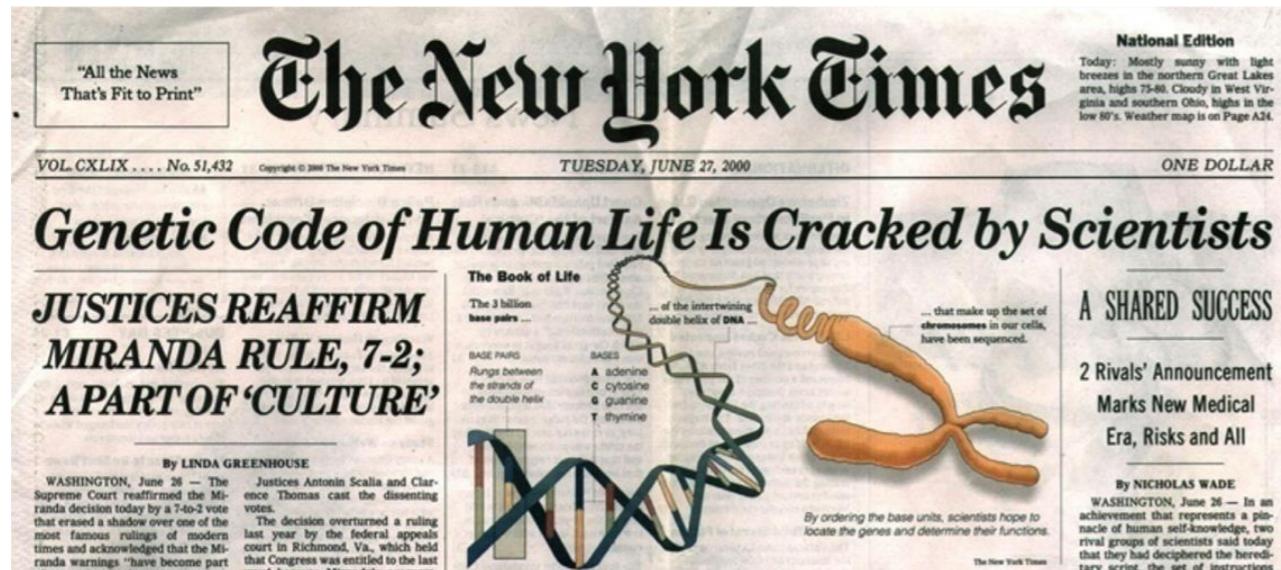


# Concepts, islands & continuums: a perspective on speciation genomics

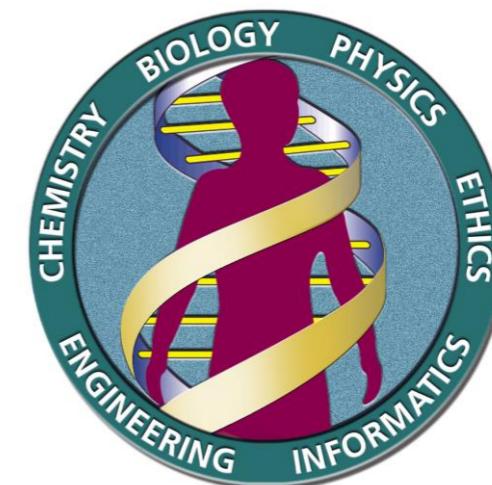


Mark Ravinet  
University of Nottingham, UK  
 [@mark\\_ravinet](mailto:@mark_ravinet) [mark.ravinet@nottingham.ac.uk](mailto:mark.ravinet@nottingham.ac.uk)

# The Human Genome Project

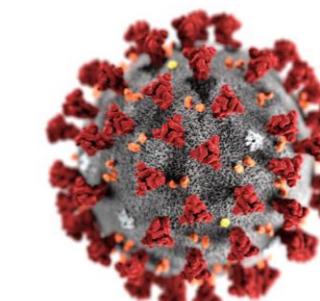
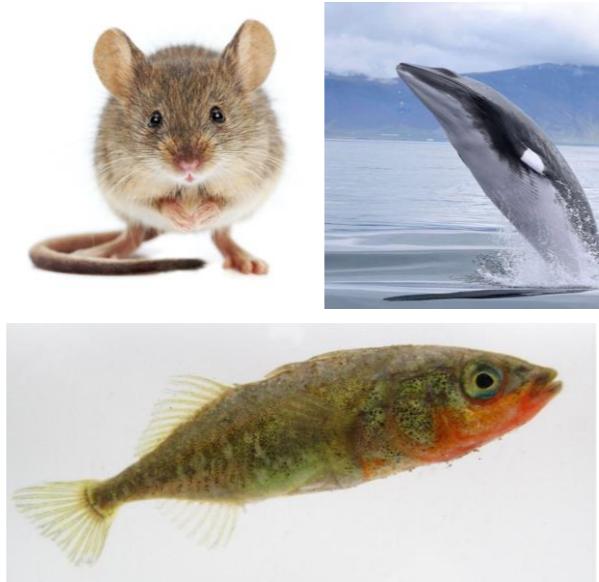


- Human genome project – started in 1990; draft sequence announced in June 2000; completed in 2003
- Sequenced across ~20 institutions worldwide
- Cost an approximate \$5 billion US dollars
- Put in place the methodological and computational infrastructure for large-scale sequencing projects



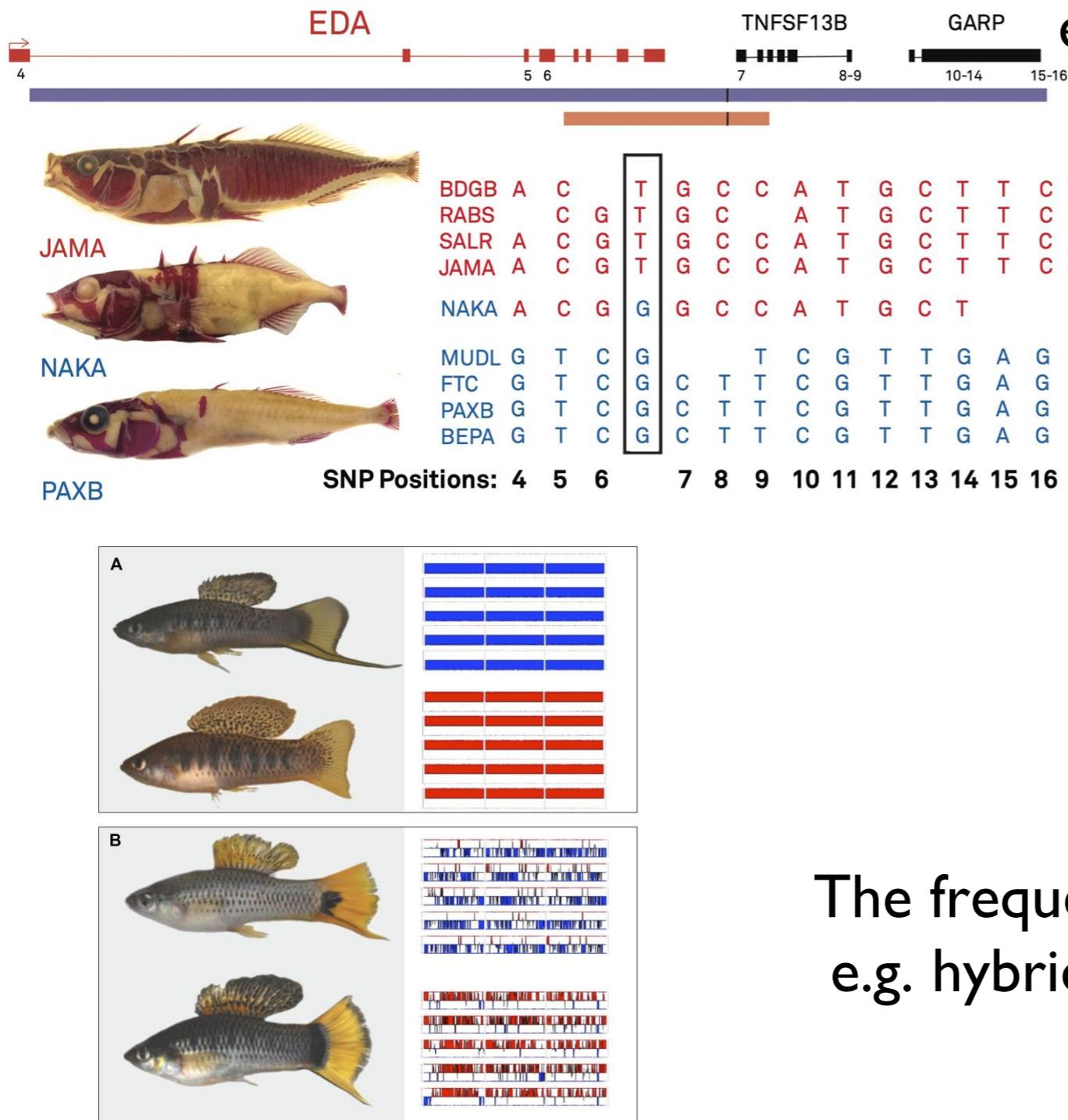
# The genomic era in biology

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

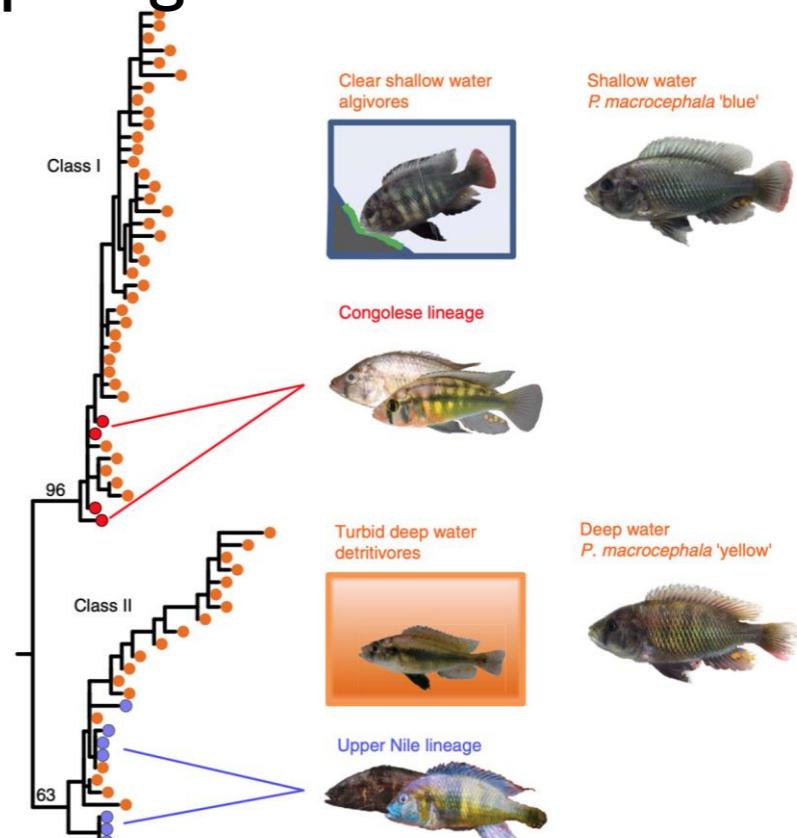


# A new look at old thinking

Genetic basis of phenotypic traits  
e.g. stickleback armour plating



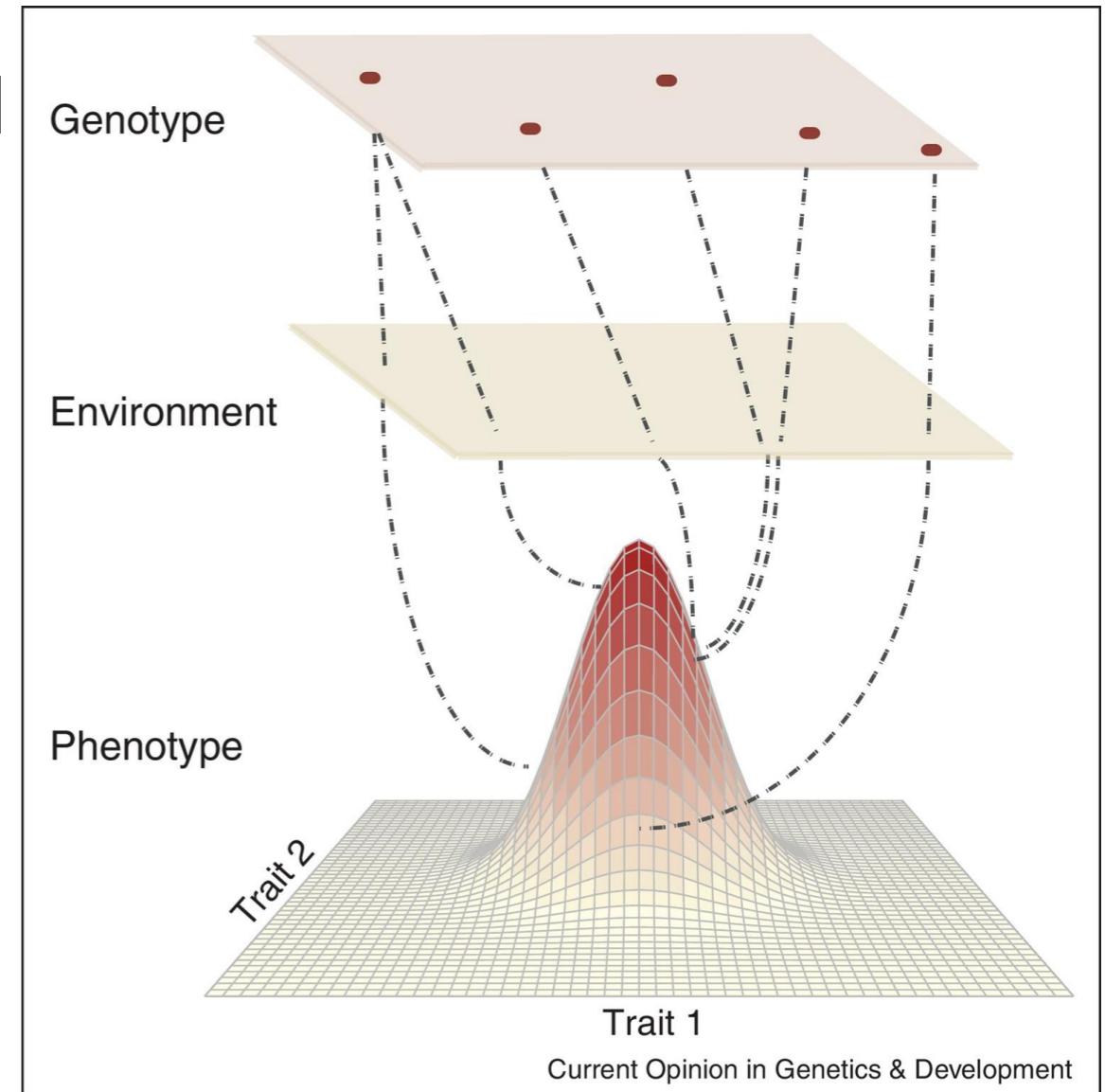
Reuse of ancient gene variants  
e.g. opsin genes in African cichlids



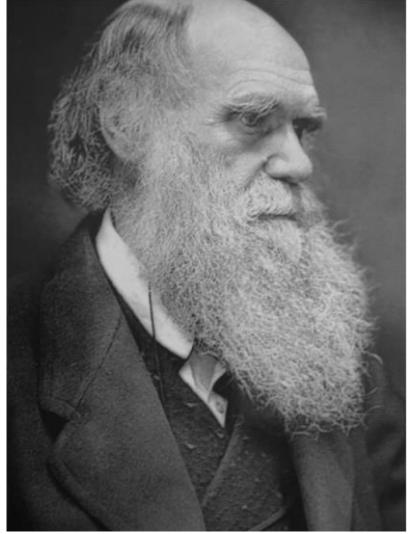
The frequency of hybridization  
e.g. hybrid origin of swordtail fishes

# 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



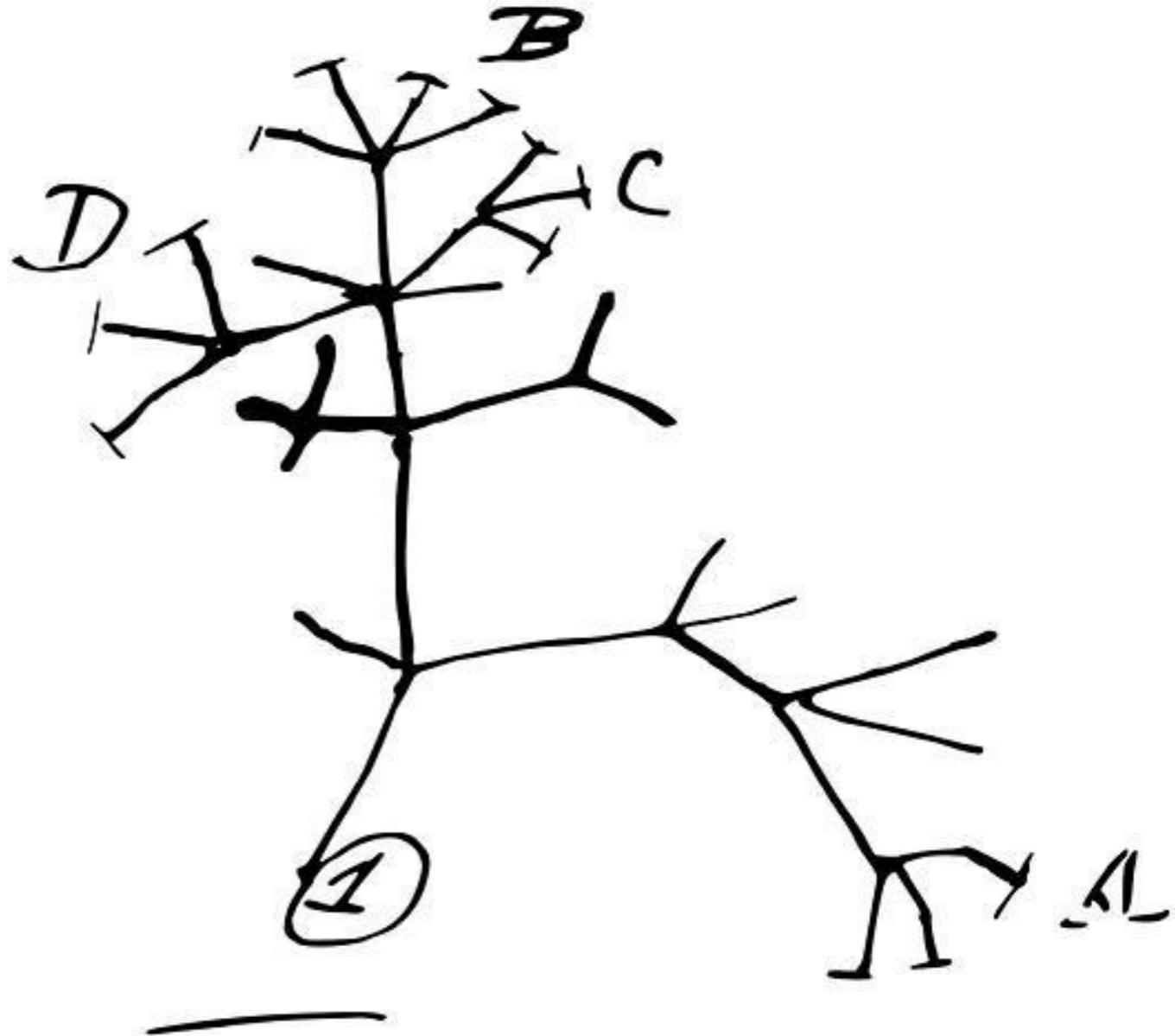
# Darwin and the origin



“...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”

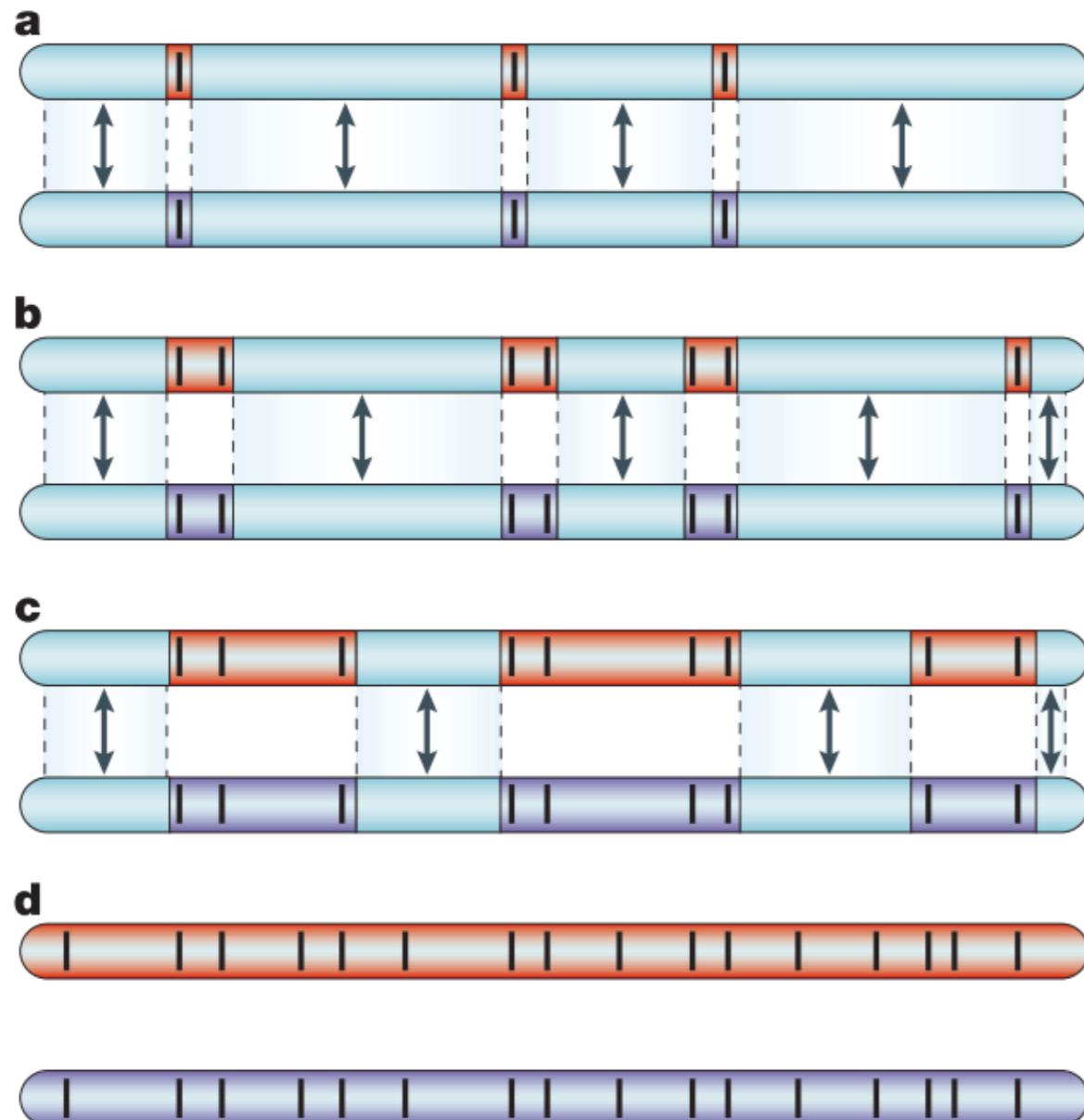
Ernst Mayr (1942) *Systematics and the Origin of Species*



“[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”

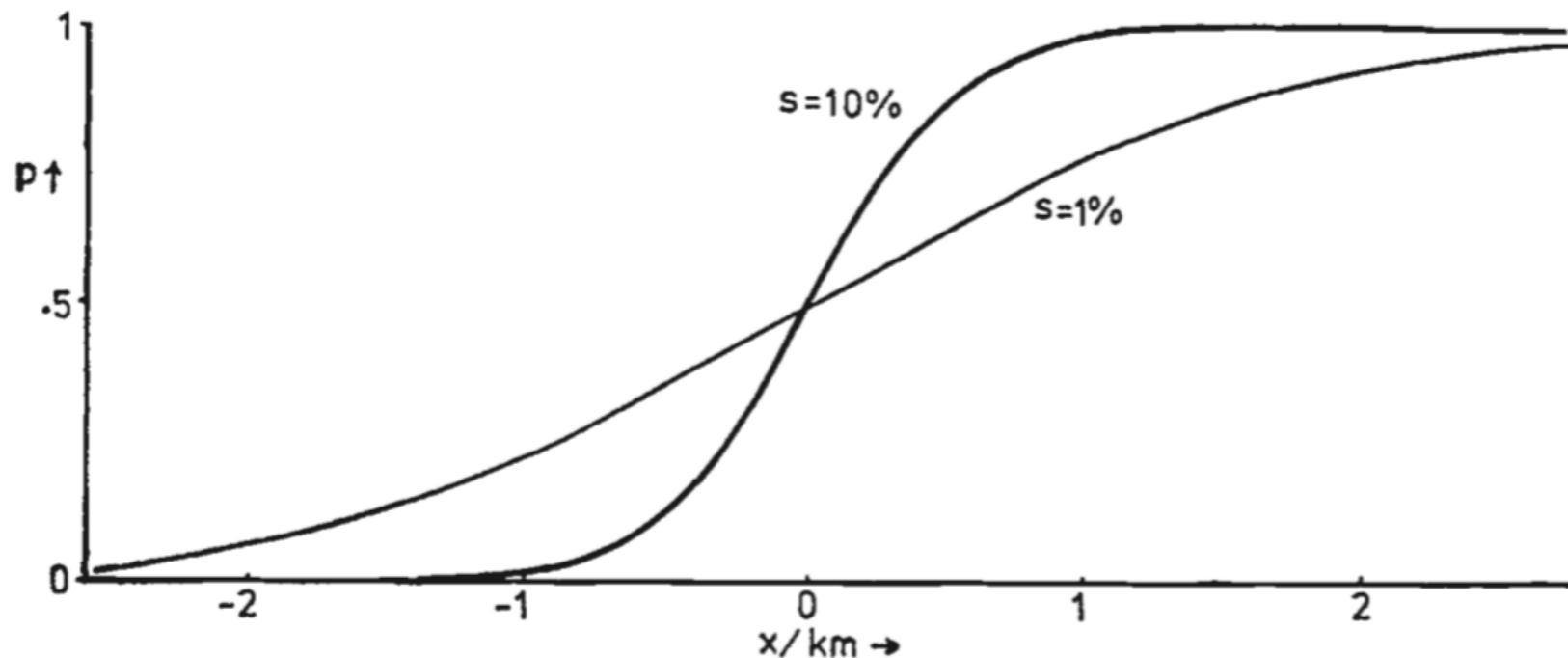


FIG. 1.—Hybrid zones produced by selection against heterozygotes;  
dispersal  $\sqrt{m} = 112 \text{ m.gen.}^{-\frac{1}{2}}$

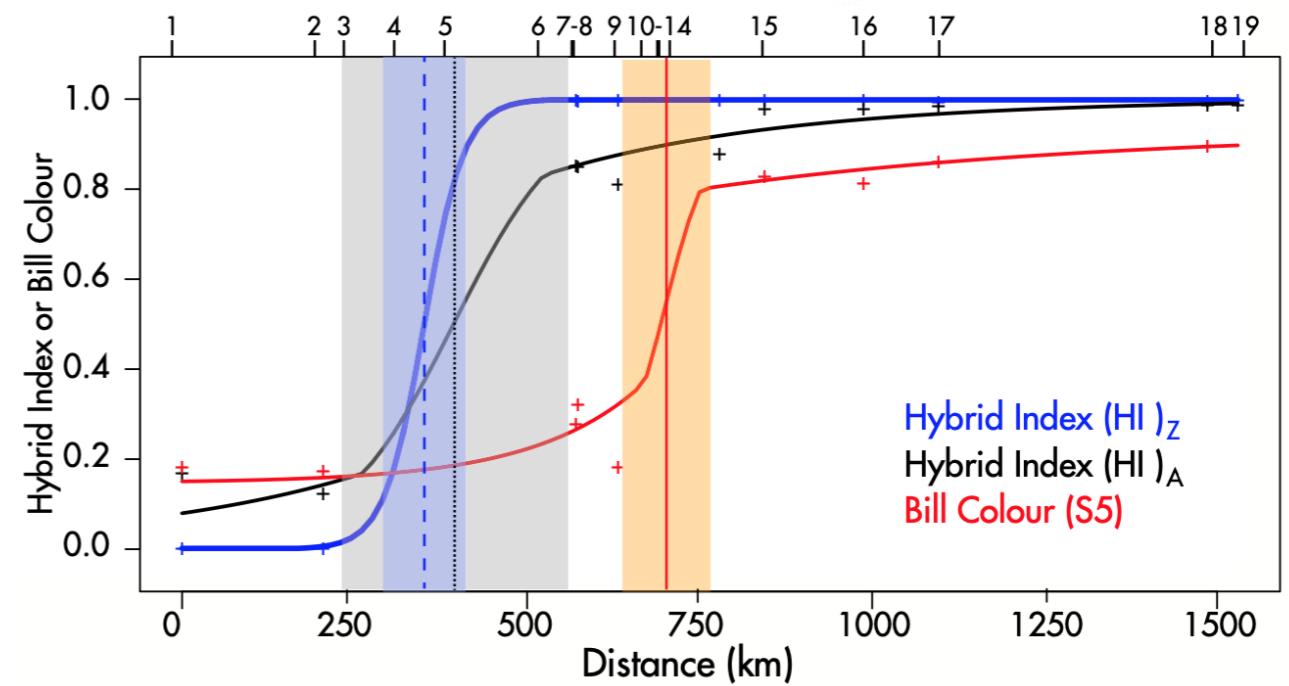
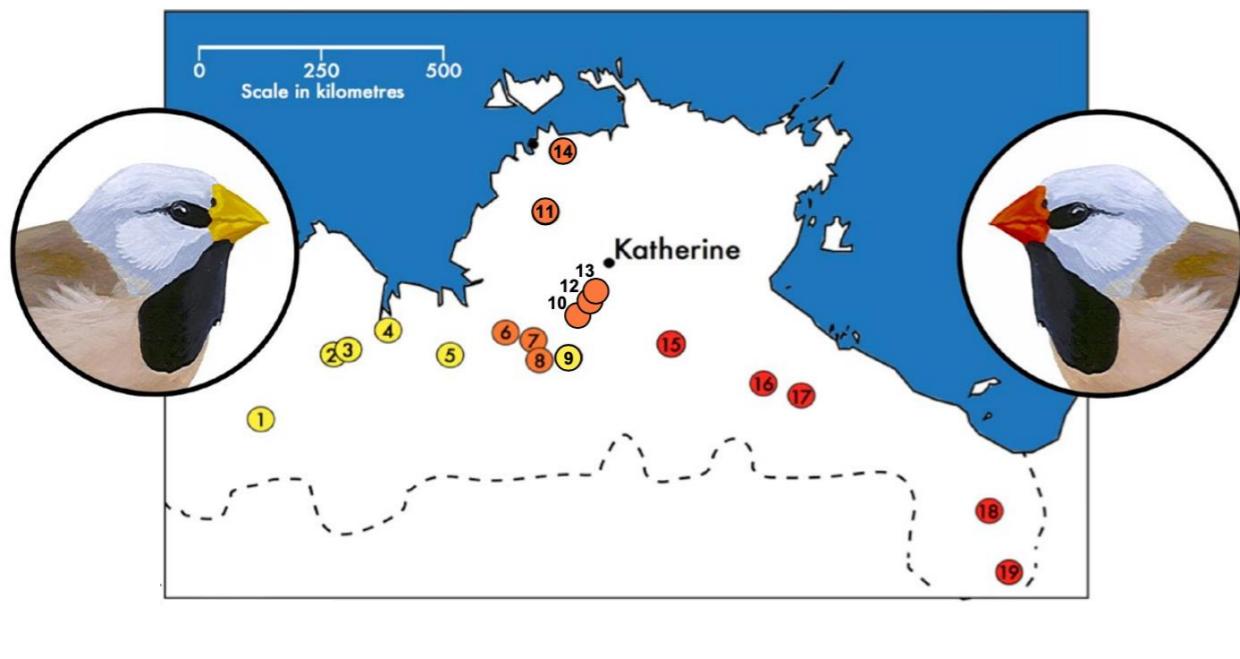
Barton (1979) Heredity

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

Barton & Hewitt (1989) Nature

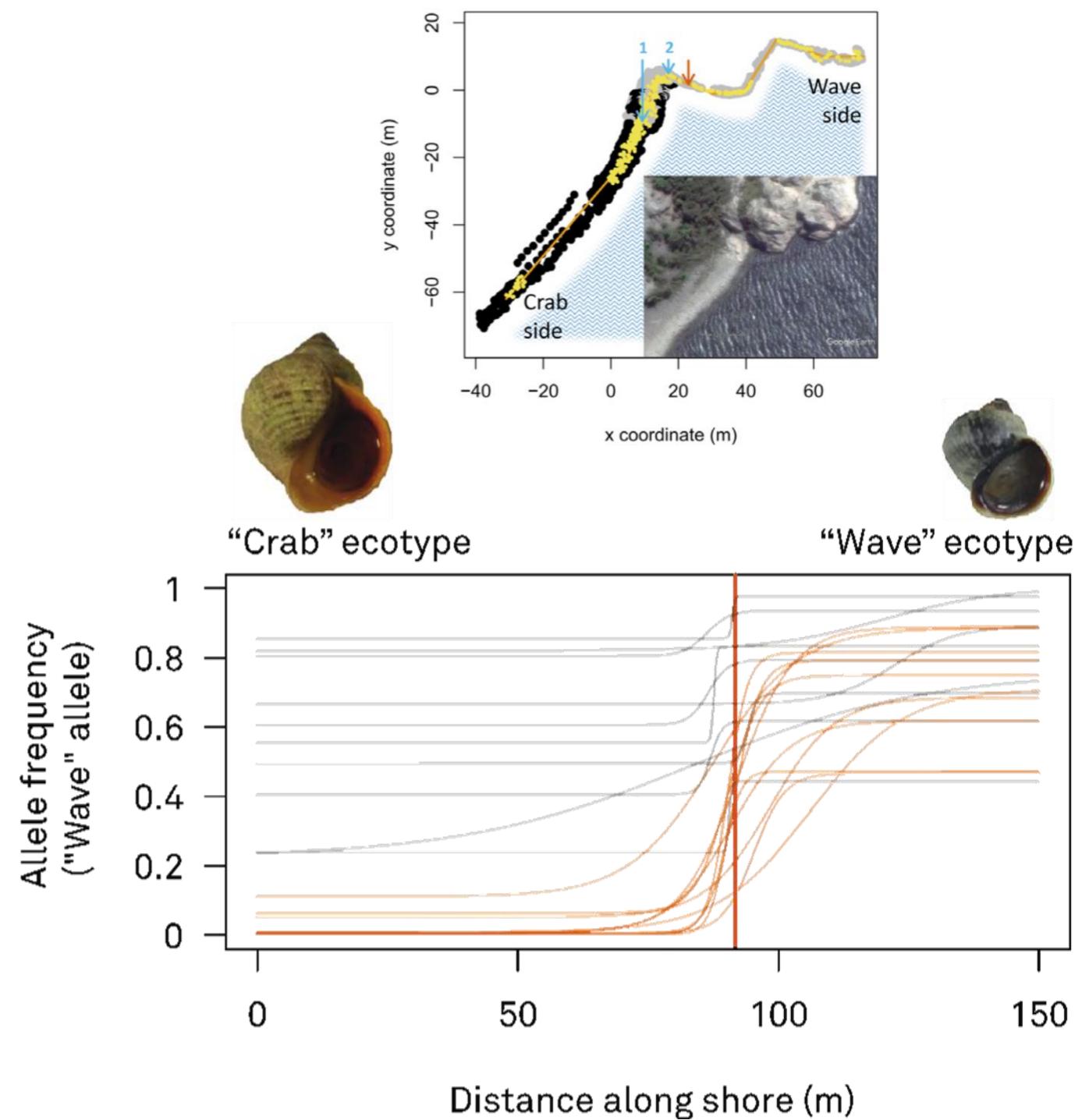
# Hybrid zones: natural laboratories

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



# Hybrid zones: natural laboratories

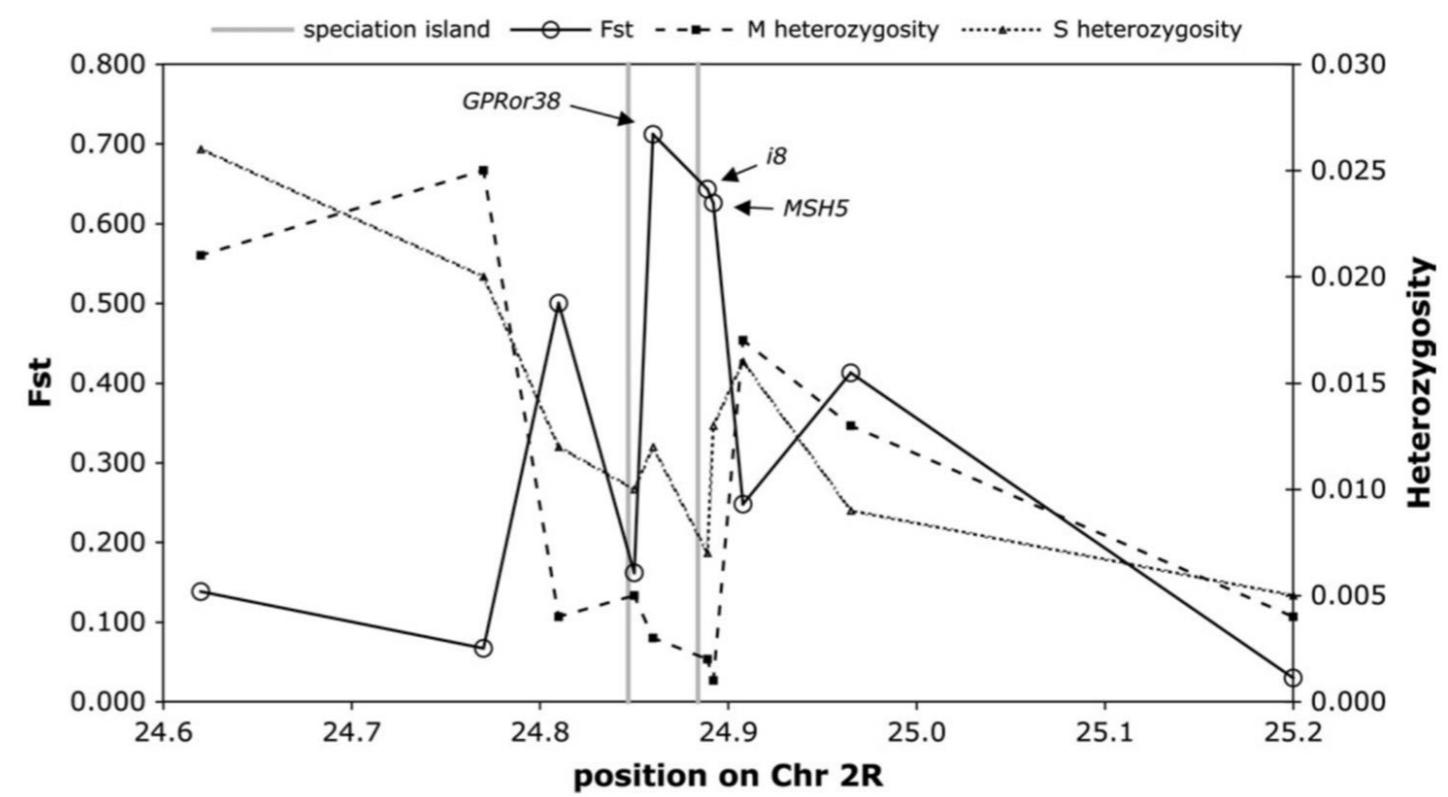
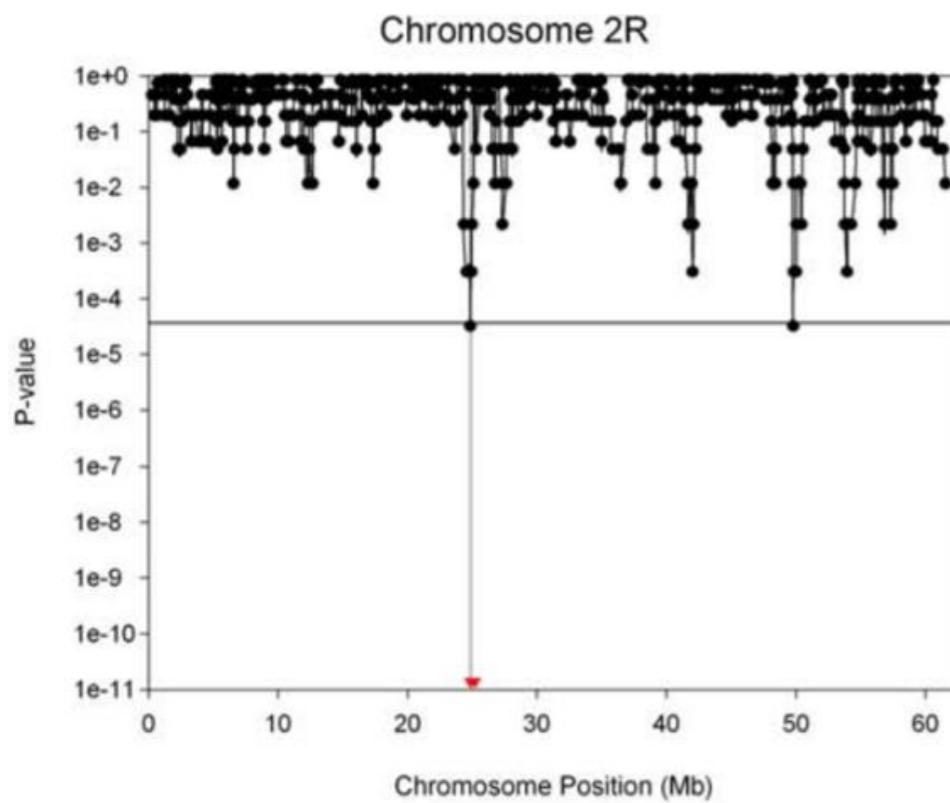
*Littorina saxatilis*  
Western Sweden



# The rise of speciation islands

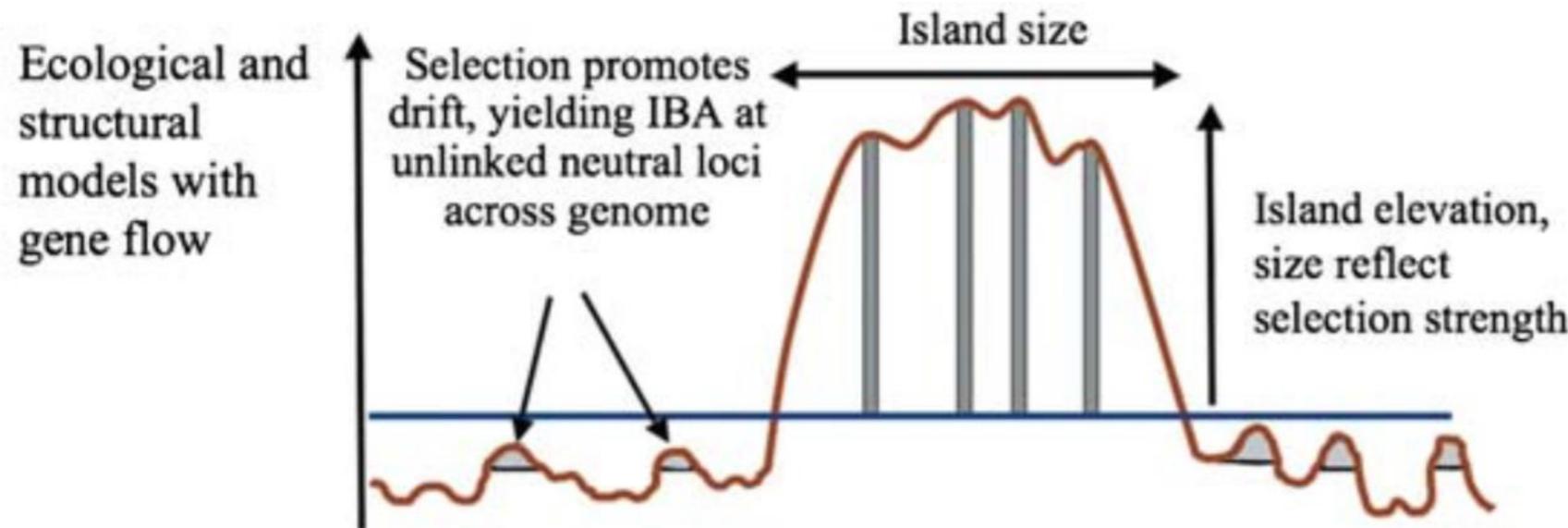


*Anopheles  
gambiae*  
M + S forms

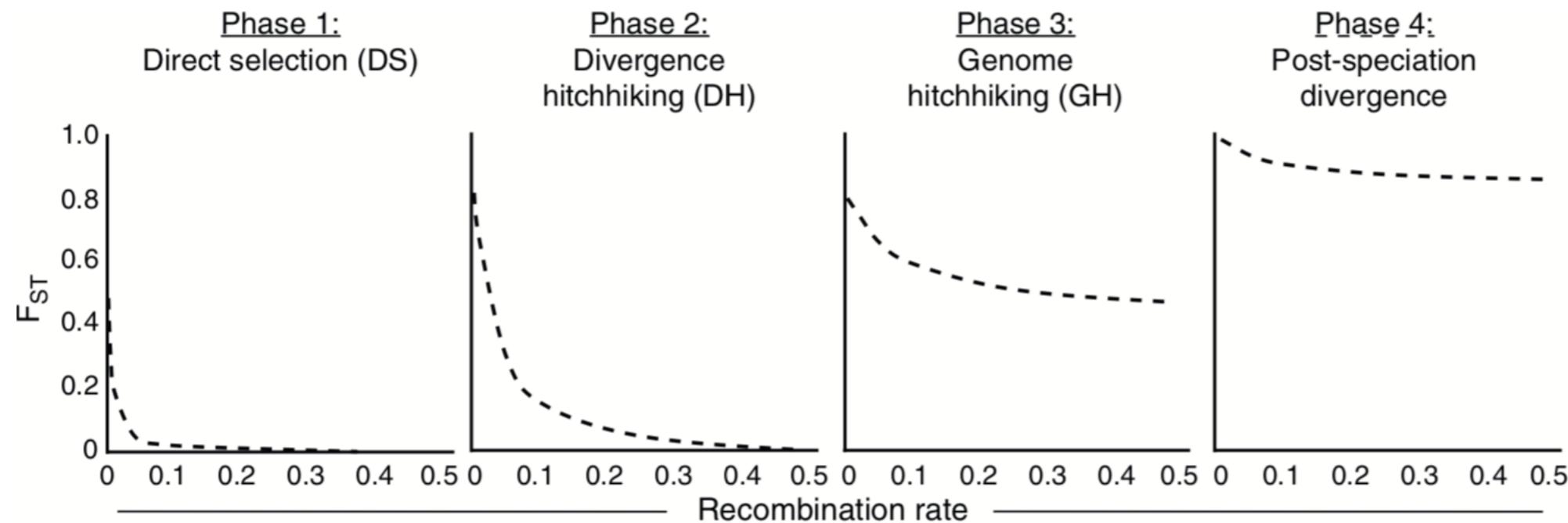


Turner et al (2005) PLoS Biology; Turner & Hahn (2007) MBE

# Speciation islands and processes

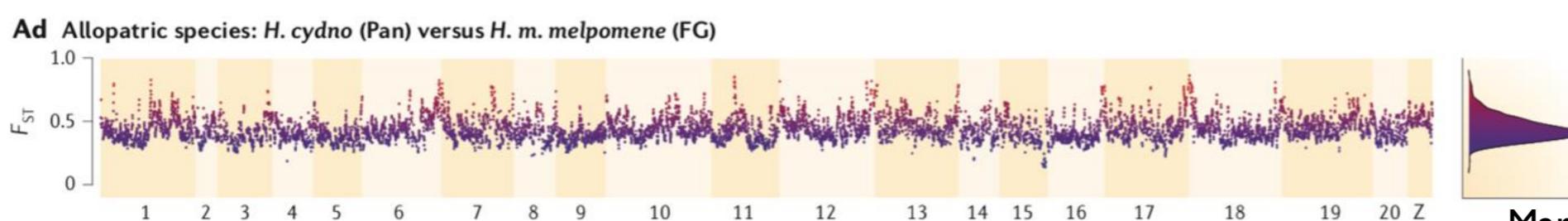
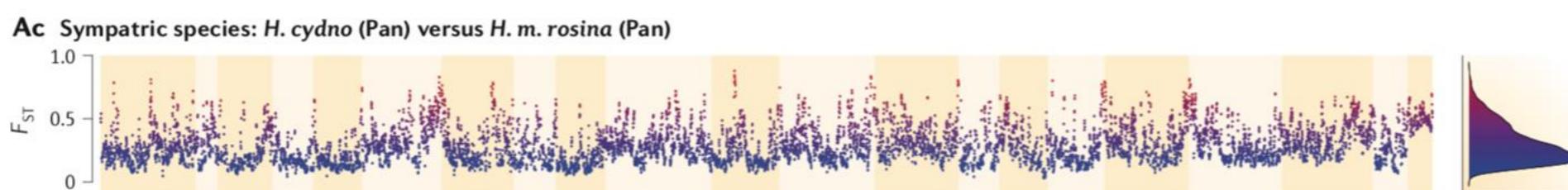
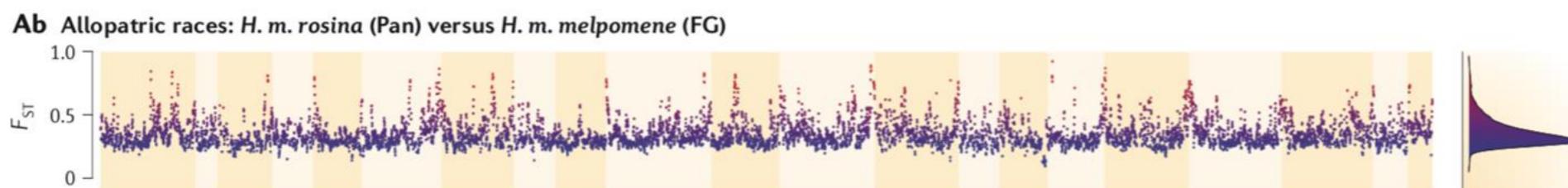
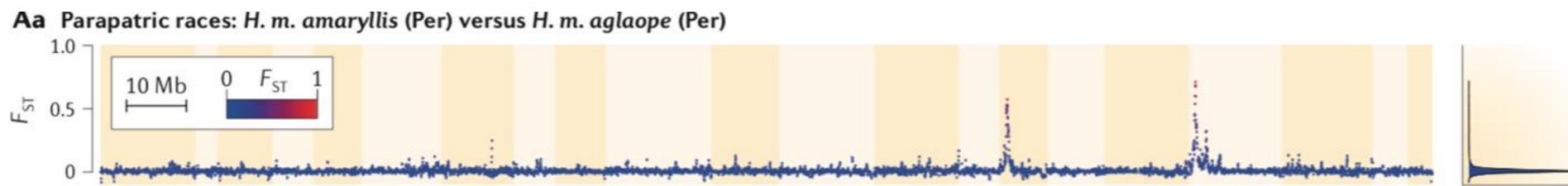
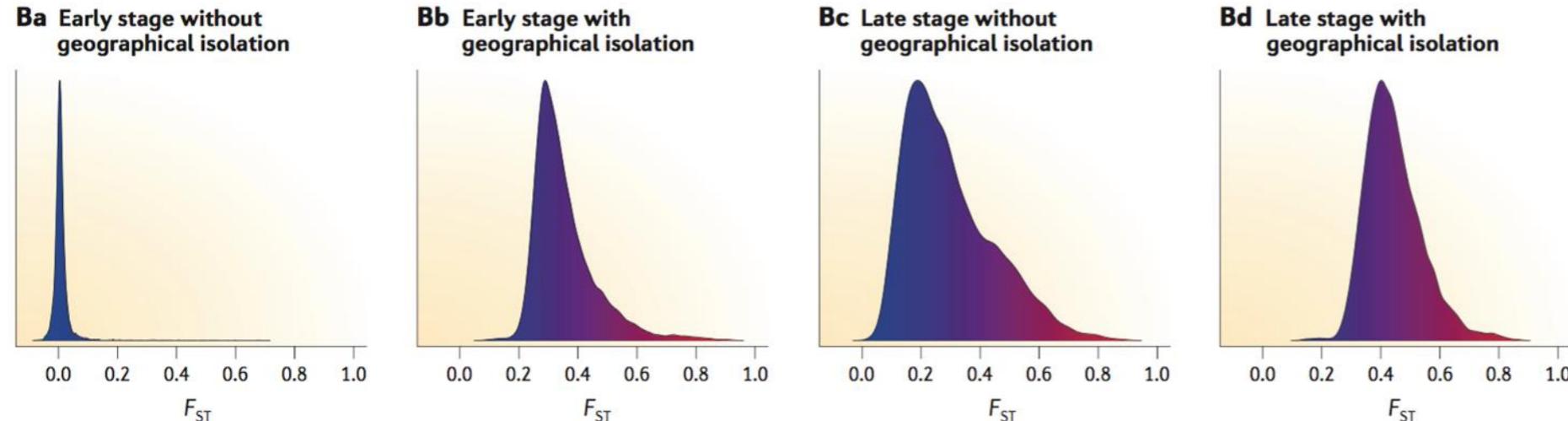


Nosil et al (2009) Mol Ecol



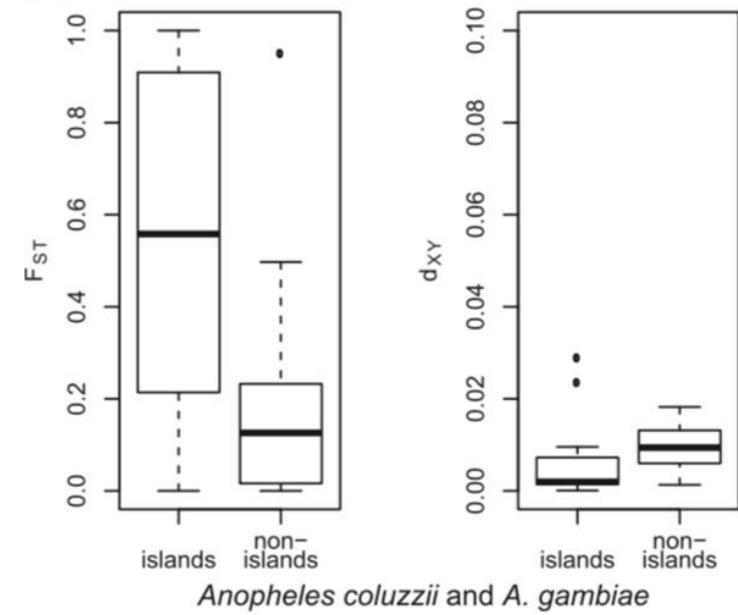
Feder et al (2012) Trends in Genetics

# Continuums and islands

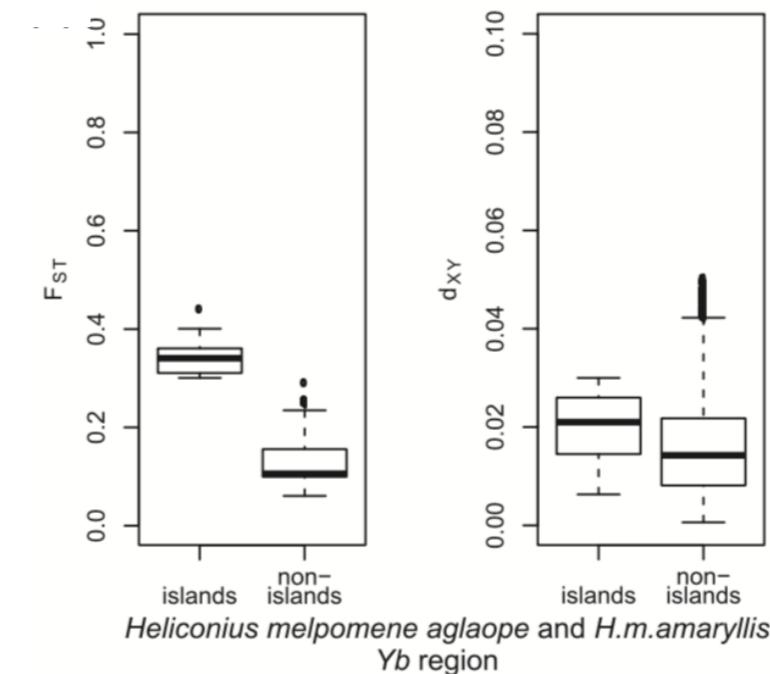


Martin et al. (2013) Genome Research  
Seehausen et al (2014) Nat. Rev. Gen

# Mirages and alternative explanations

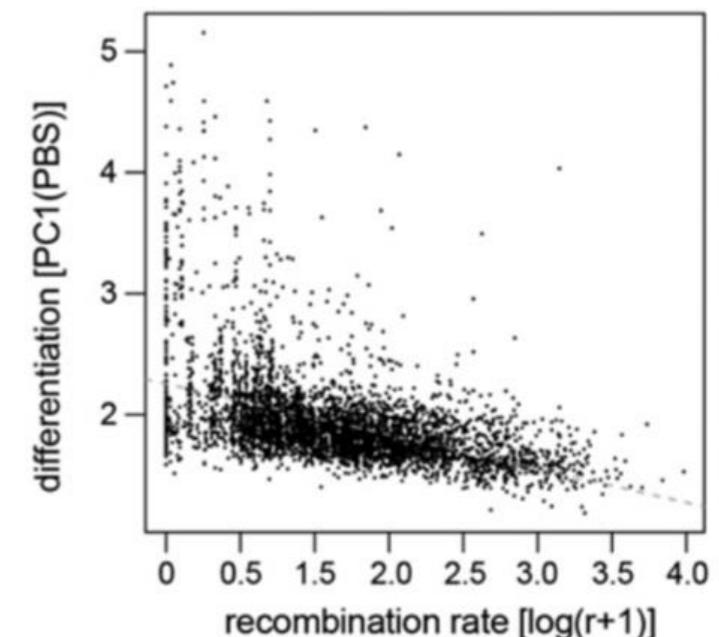
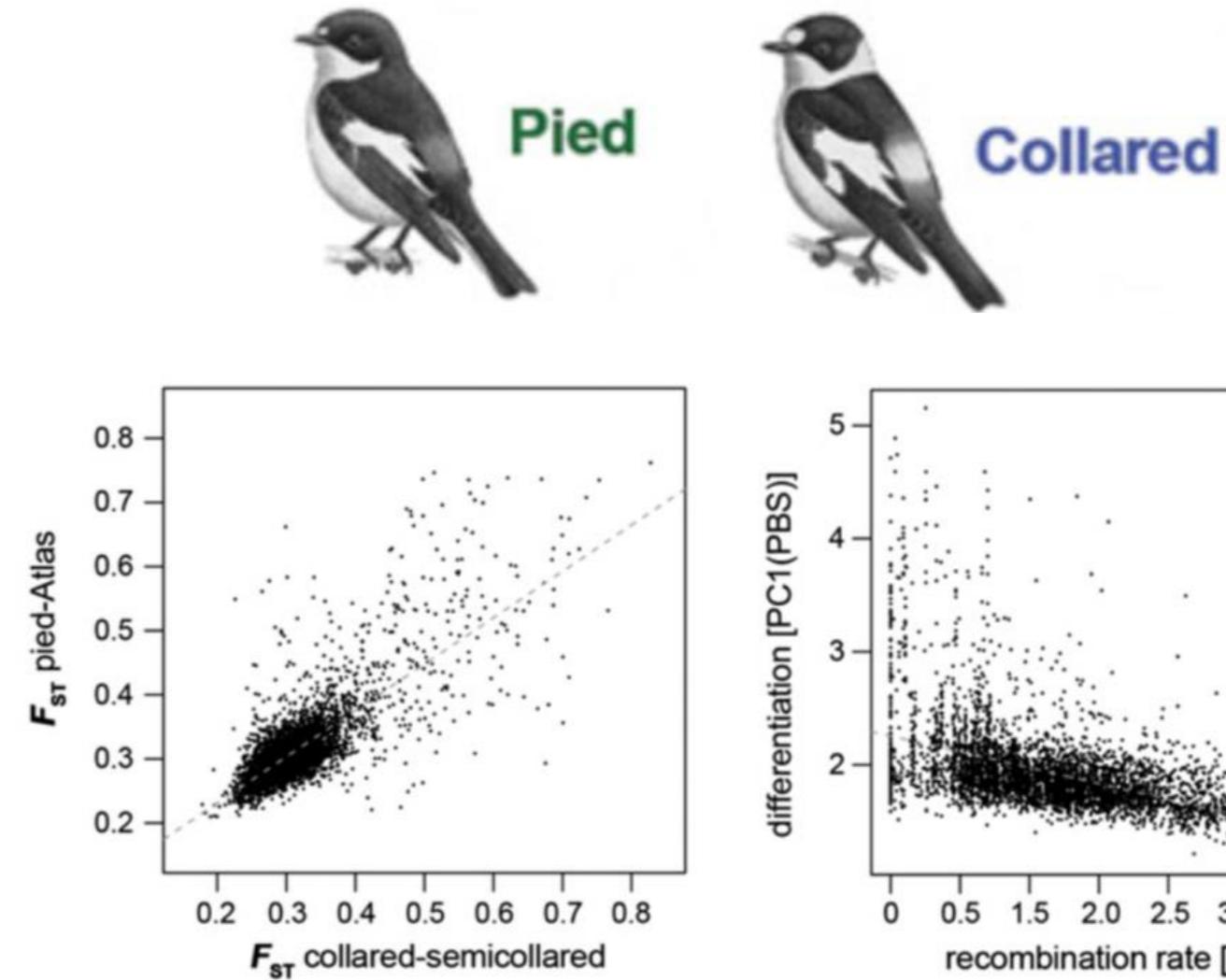
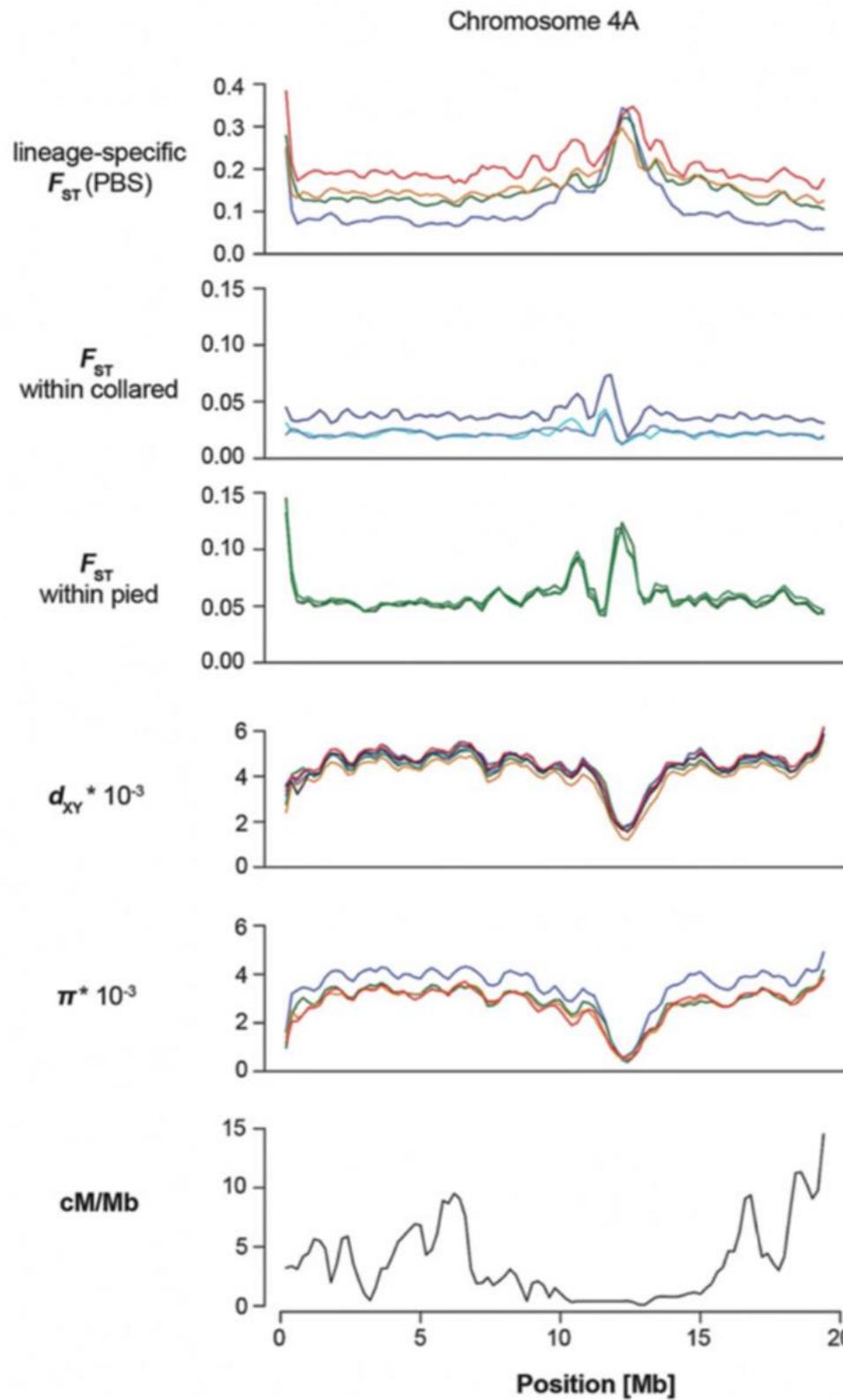


- Background selection
- Local adaptation after isolation
- Shared ancestral polymorphism



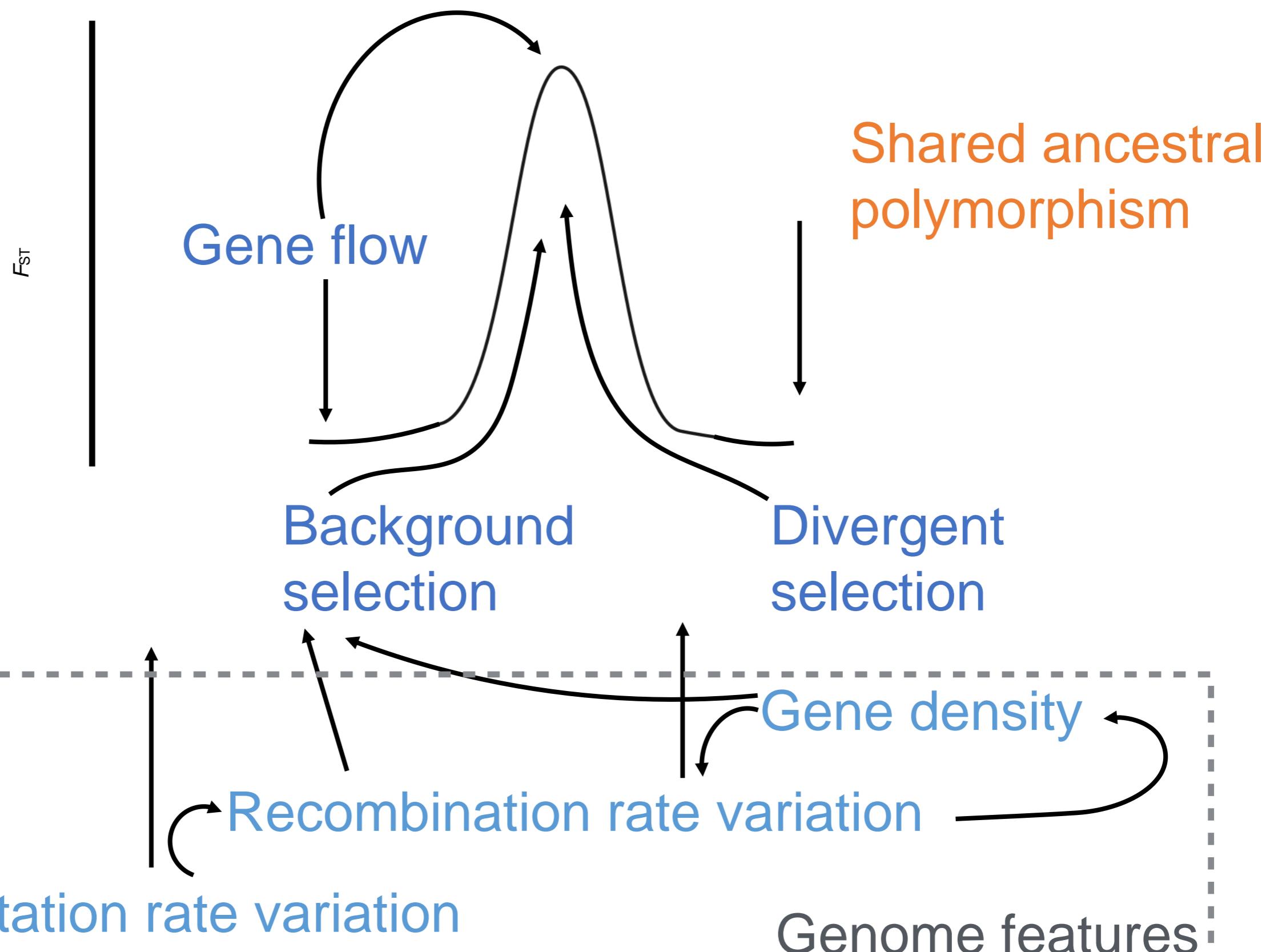
Noor & Bennett (2008) Heredity  
Cruickshank & Hahn (2014) Mol Ecol

# Linked selection and recombination



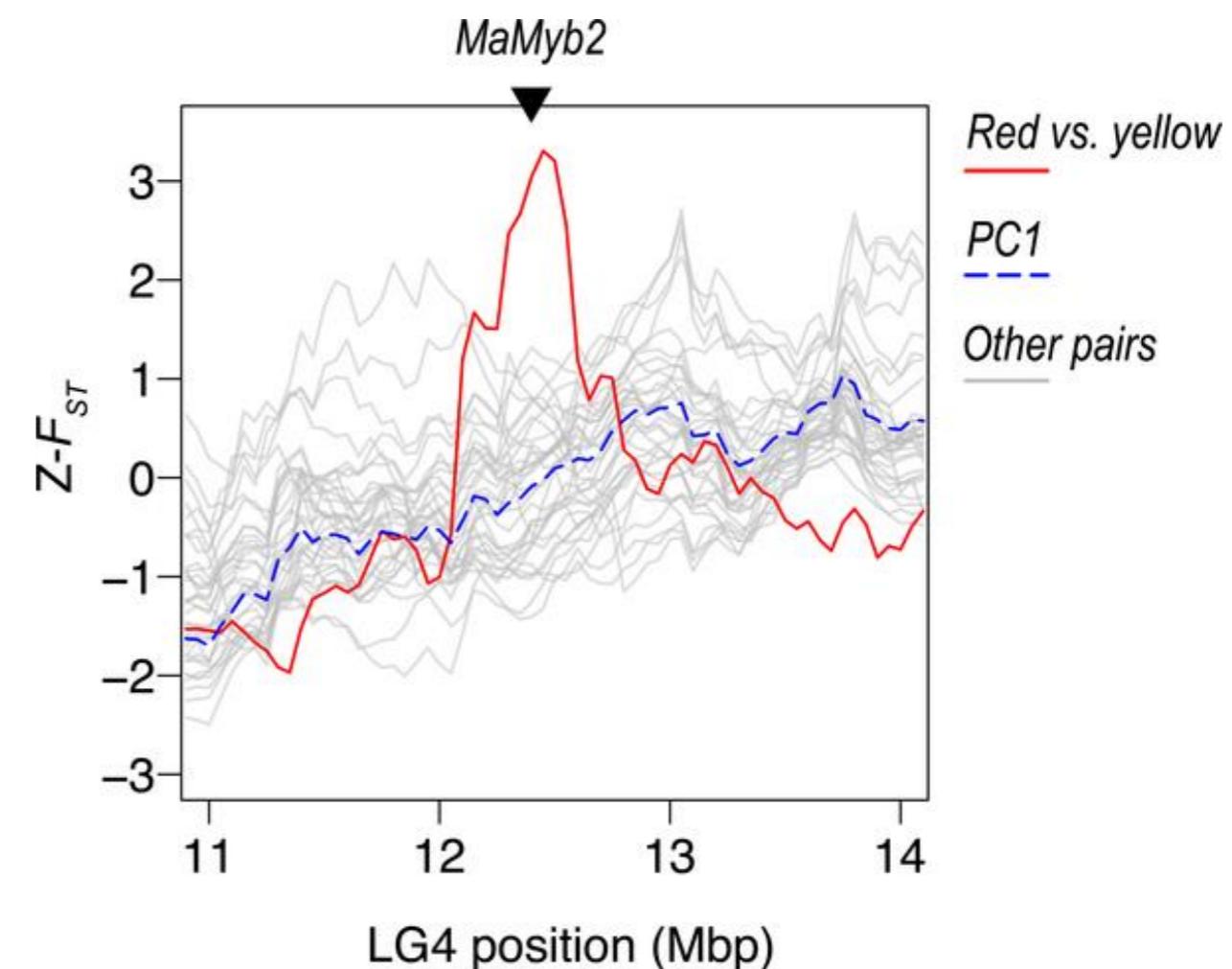
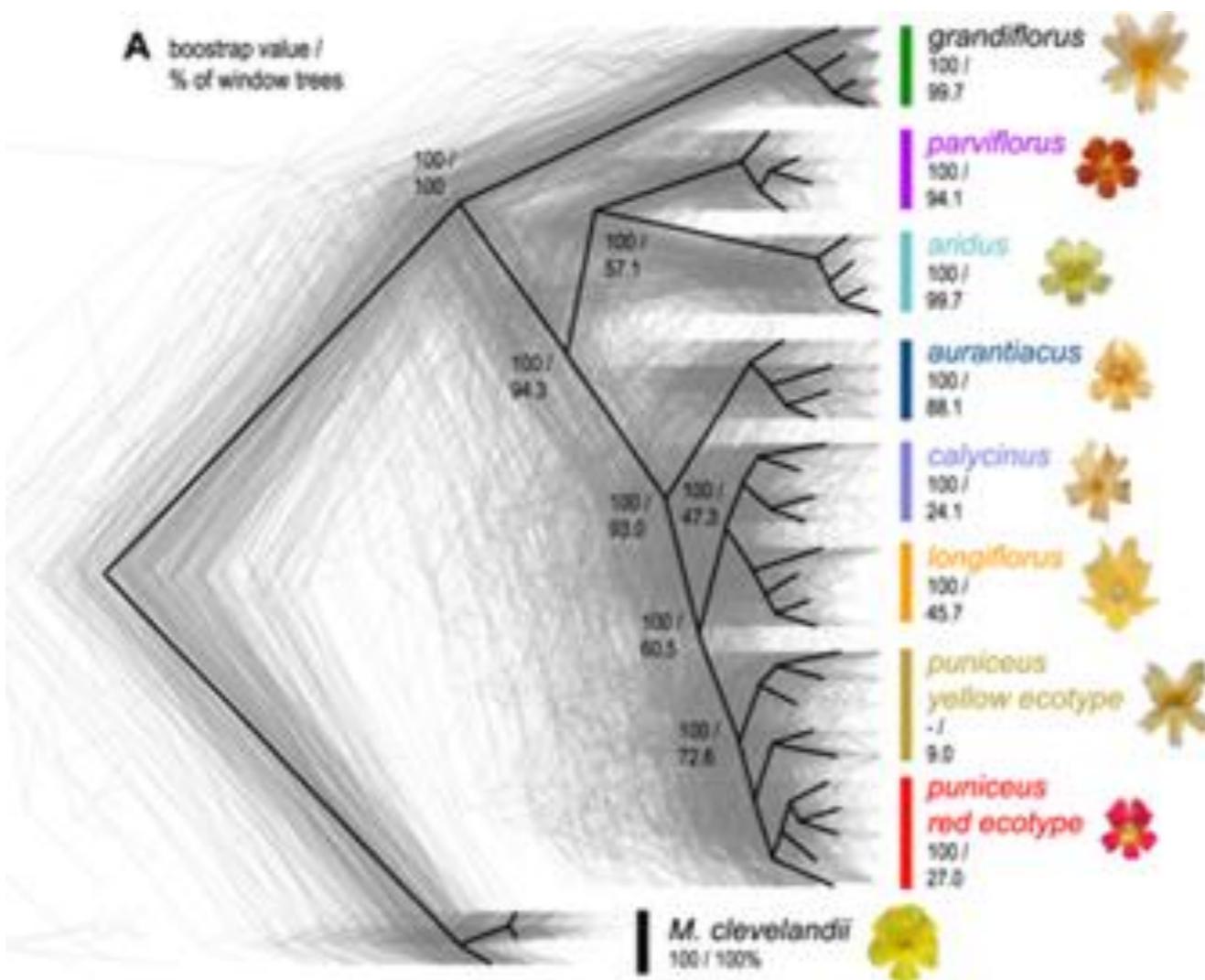
# Confounding factors

Demographic history

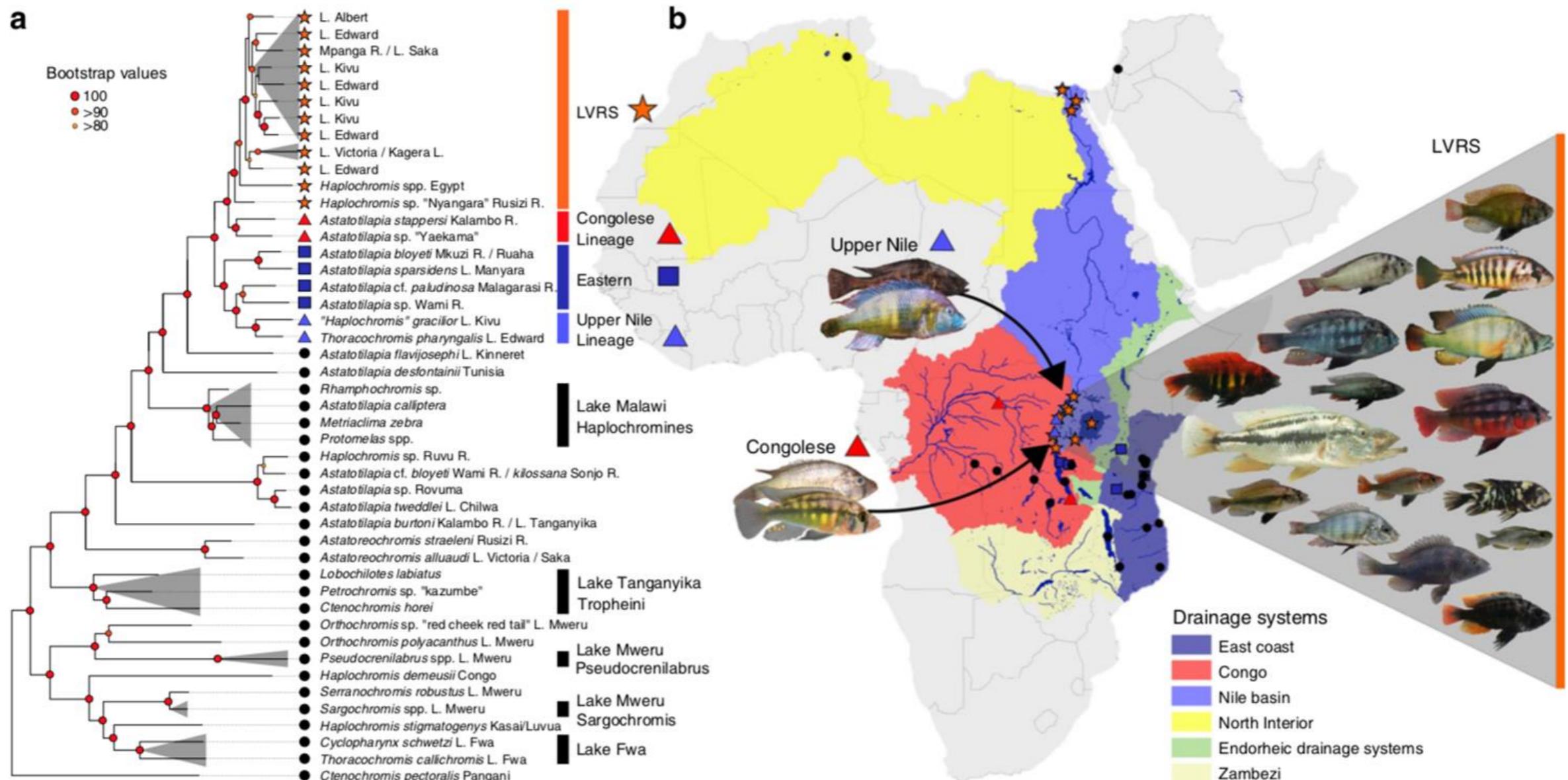


# Evidence for speciation-with-gene-flow

- *Mimulus* monkeyflowers

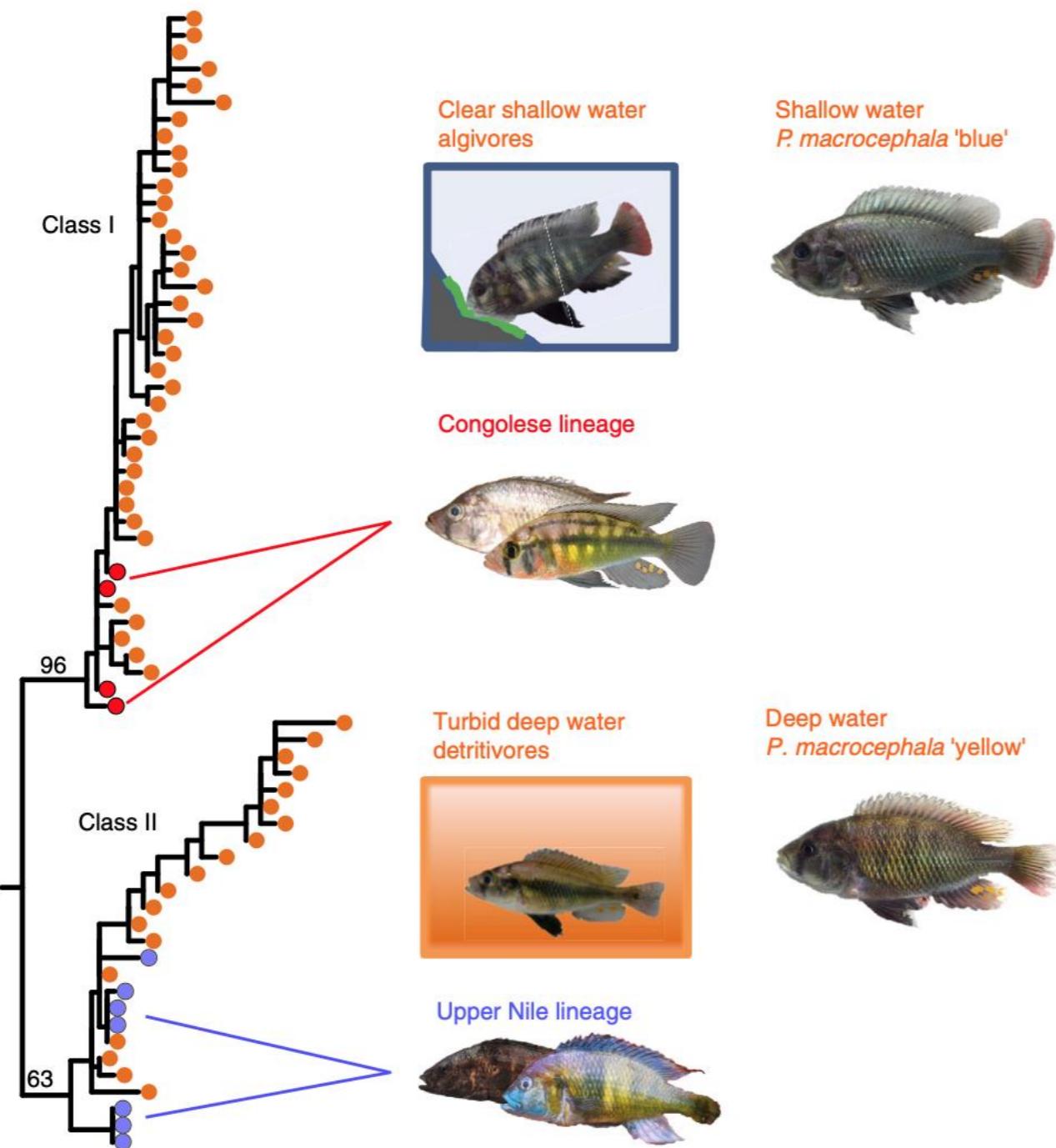


# The Lake Victoria cichlid radiation



# The importance of hybridization

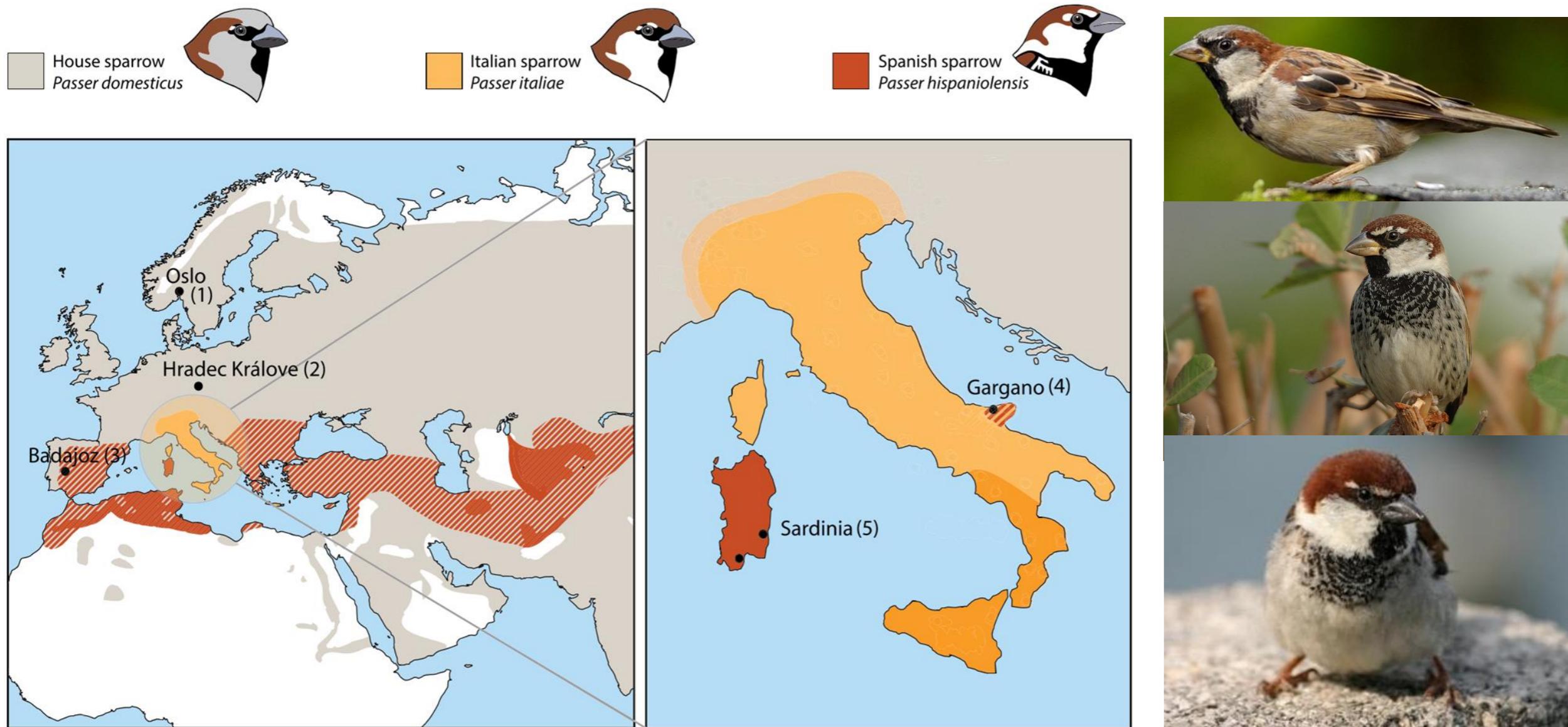
- Opsin genes in Lake Victoria fish



Meier et al 2017 *Nat Comm*

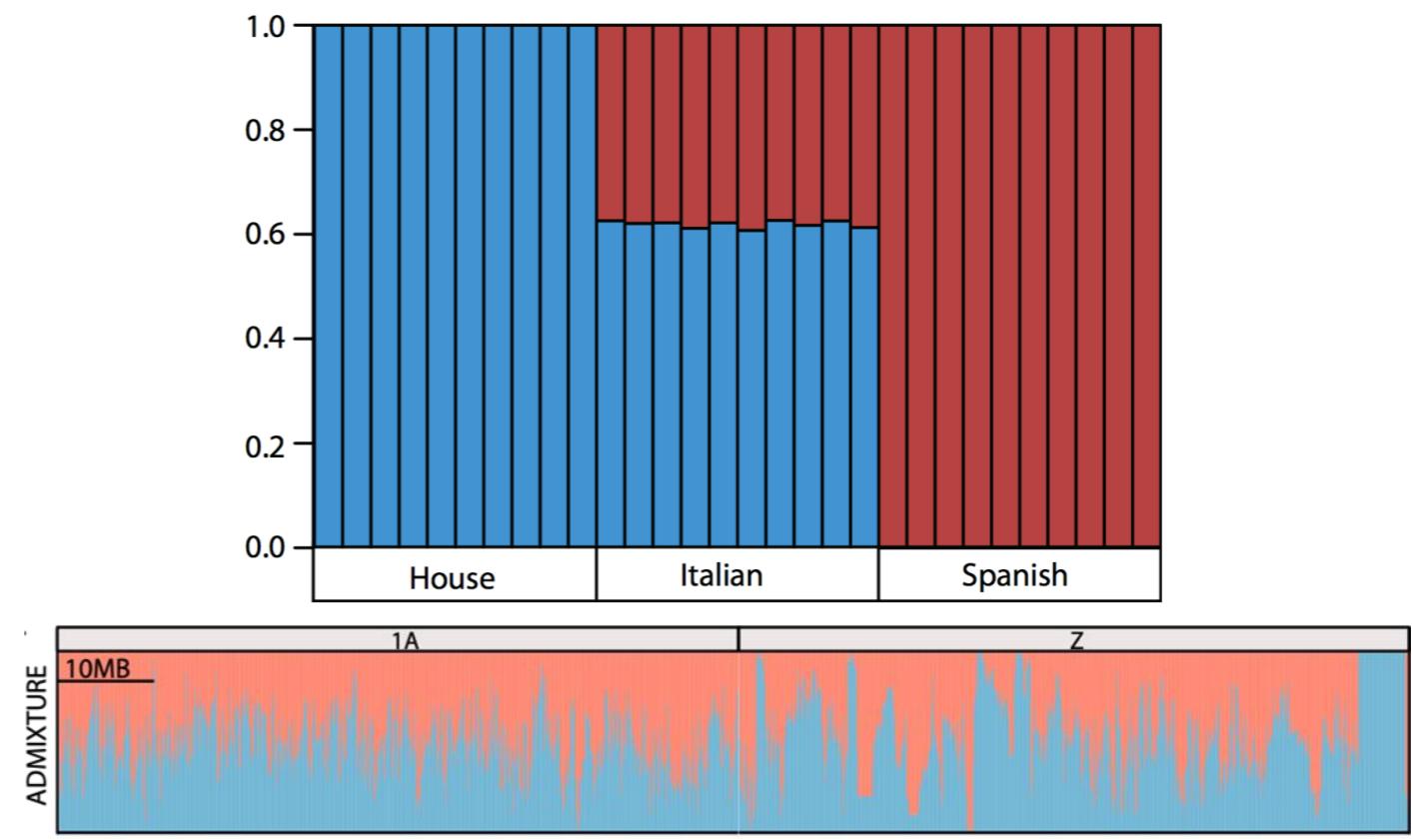
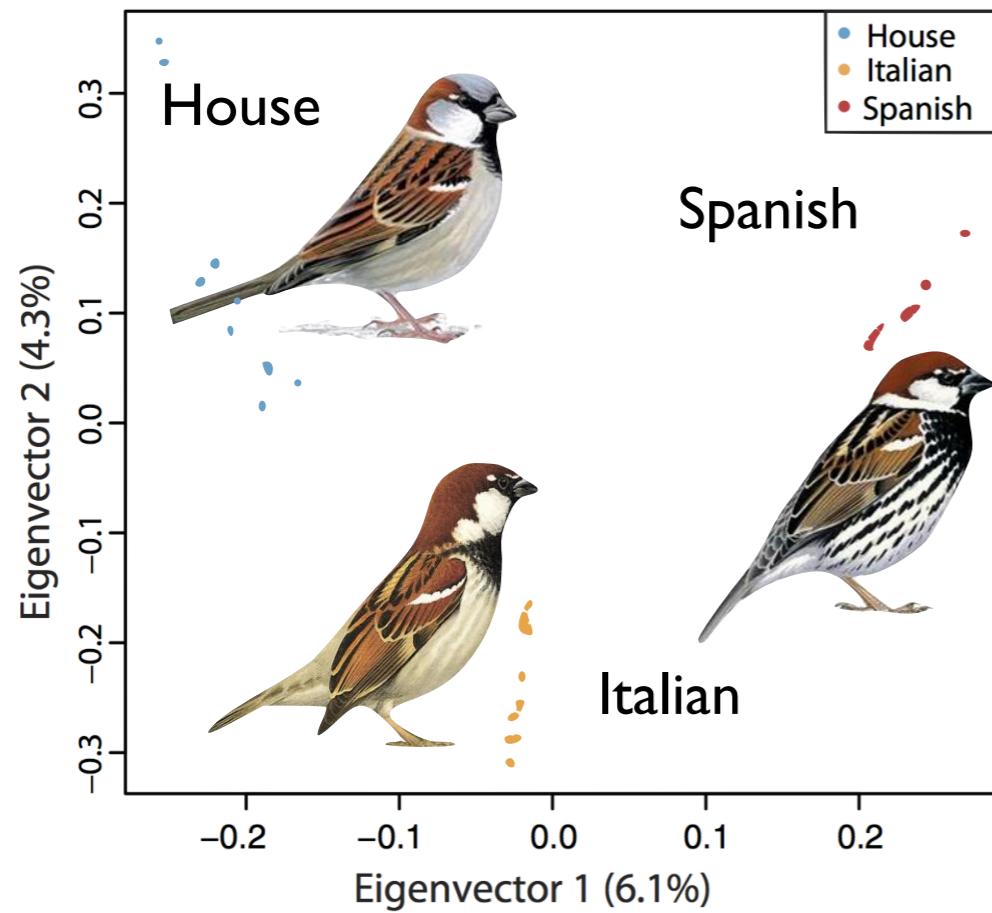
# Hybridization and speciation

- Creative power of gene flow – resulting in new species

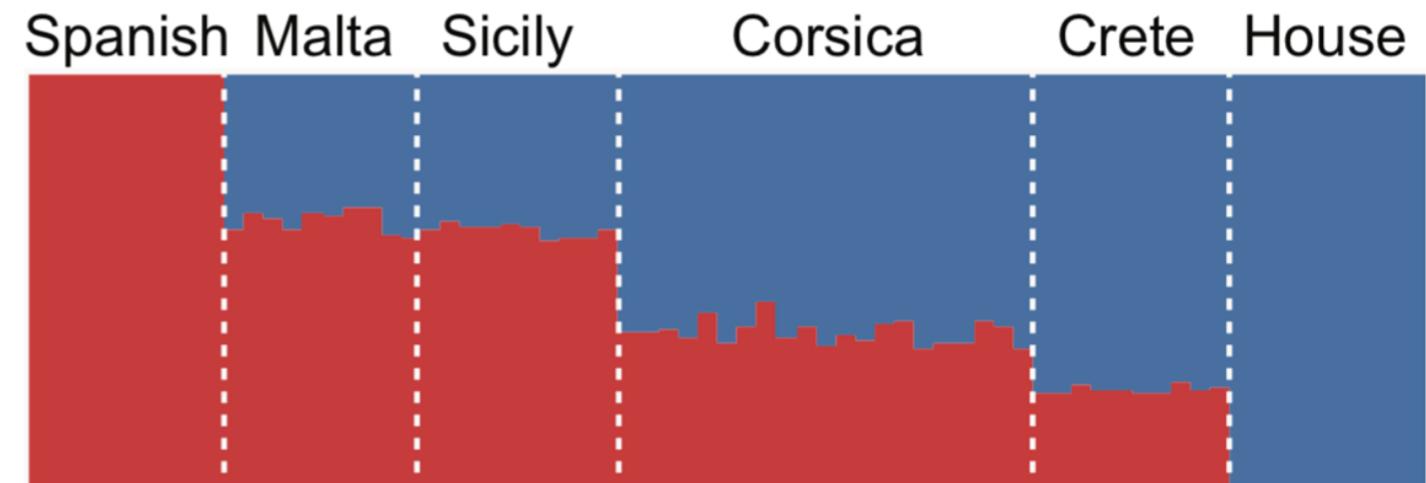
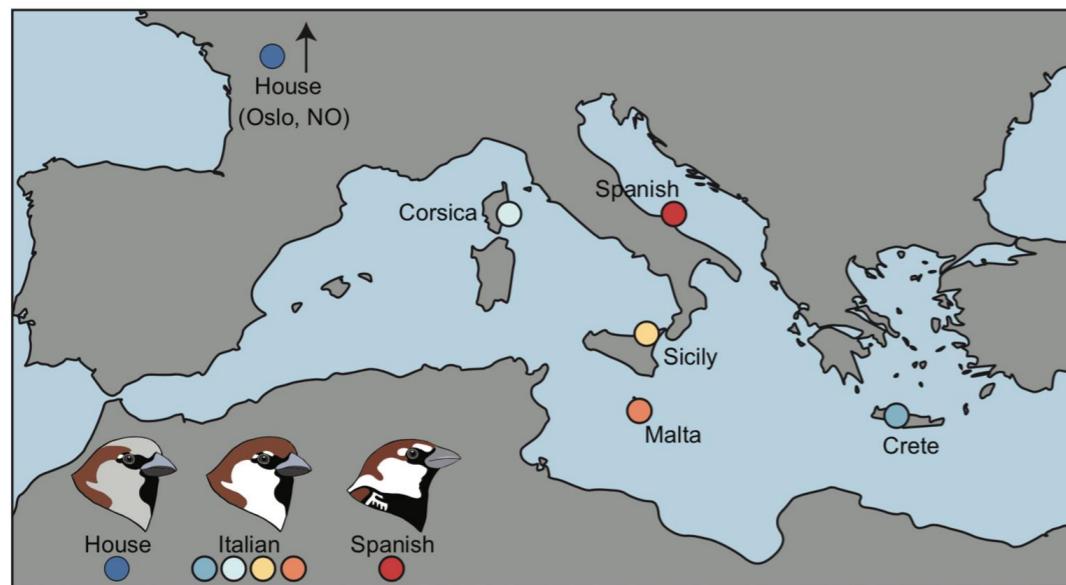


Hermansen et al (2014) *Mol Ecol*

# Hybridization and speciation



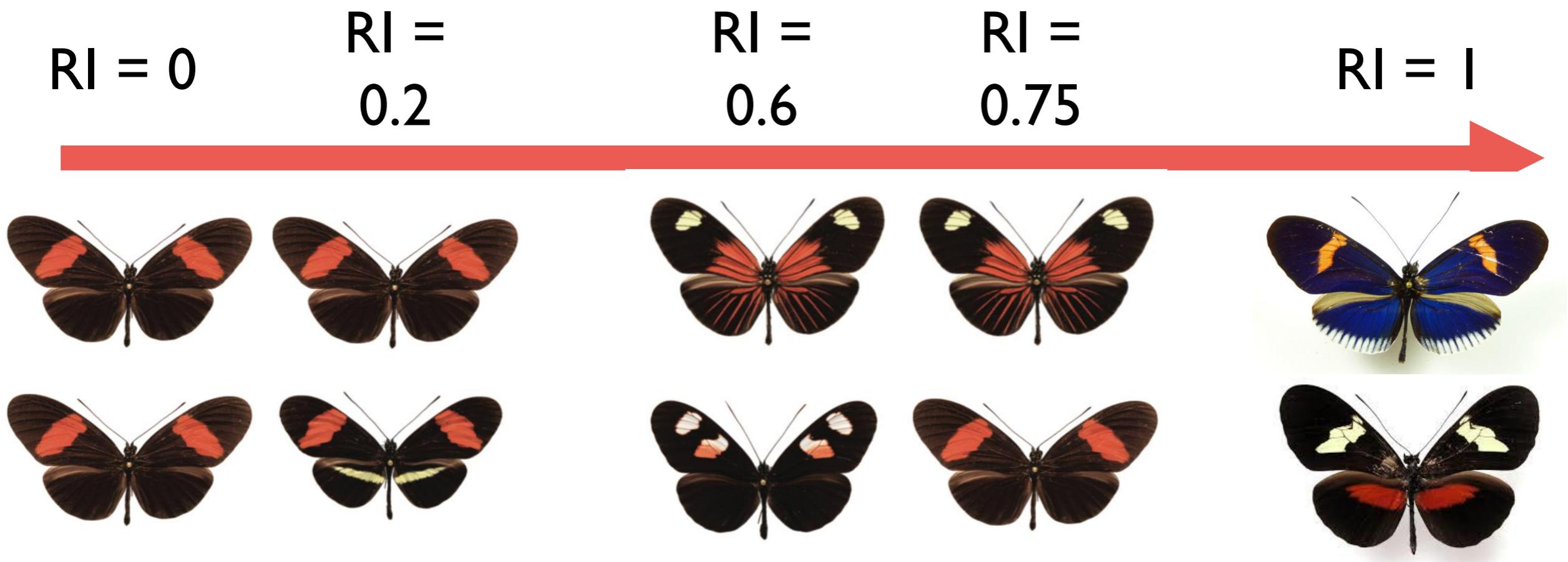
Elgvin et al (2017) *Science Advances*



Runemark et al (2018) *Nat Ecol Evol*

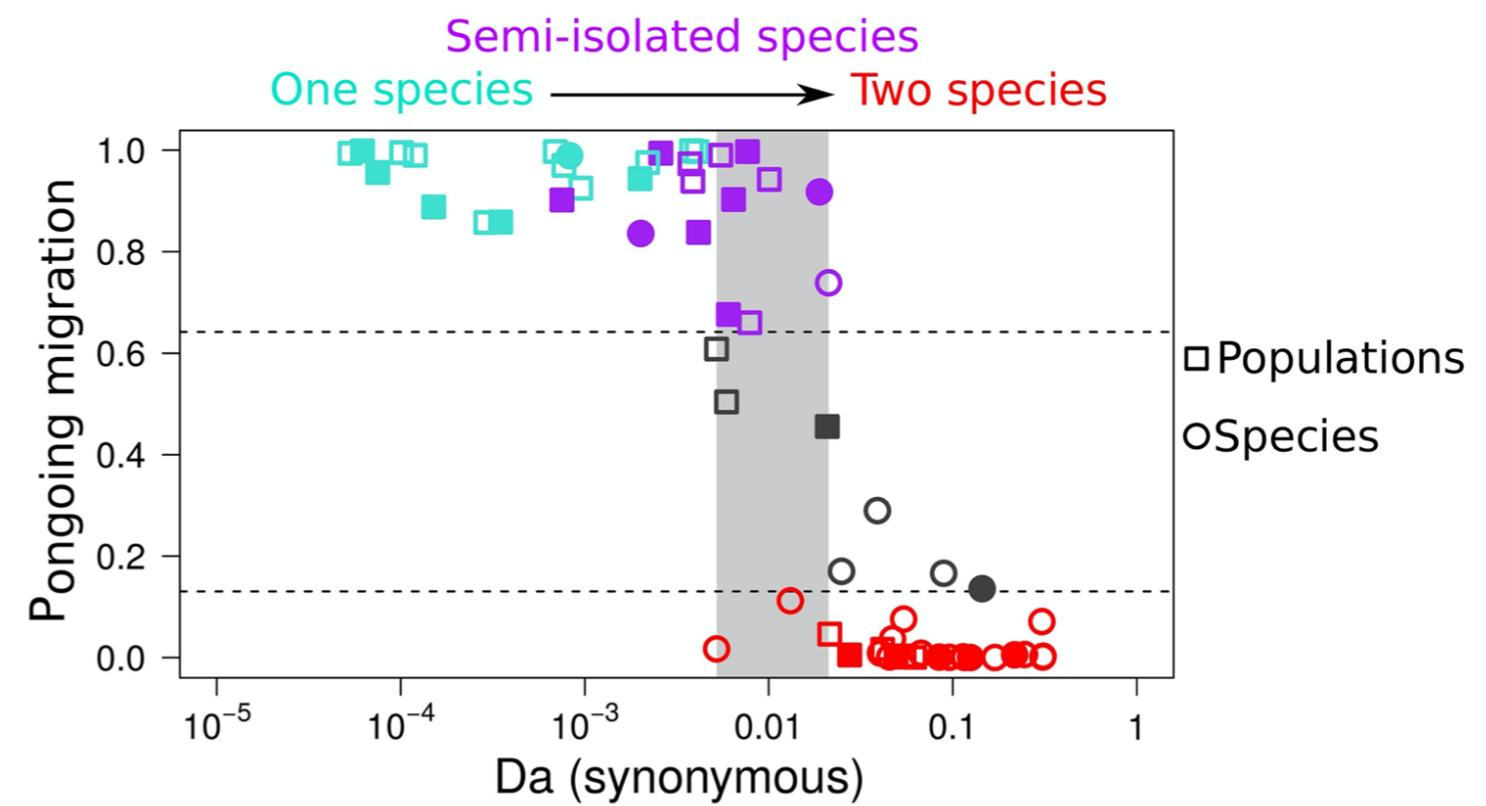
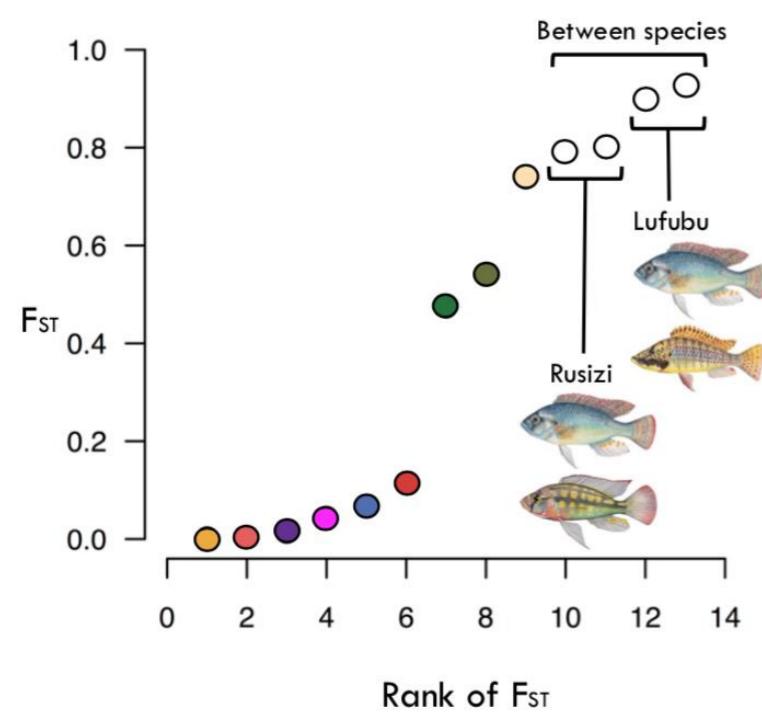
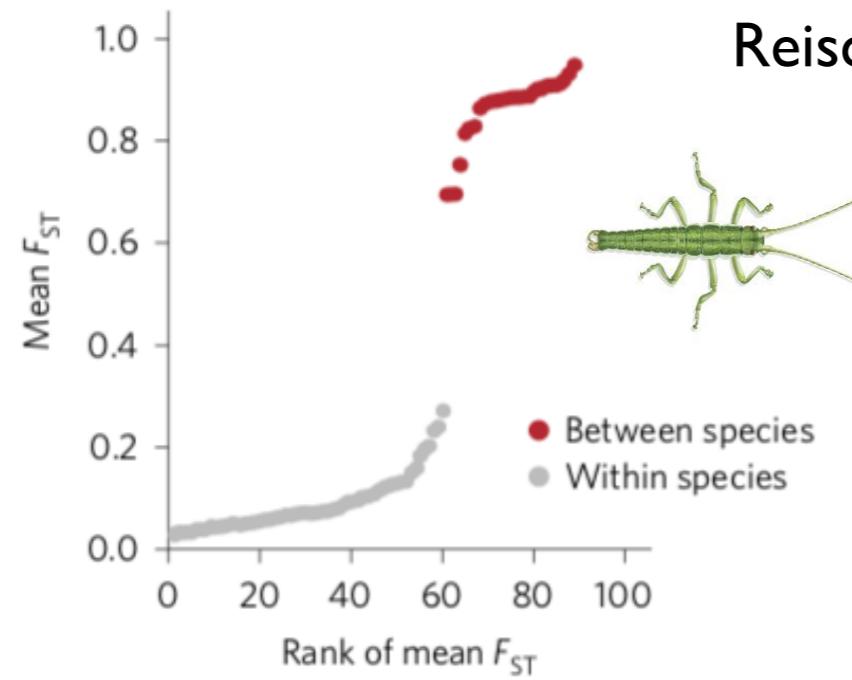
# The speciation continuum

The speciation continuum is a *continuum of reproductive isolation*



# Other axes of the continuum?

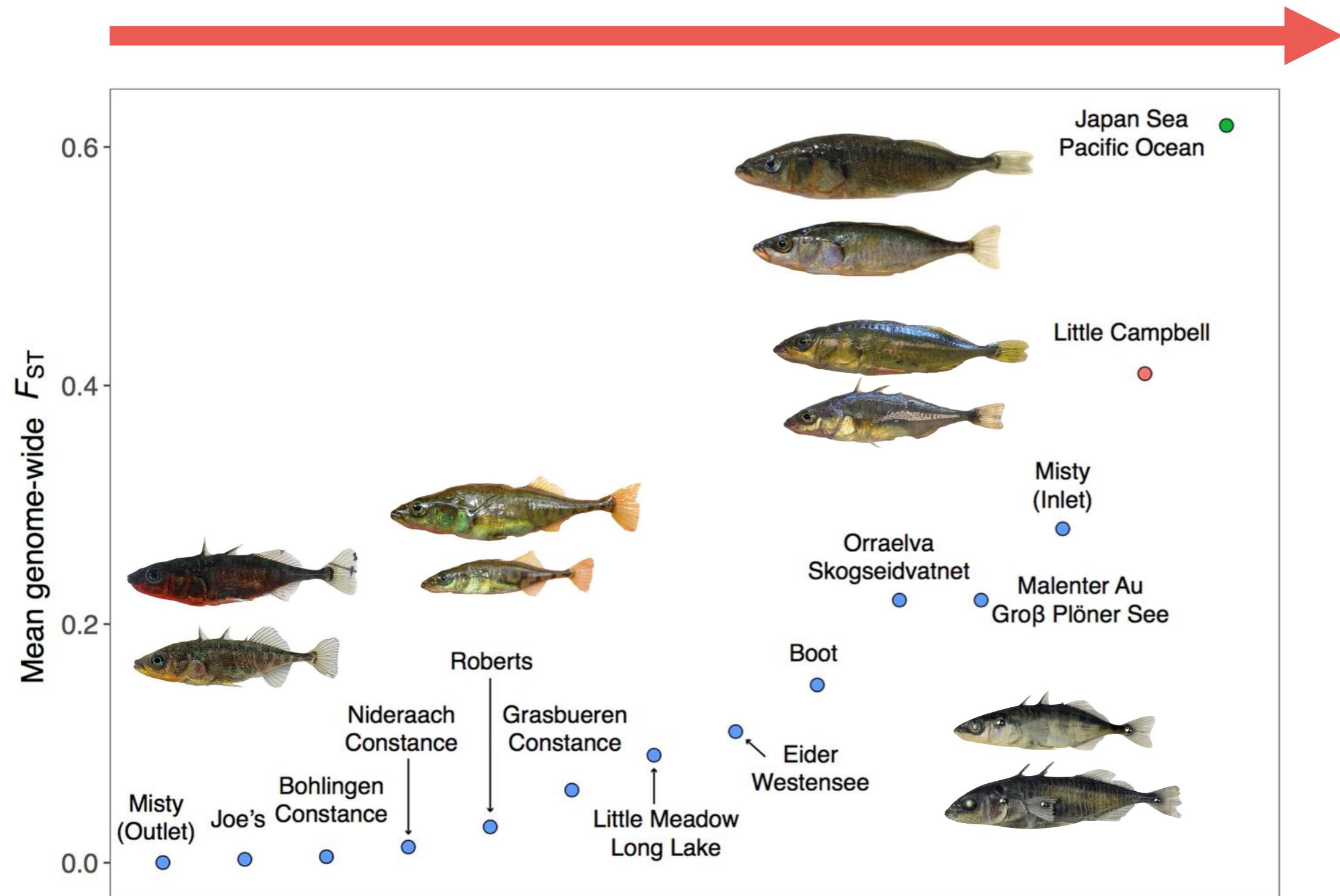
Divergence time and genetic divergence



Weber et al 2021 bioRxiv

Roux et al 2016 PloS Bio

# 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



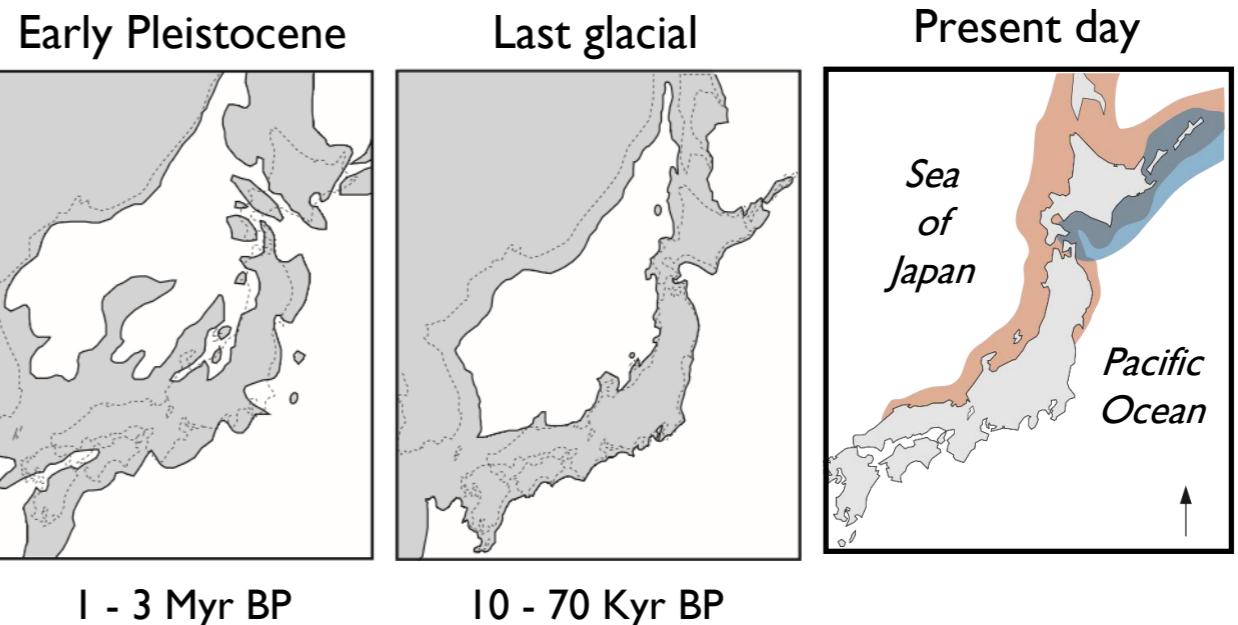
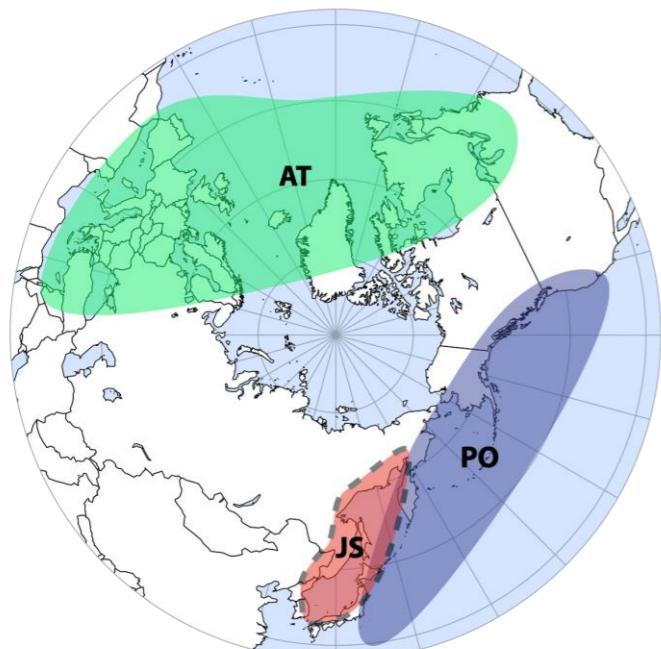
Three-spined  
stickleback  
**Pacific**  
Ocean



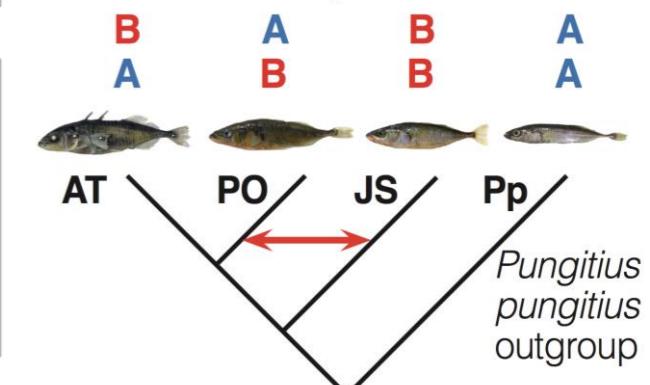
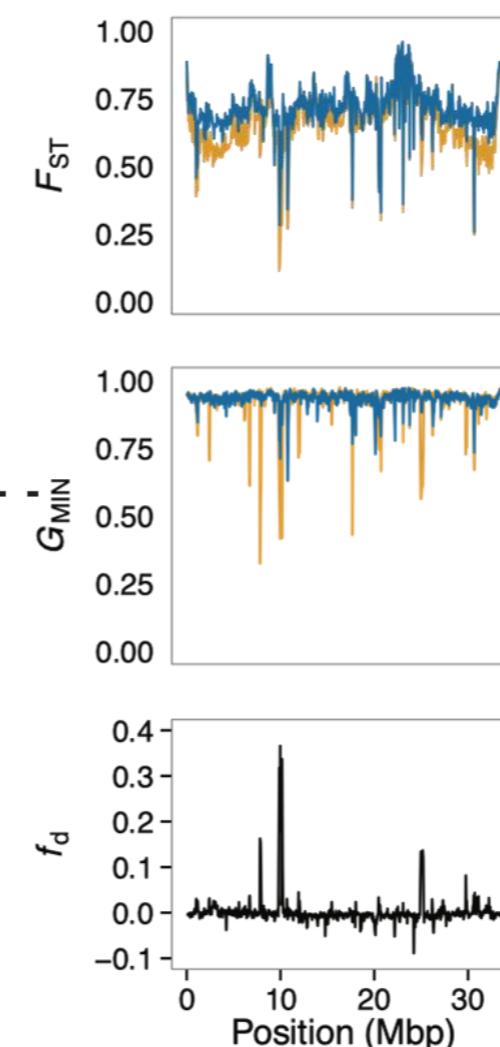
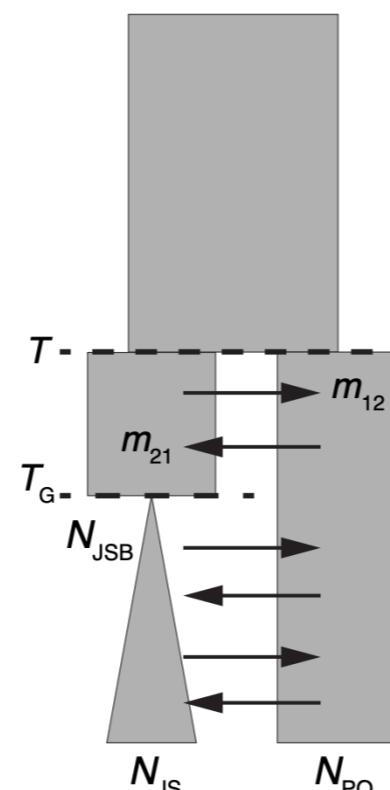
Japan Sea  
stickleback  
**Sea of**  
Japan

Atlantic  
Ocean

Sea of  
Okhotsk

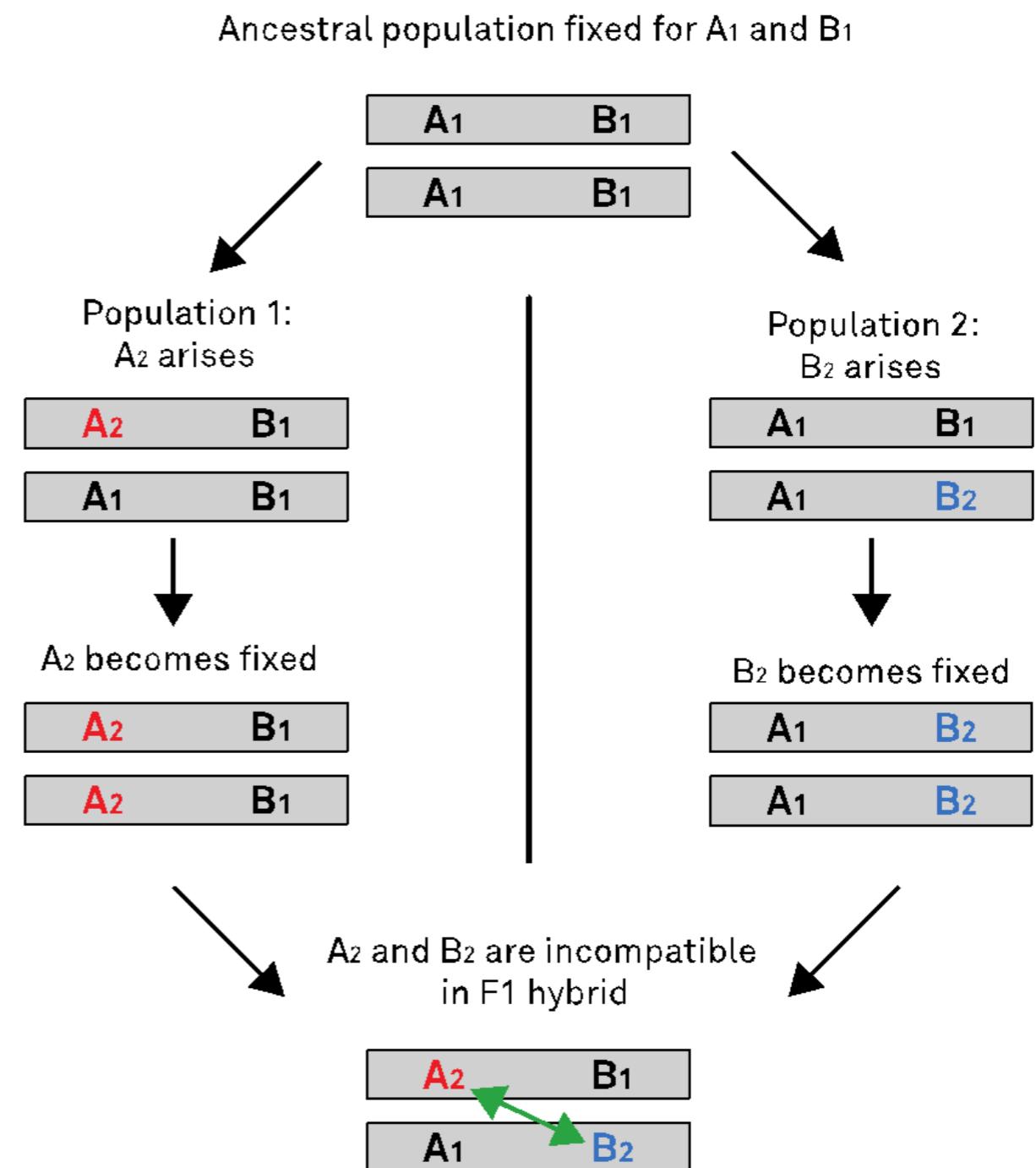


A Constant migration  
+ bottleneck



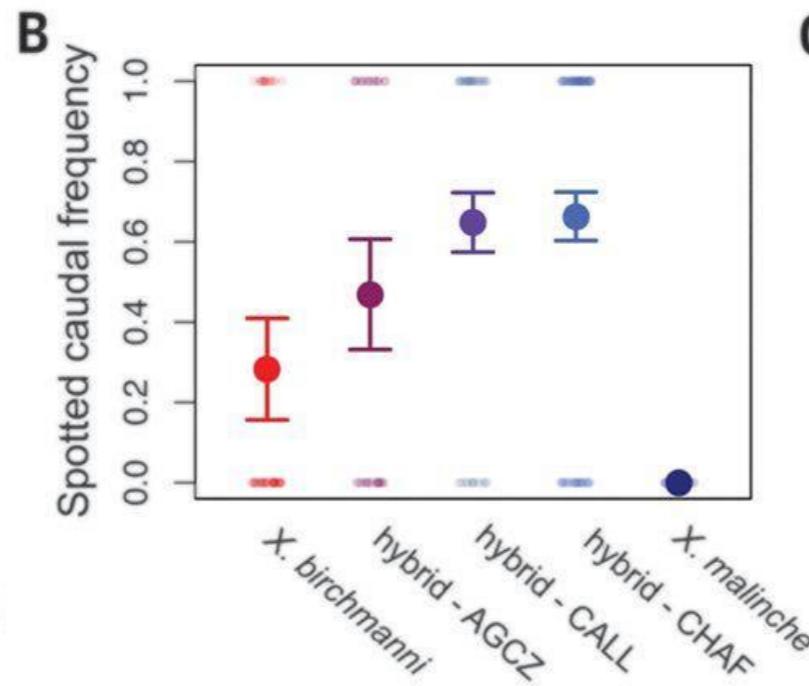
# Genetic basis of reproductive isolation

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

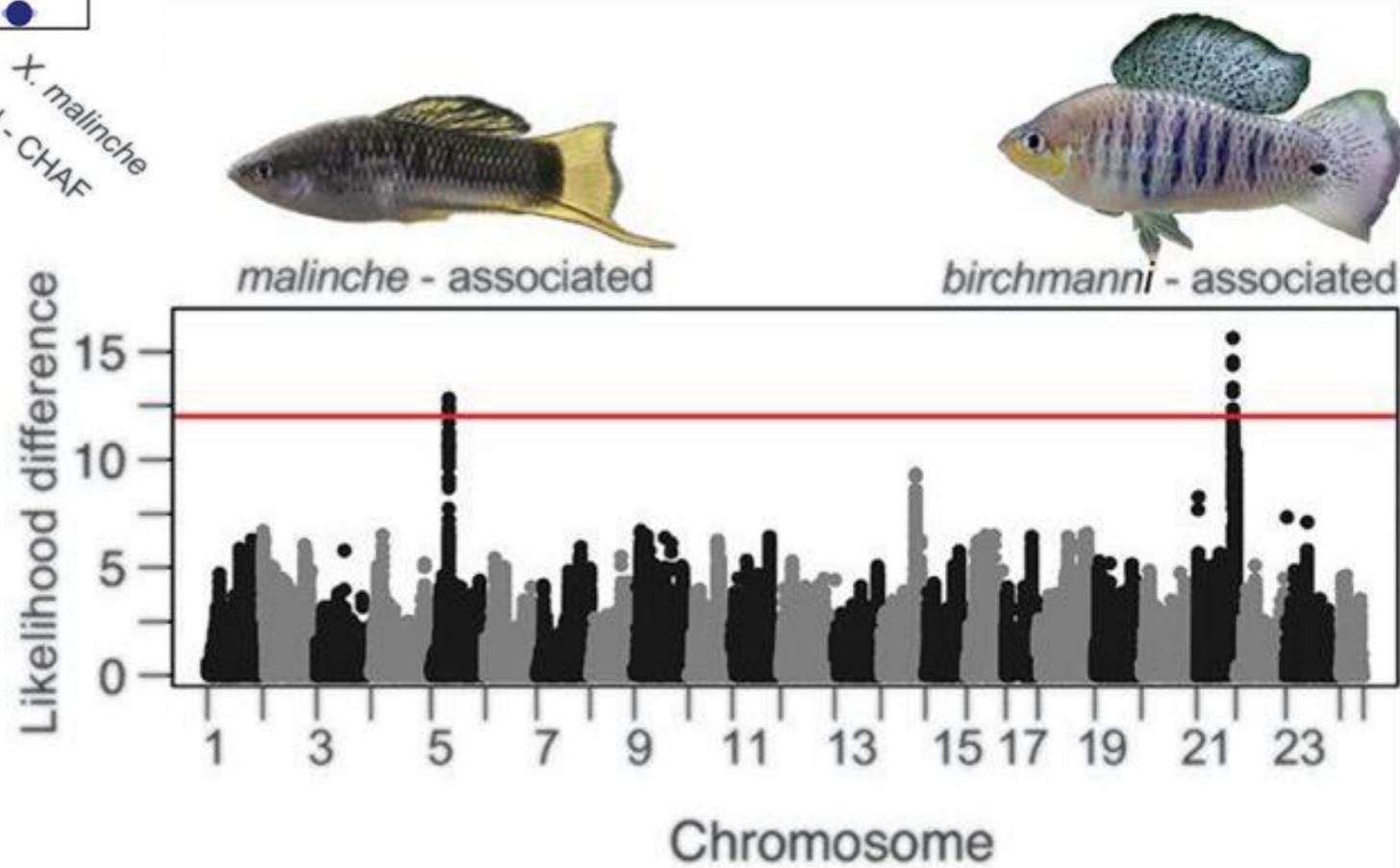


# Genetic basis of reproductive isolation

- *Xiphophorus* swordtails – caudal melanoma

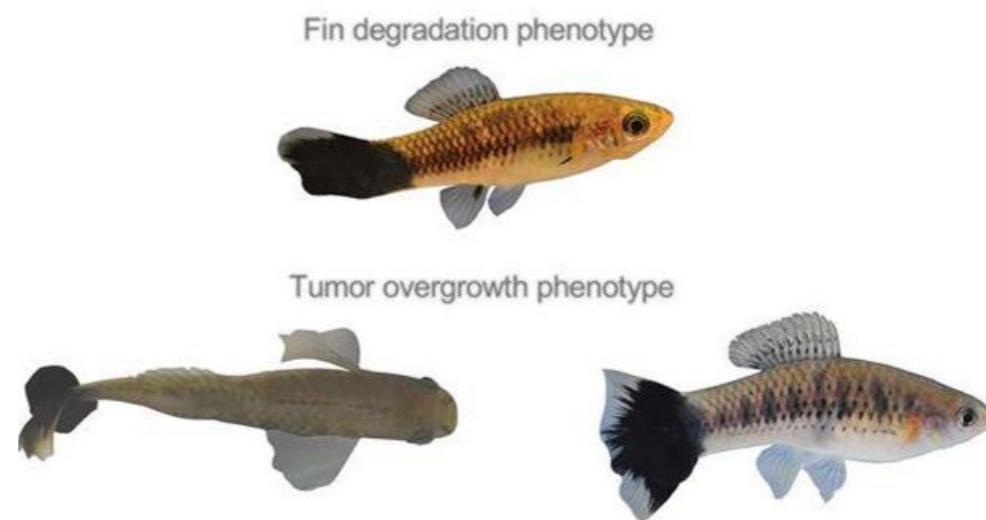


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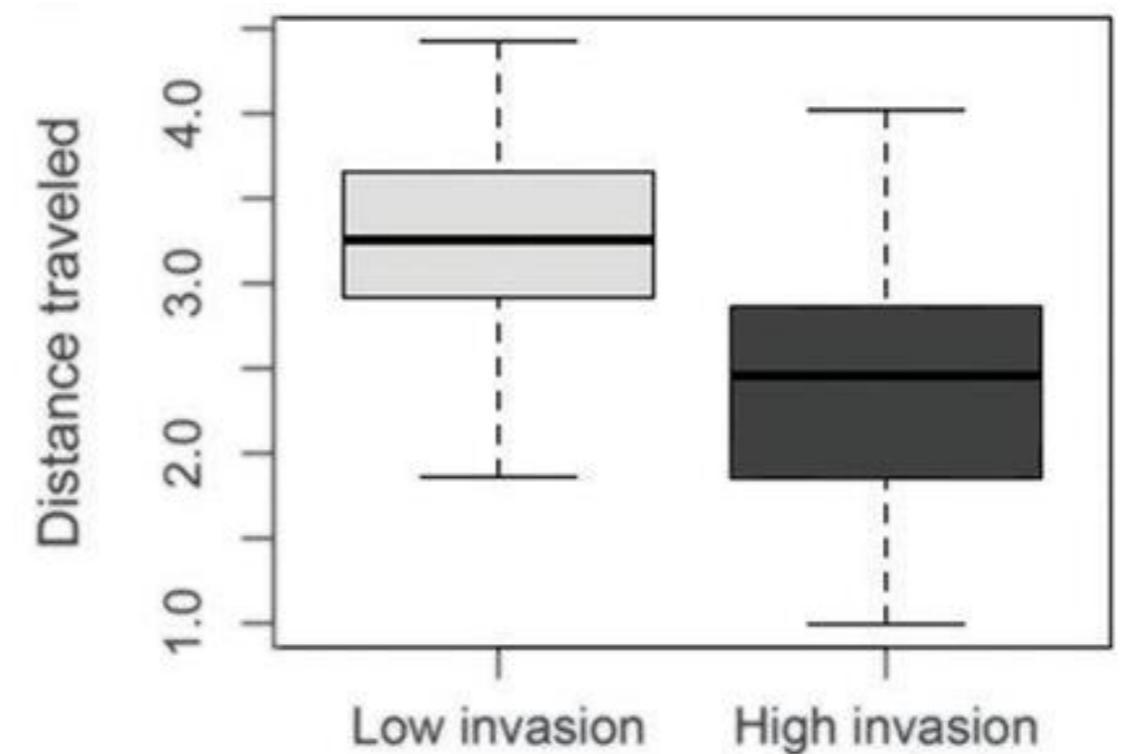
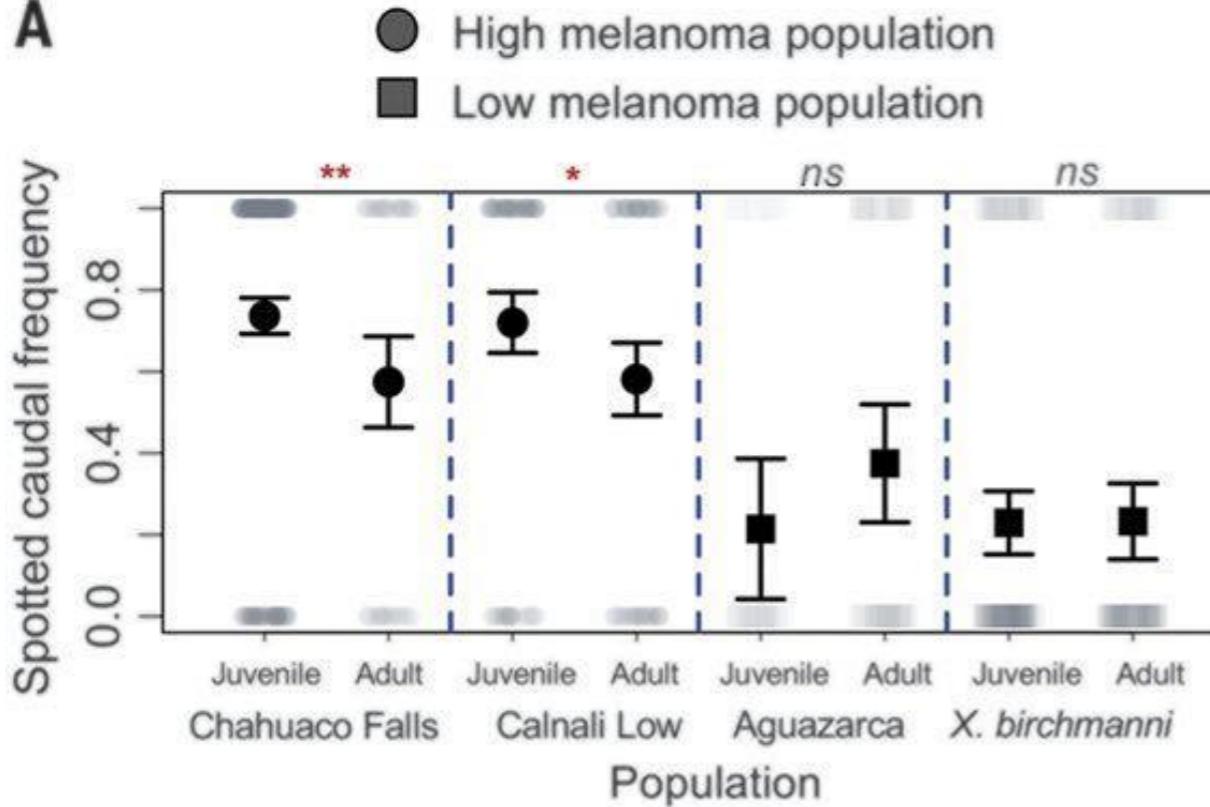


Powell et al (2020)  
*Science*

# Genetic basis of reproductive isolation



A





# A confusing field – what is the way forward?



Available online at [www.sciencedirect.com](http://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



Interpreting differentiation landscapes  
in

Jochen B. W. Wolf<sup>1</sup>

Reto<sup>1</sup> 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](https://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

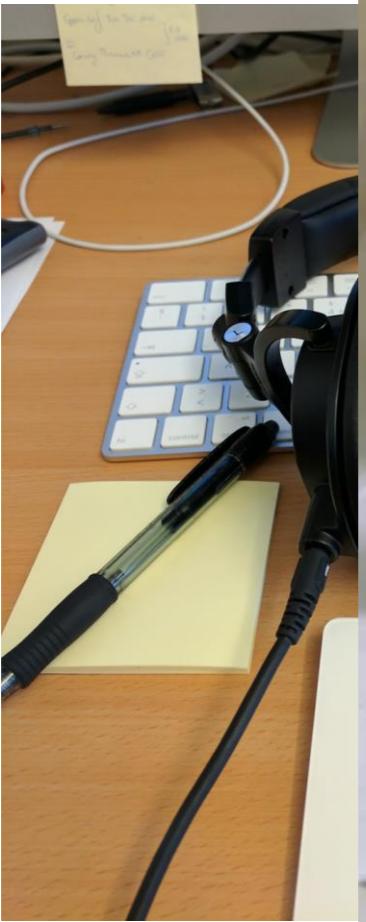
[speciationgenomics.github.io](http://speciationgenomics.github.io)

# Plan for today

1. Learning how to use Unix
2. Introduction to NGS data
3. Assessing the quality of NGS reads
4. Filtering NGS reads

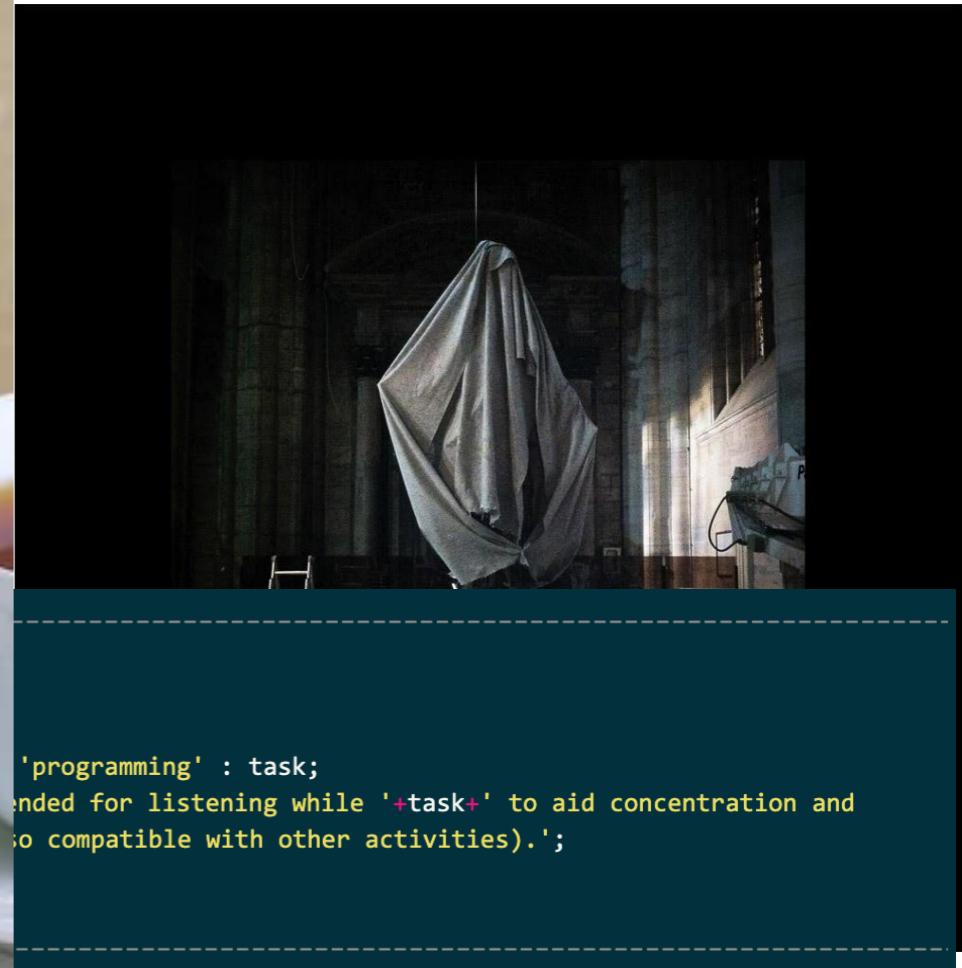
[speciationgenomics.github.io](https://speciationgenomics.github.io)

# Bioinformatics secret weapons



Google

Please help me with my bioinformatics problems



# Bioinformatics secret weapons

