**

Roesti et al (2015) **Nat Comm**

Ravinet et al (2018) **PloS Genetics**

Rank order

● Anadromous-stream ● Japanese ● Lake-stream

Feulner et al (2015) **PloS Genetics**

Kusukabe et al (2017) **Mol Ecol**

Marques et al (2016) **PloS Genetics**

Late stage speciation in sticklebacks



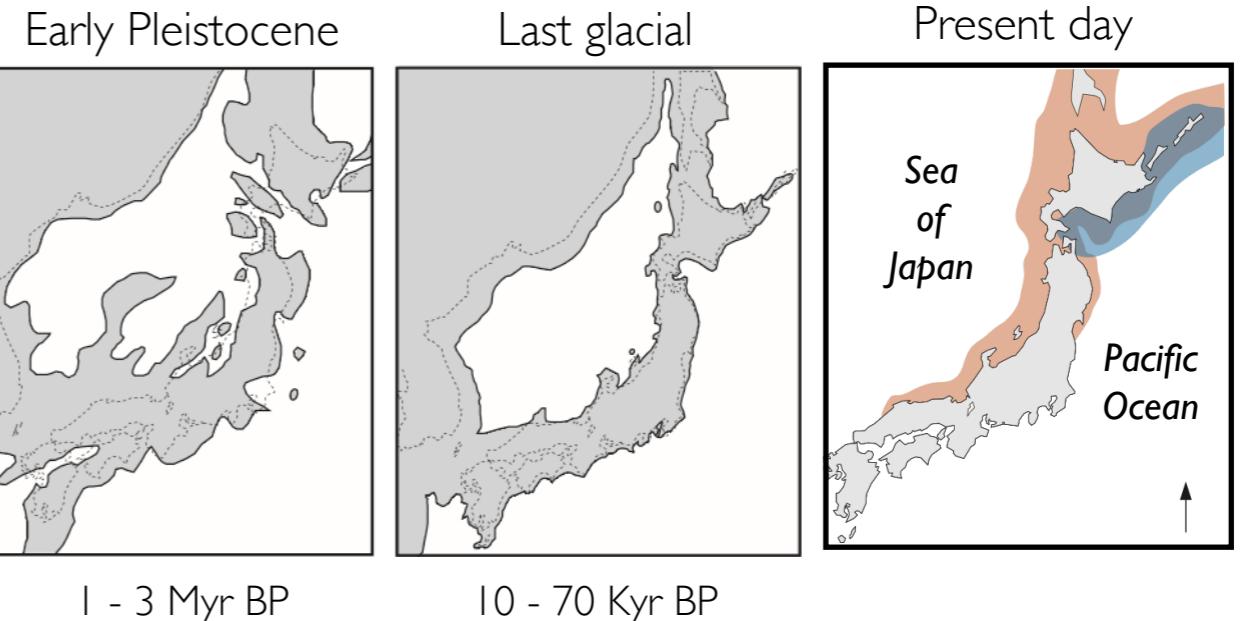
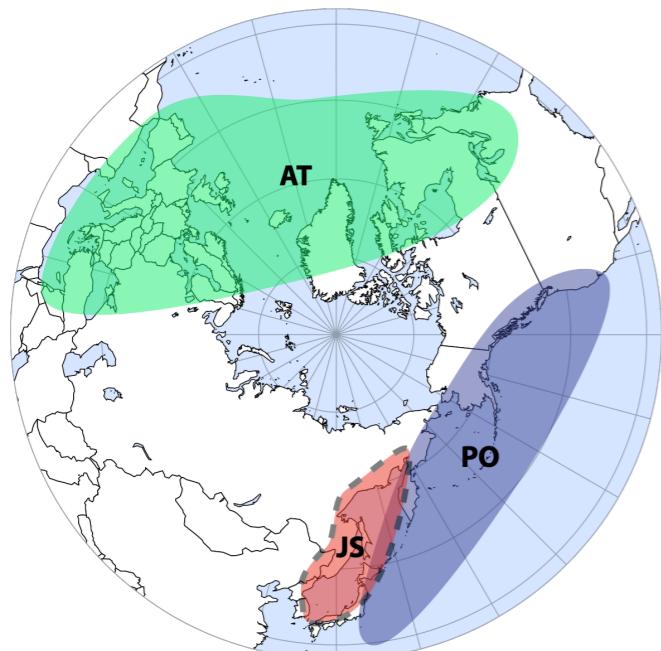
Three-spined stickleback

Pacific Ocean Atlantic Ocean



Japan Sea stickleback

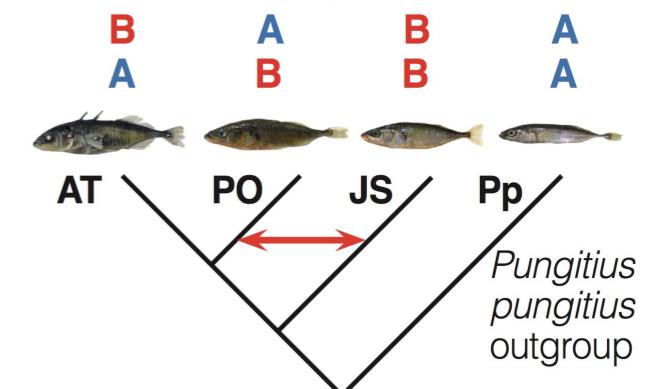
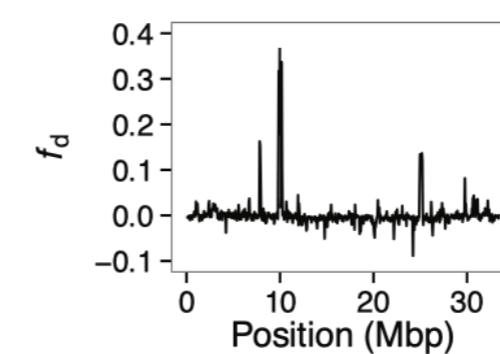
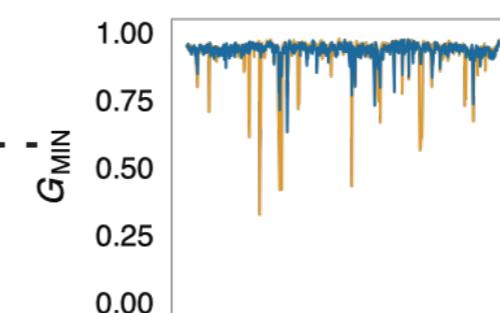
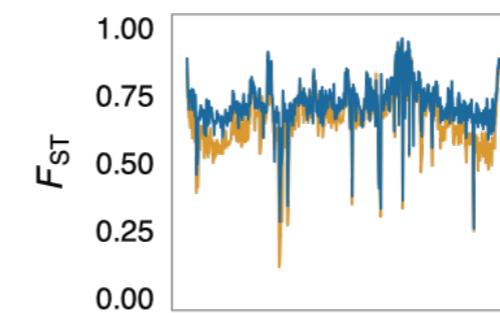
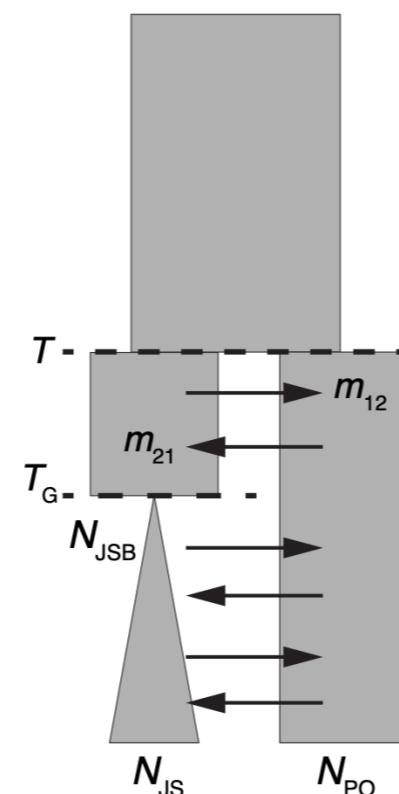
Sea of Japan Sea of Okhotsk



1 - 3 Myr BP

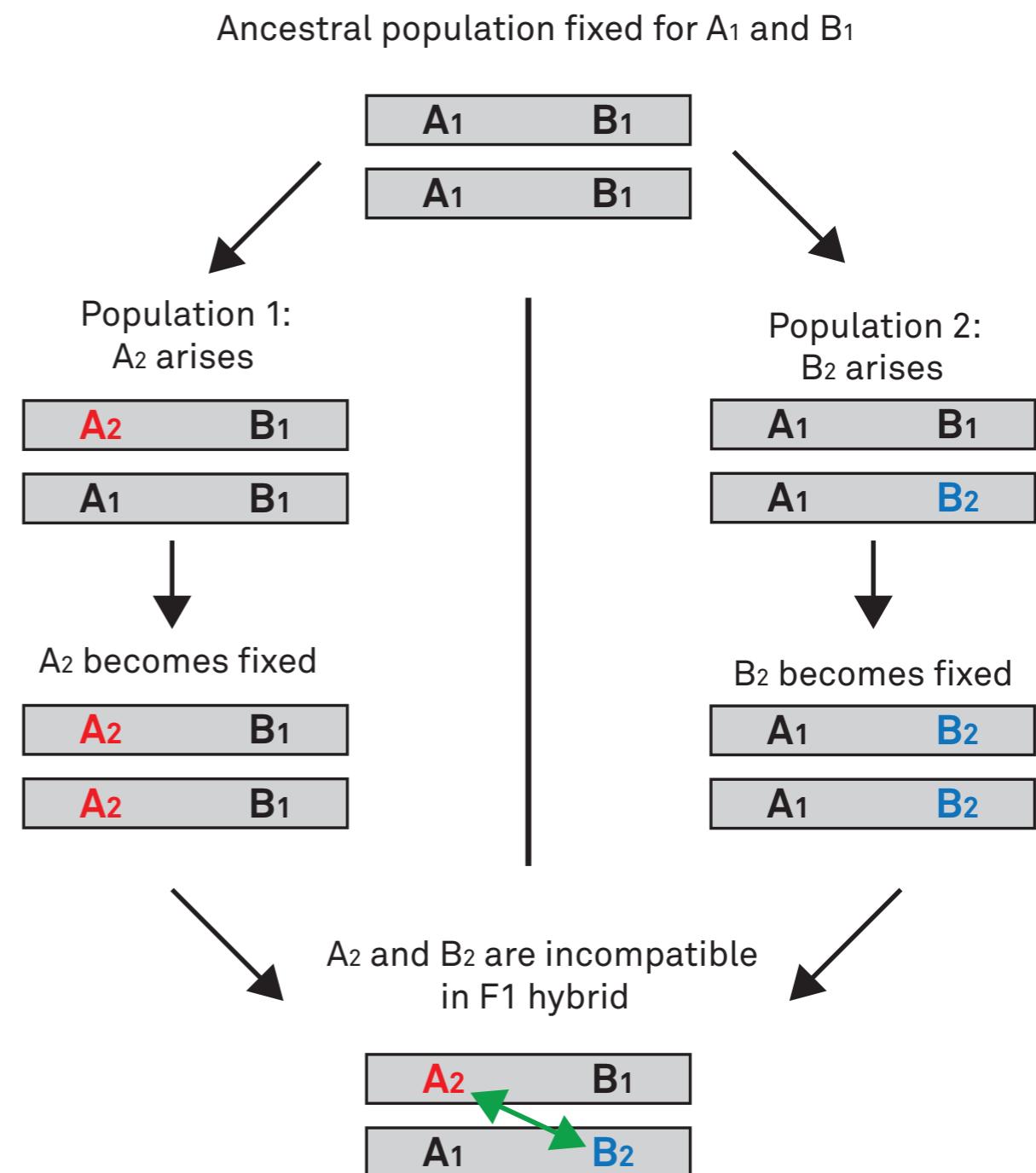
10 - 70 Kyr BP

A Constant migration + bottleneck



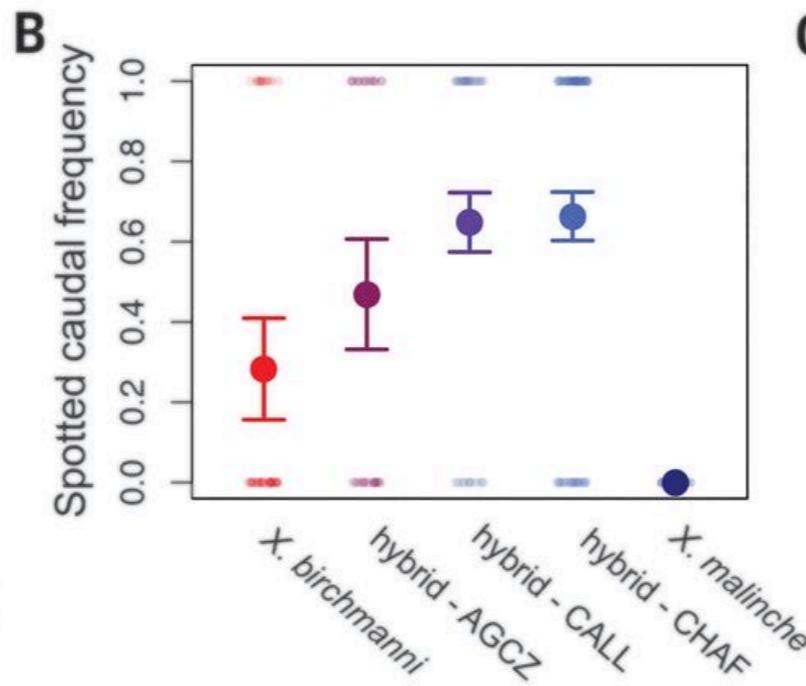
Genetic basis of reproductive isolation

- DMI – Dobzhansky-Mueller Incompatibilities
- Limited understanding of genetic basis
- ~12 genes identified across different species
- Mainly model species

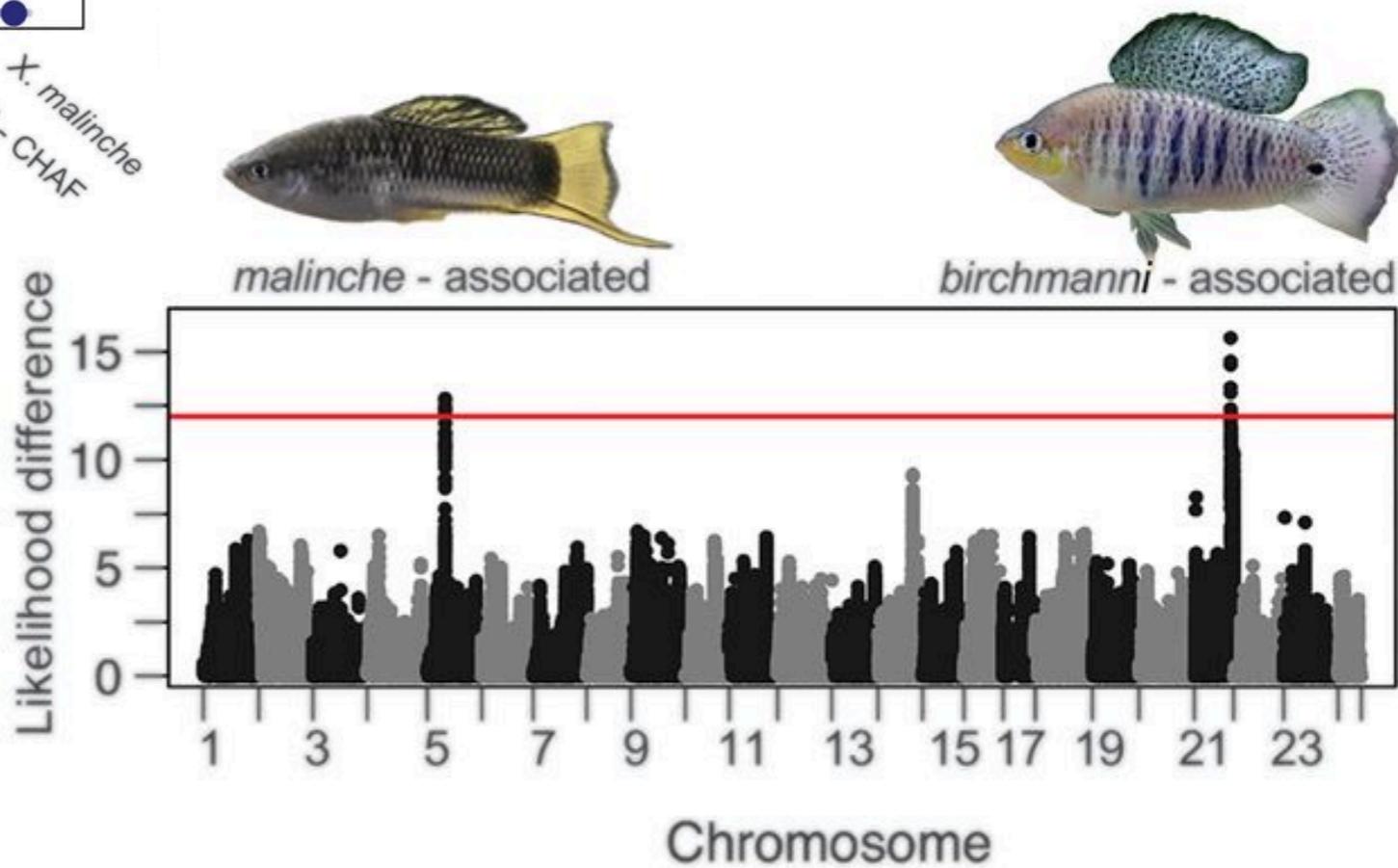


Genetic basis of reproductive isolation

- *Xiphophorus* swordtails – caudal melanoma

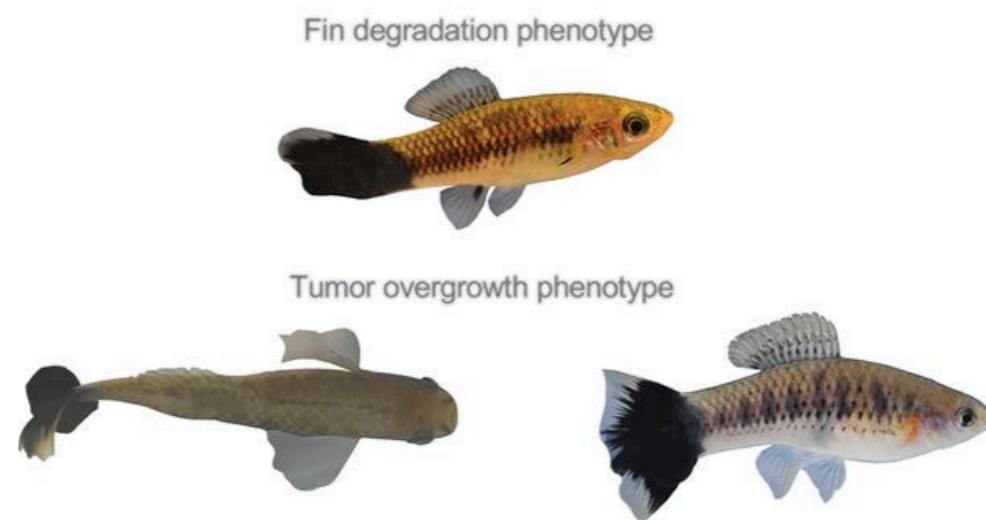


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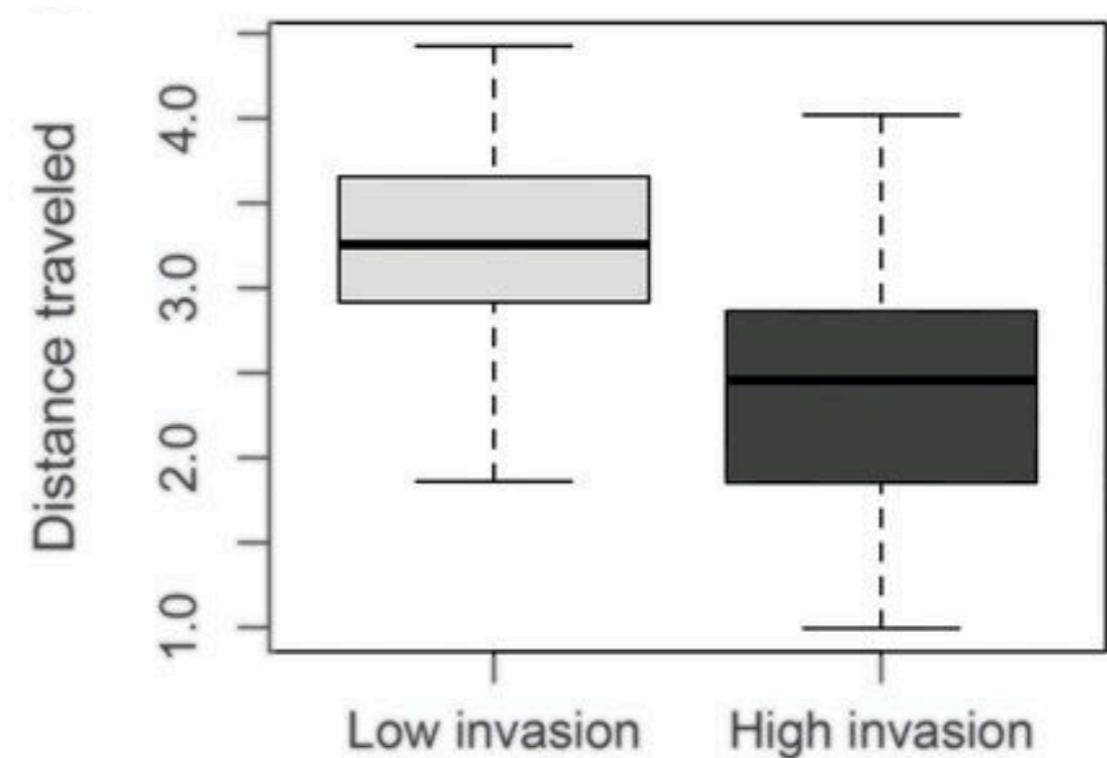
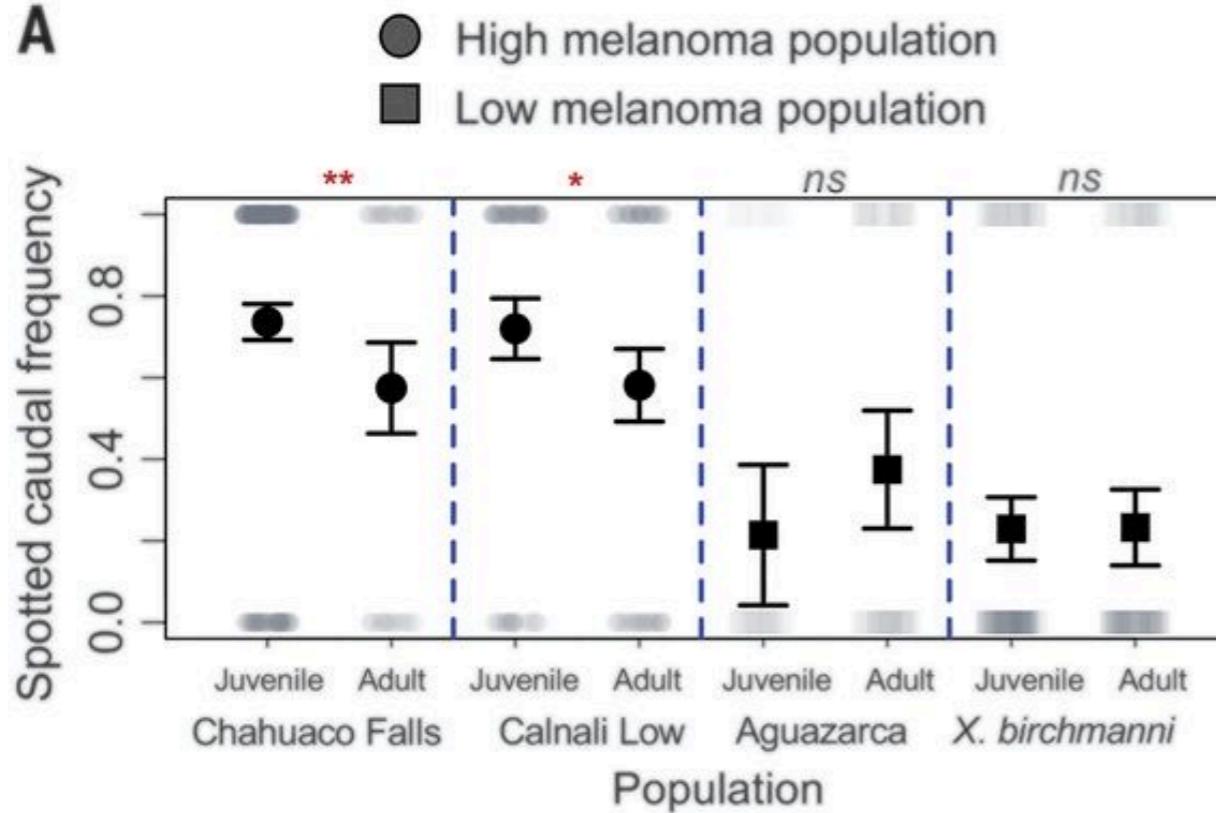


Powell et al (2020) Science

Genetic basis of reproductive isolation



A





A confusing field - what is the way forward?



Available online at www.sciencedirect.com

ScienceDirect

TARGET
**Inter-
findin**

Interpreting the genomic landscape of introgression

Simon H Martin and Chris D Jiggins



M. RAVINET*† R. FARIA‡§¶, R. K. BUTLIN¶**, J. GALINDO††, N. BIEF
M. RAFAJLOVIĆ§§ M. A. F. NOOR¶¶ B. MEHLIG§§ & A. M. WESTR

COMMENTARY

**Parallelism in genomic
landscapes of differentiation,
conserved genomic features
and the role of linked selection**

EVIEWS

Current Opinion in
Genetics
& Development

RESPONSE

**Land ahoy? Navigating the
genomic landscape of
speciation while avoiding
shipwreck**

A. M. WESTRAM* & M. RAVINET†

H. ELLEGREN

Making
different



Open Access

Jochen B. W. Wolf¹



Reto¹

**Interpreting differentiation landscapes
in**

**What is Speciation Genomics? The roles of ecology, gene
flow, and genomic architecture in the formation of species**

C. RYAN CAMPBELL, J. W. POELSTRA and ANNE D. YODER*

What we hope to achieve

- Clarify an increasingly complex and difficult field
- Teach you the tools and approaches necessary to go from raw sequencing reads to finished analyses
- Teach best practices - learn from our mistakes!
- Generate discussion and interaction
- Create a resource you can refer back to throughout your analyses and research

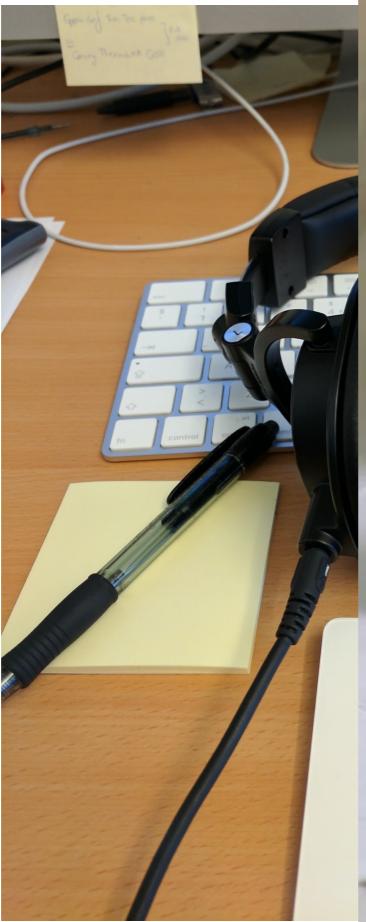
speciationgenomics.github.io

What we hope to achieve

1. Learning how to use Unix
2. Handling NGS data - mapping reads, variant calling & filtering
3. Investigating population structure
4. Detecting and testing for hybridisation
5. Demographic inference
6. Genome scans and identifying signatures of selection

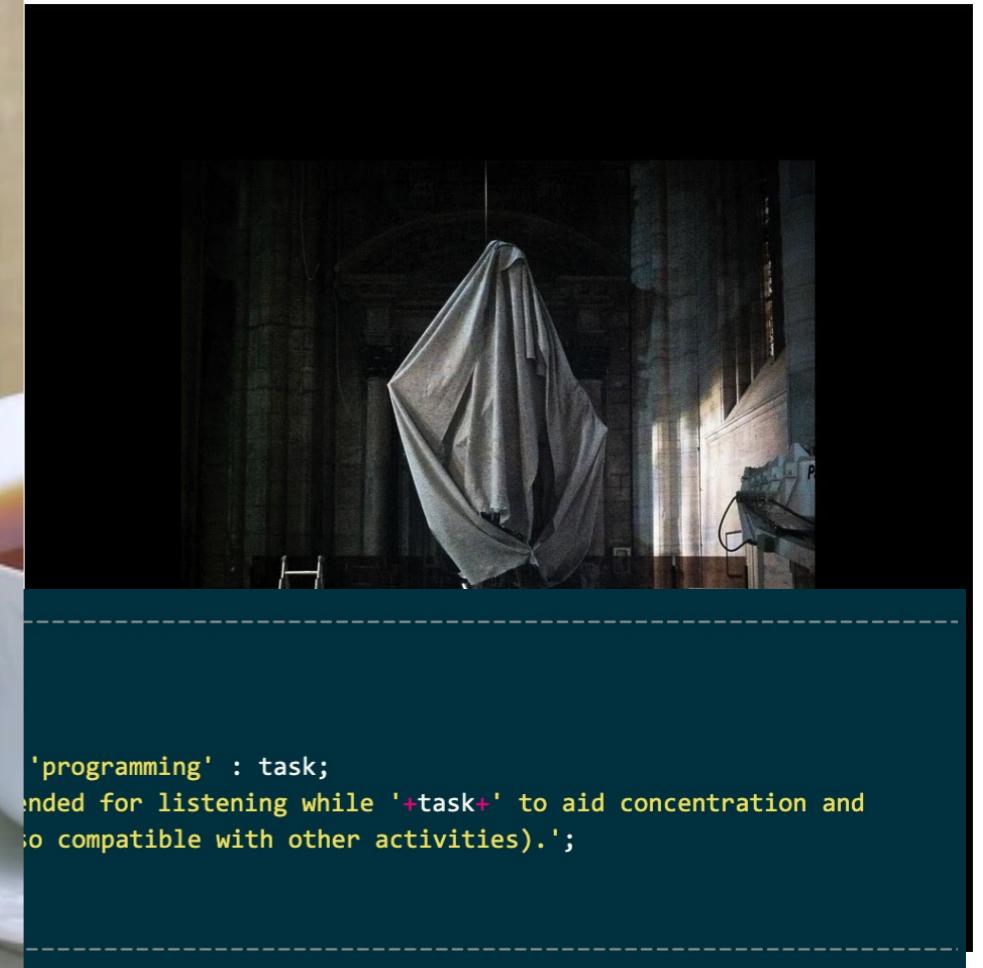
speciationgenomics.github.io

Bioinformatics secret weapons



Google

Please help me with my bioinformatics problems



```
'programming' : task;  
    intended for listening while '+task+' to aid concentration and  
    so compatible with other activities).';
```

Bioinformatics secret weapons

