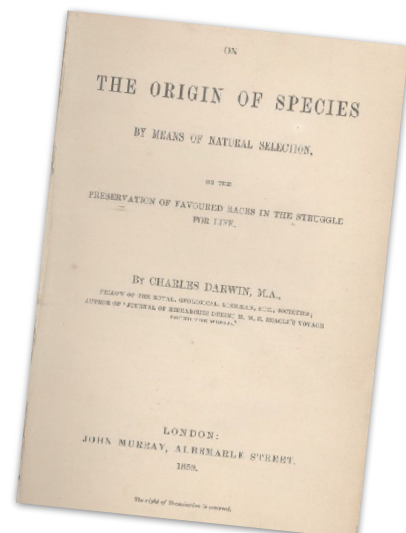


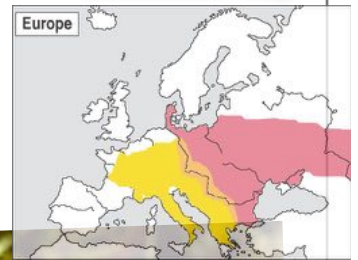
The Oxford Advanced Learner's Dictionary



① Charles R. Darwin (1809-1882)

What is a species?

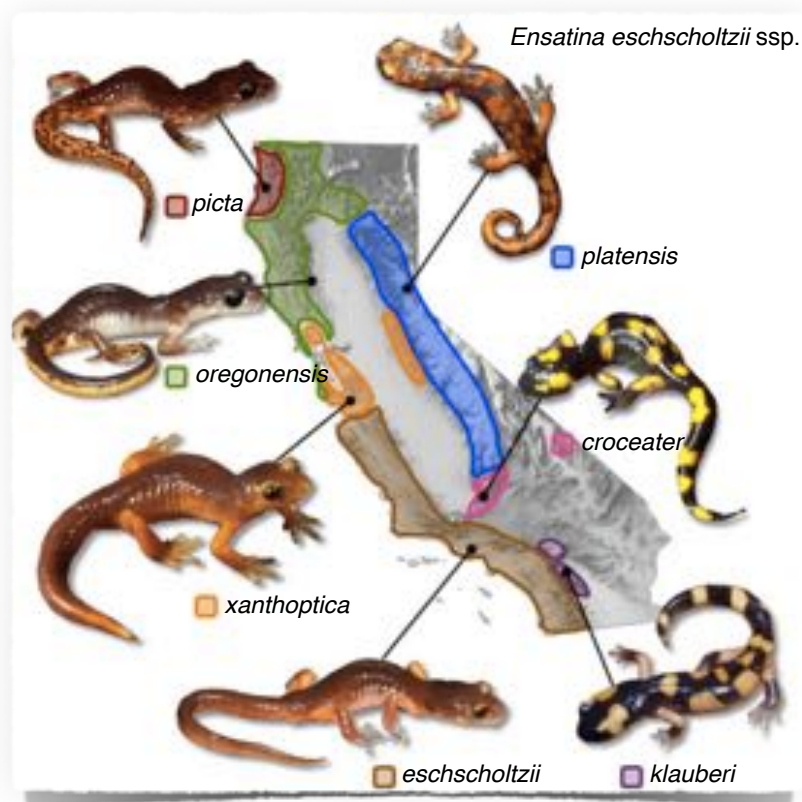
distribution map



① Hybrid zone between yellow- and fire-bellied toad

What is a species?

ring species

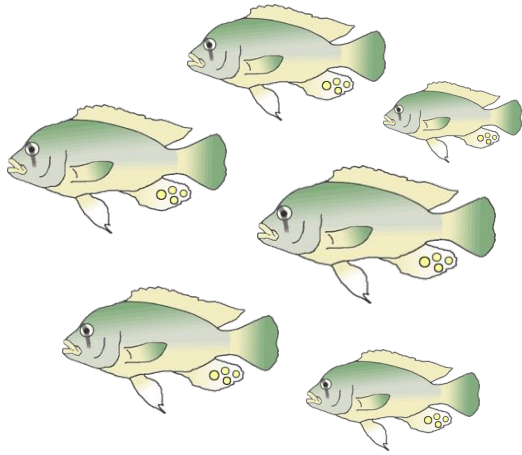


Stebbins (1994)

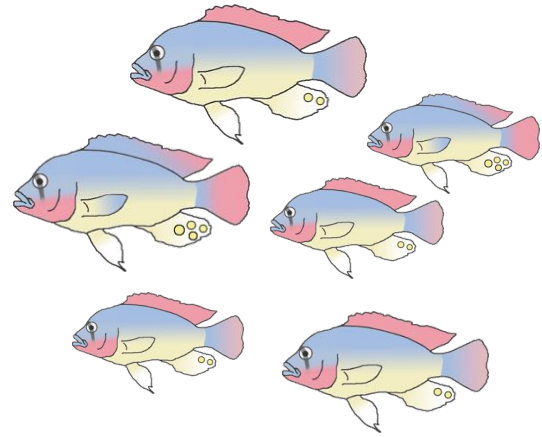
① *Ensatia eschscholtzii* inhabits the western part of the USA

Biological species concept

Members of a species share a gene pool; selection and drift operate within species.



species X



species Y

① Evolutionary biologists interpret species as independent evolutionary units

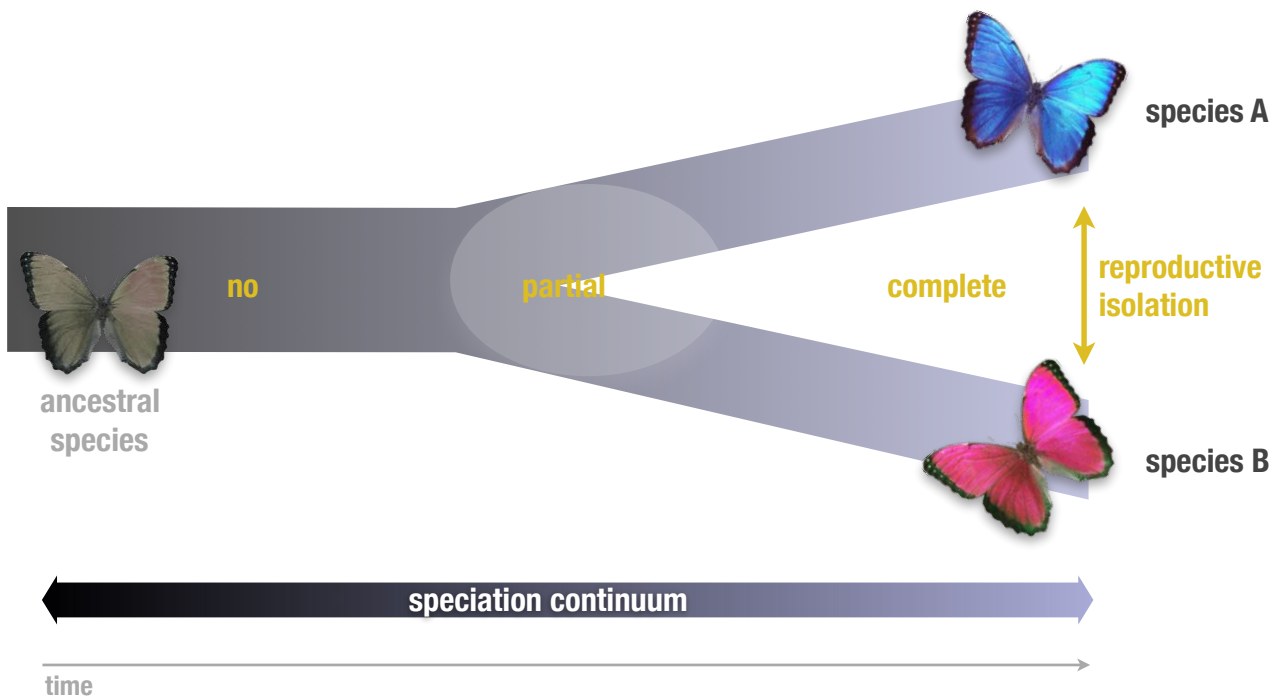
Biological species concept

A species is a group of interbreeding natural populations that is reproductively isolated from other such groups (Mayr 1963).

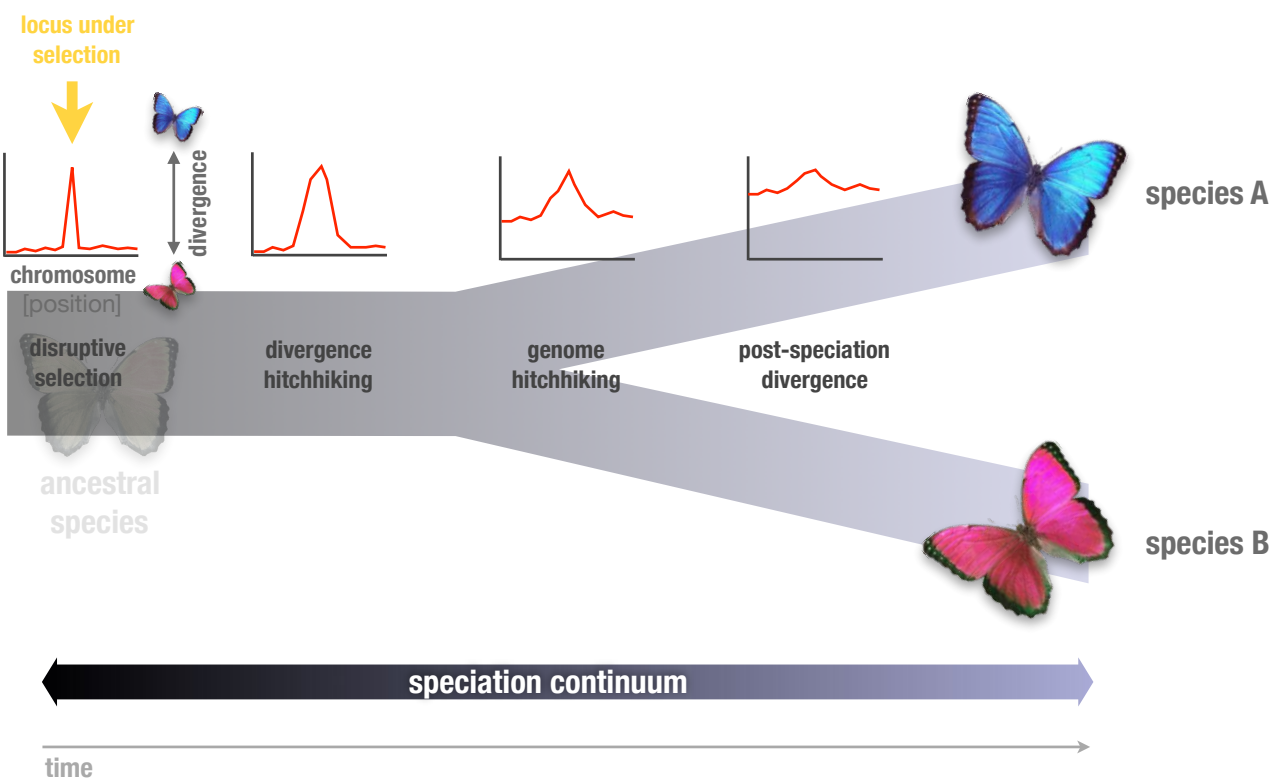


① The biological species concept places the category species within the framework of population genetics

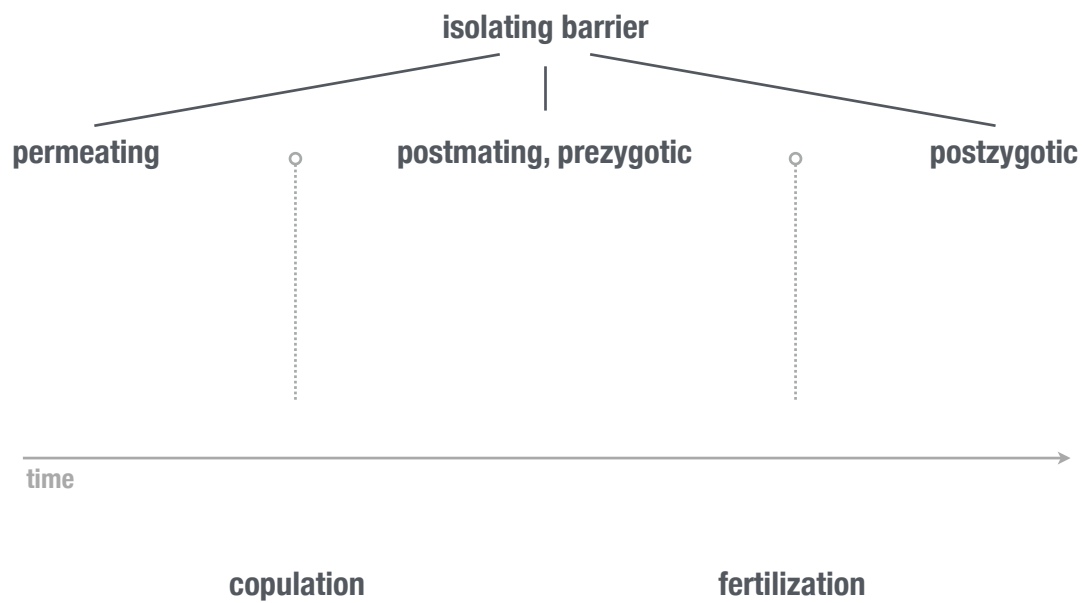
Reproductive isolation



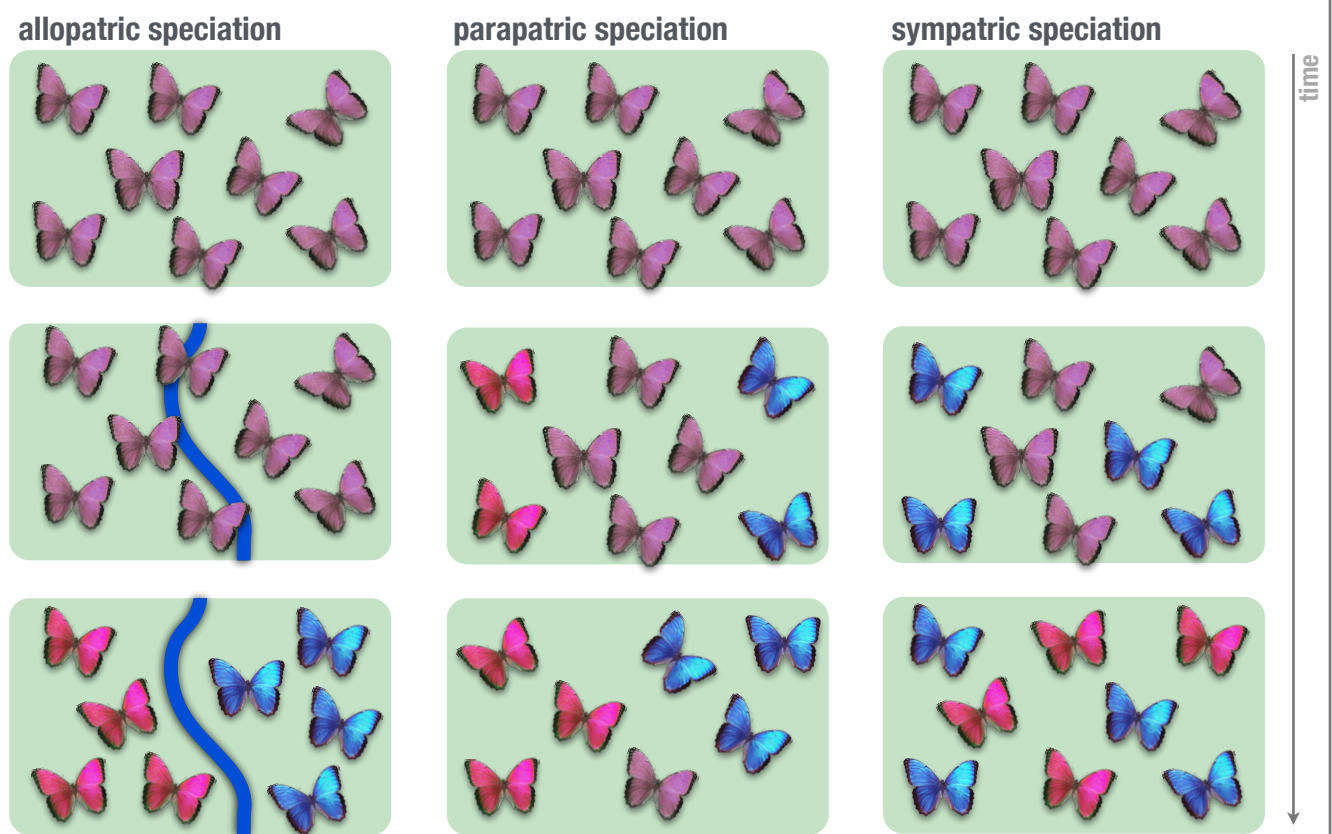
Reproductive isolation



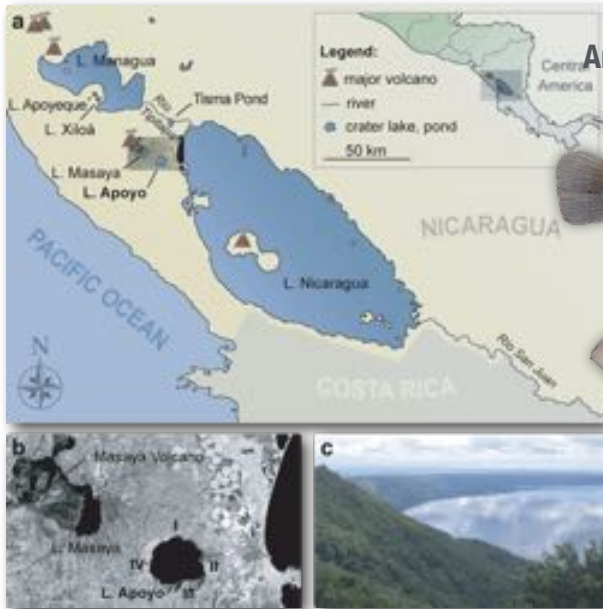
Reproductive isolation



Geographic conditions



Sympatric speciation

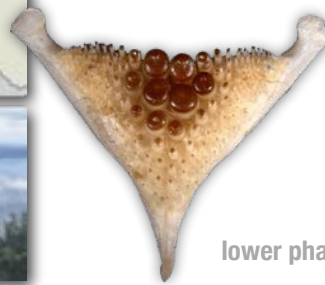


Berluenga et al. (2006) Nature

Amphilophus citrinellus



Amphilophus zaliosus

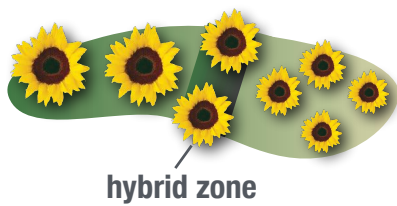


lower pharyngeal jaw bone

- ① The Laguna de Apoyo is a small volcanic crater lake in Nicaragua

Parapatric speciation

Clinal models



colonization

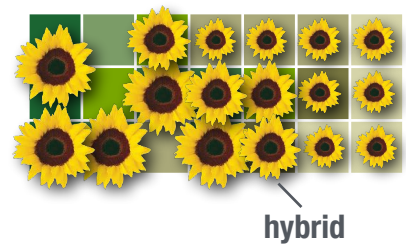


local adaptation



reproductive isolation

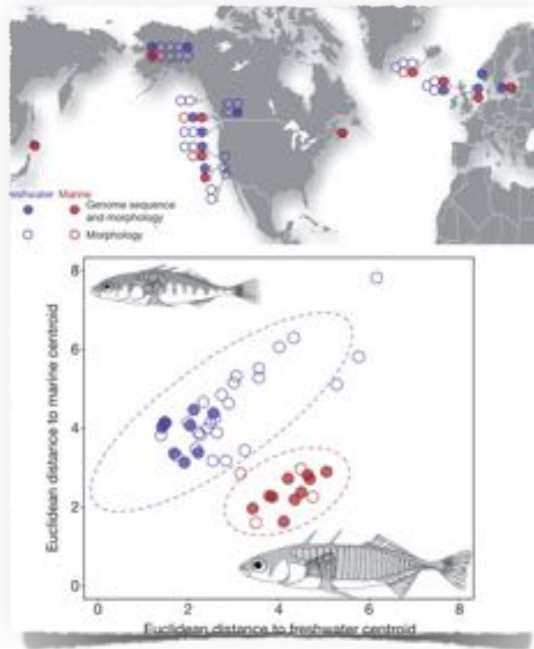
"Stepping-stone" models



Ecological speciation

The evolution of reproductive isolation between populations by adaptation to different environments.

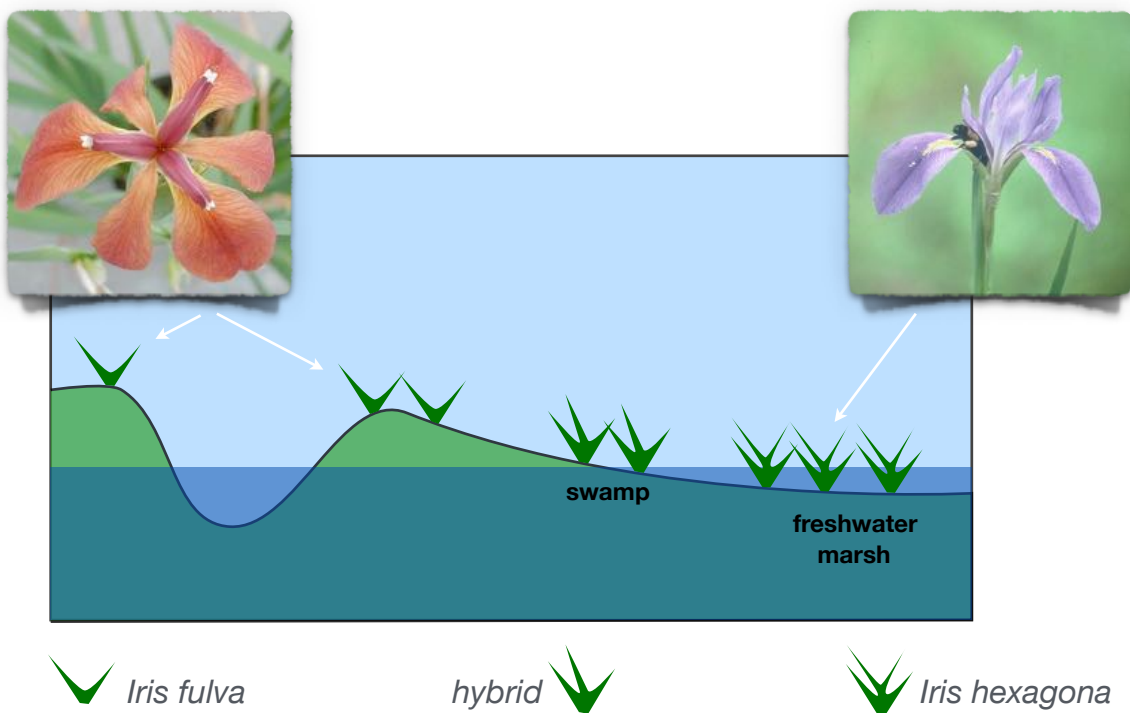
threespine
stickleback



Jones et al. (2012) Nature

① Ecological speciation can happen in allopatry, parapatry and sympatry

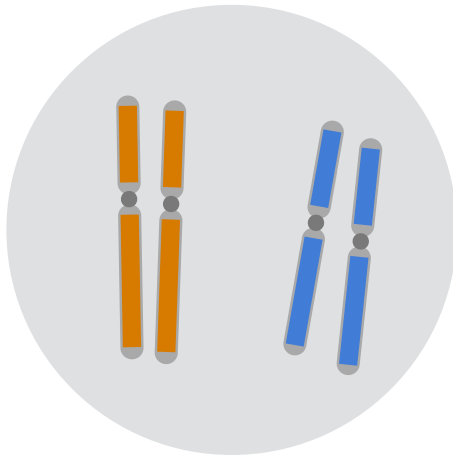
Hybrid speciation



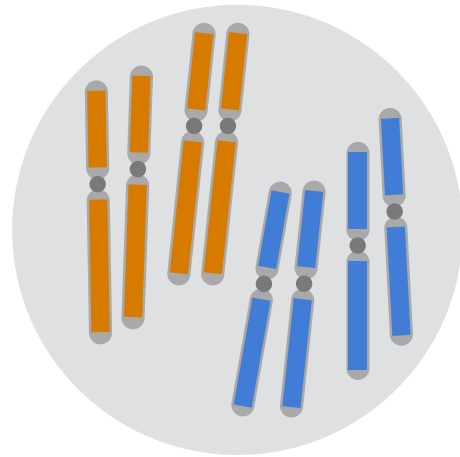
from: Arnold & Bennett (1993)

① Louisiana irises

Polyloid speciation



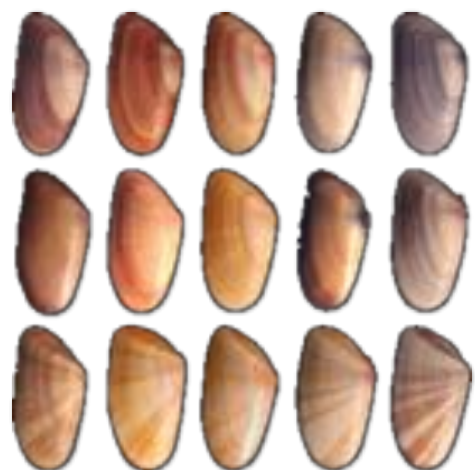
diploid
($2n=4$)



tetraploid
($4n=8$)

Natural selection

- ▶ ... is the process by which the forms of organisms in a population that are best adapted to the environment increase in frequency relative to less well-adapted forms over a number of generations (Ridley 2004)



Sexual selection

- ▶ ... is the selection on mating behavior, either through:
 - competition among members of one sex (usually males) for access to members of the other sex or through
 - choice by members of one sex (usually females) for certain members of the other sex (Ridley 1996)



Natural selection

Sexual selection

Both natural and sexual selection operate if the following conditions are met:

reproduction	organisms must reproduce to form new generations
heredity	offspring resemble parents ("like must produce like")
trait variation	individuals in natural populations vary in (adaptive) traits
variation in fitness	individuals in natural populations vary in the number of their offspring that survive to reproduce ('lifetime reproductive success')

Natural selection

Sexual selection

There are fundamental difference between natural and sexual selection:

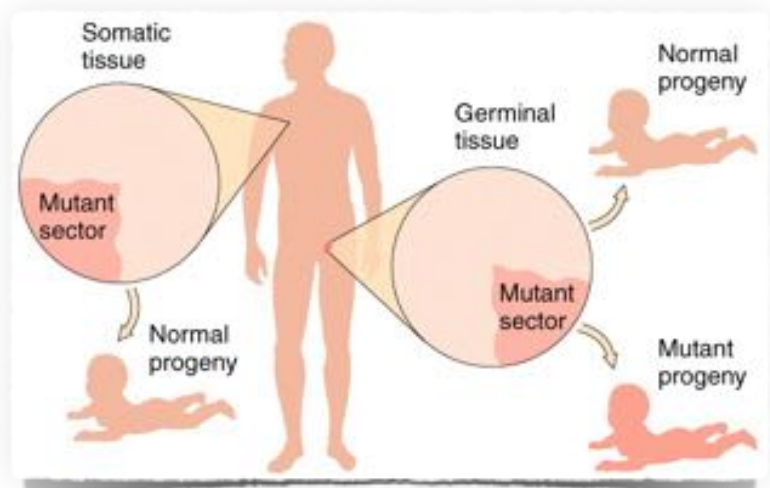
	fitness	competitors
sexual selection	individual fitness	other members of the same sex
natural selection	fitness of the genotype	other individuals in the same population

Natural variation

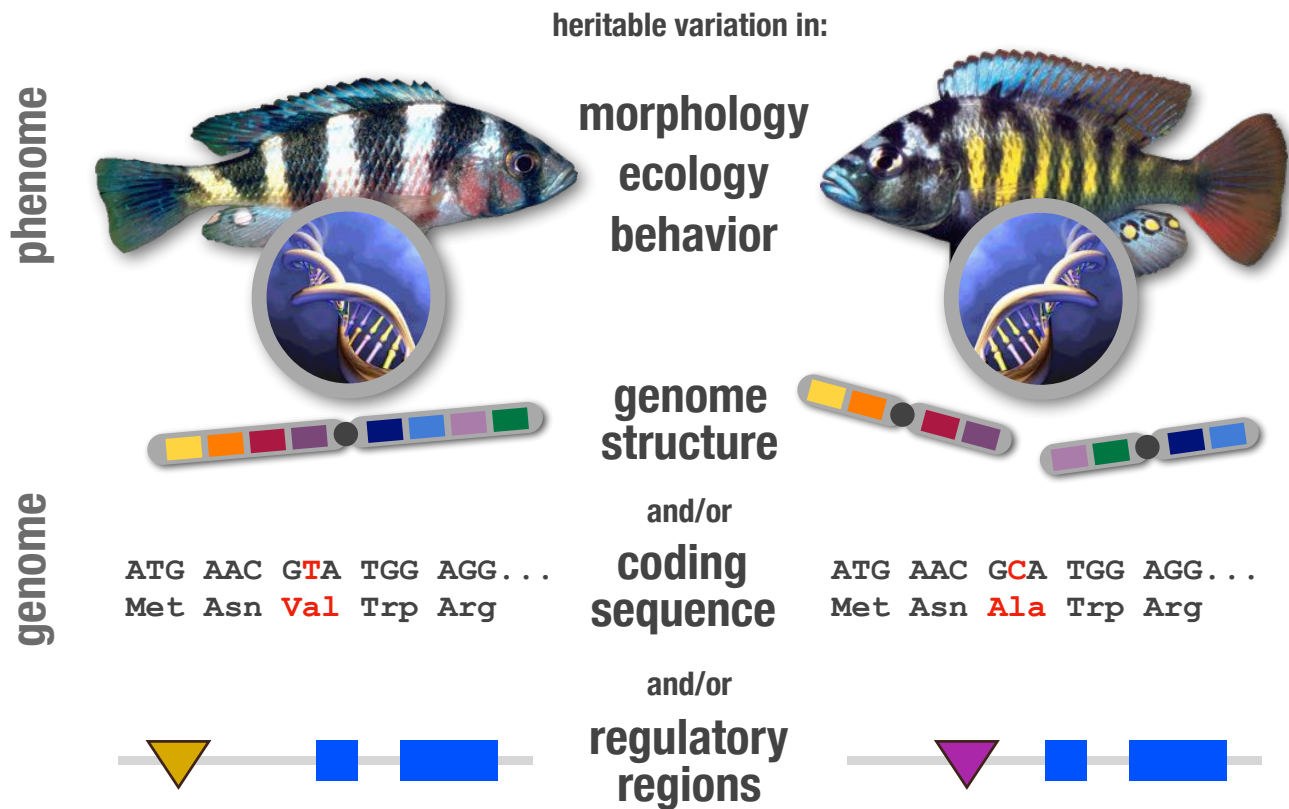
Natural populations show variation at all levels, from gross morphology to DNA sequences. Selection can only operate, if heritable variation exists.

Heritable natural variation is generated by two processes, mutation and recombination.

New mutations are only transmitted to the next generation, if they occur in germinal tissue.



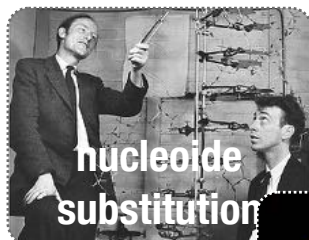
Phenotypic evolution



Molecular evolution

“The primary cause of evolution is the mutational change of genes”

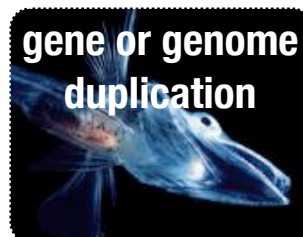
Nei & Kumar (2000)



nucleotide
substitution



insertion/
deletion

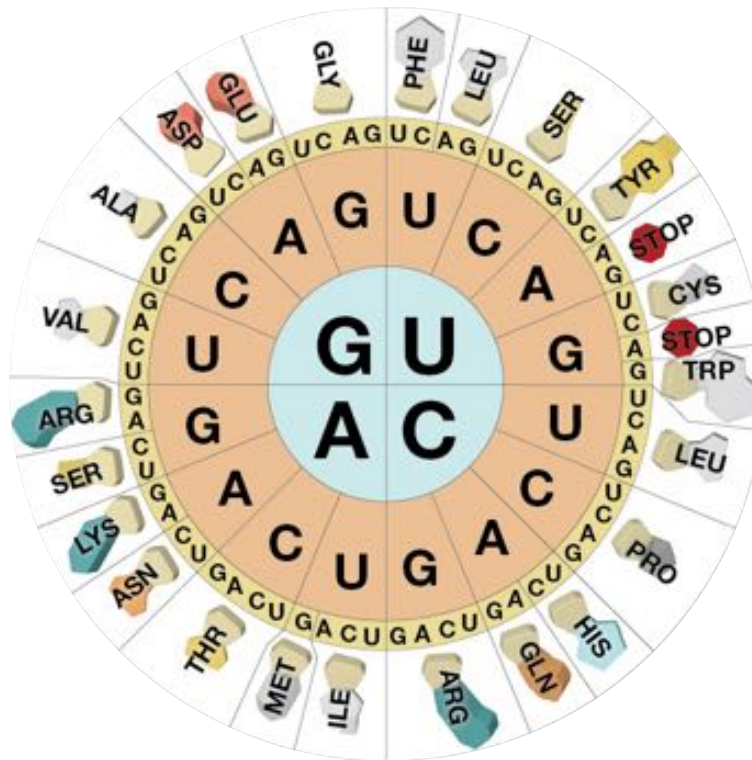


gene or genome
duplication

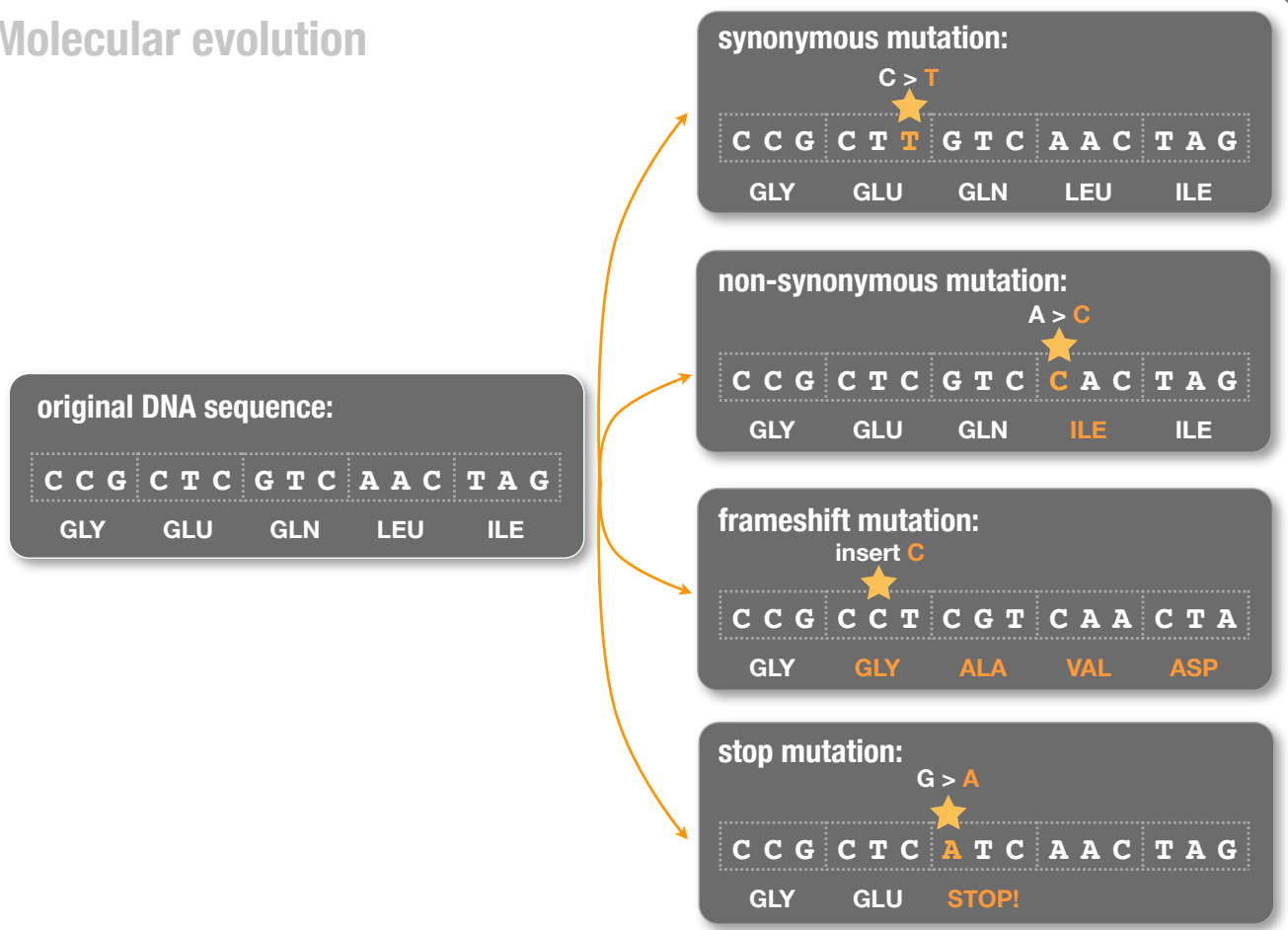


chromosome
rearrangements

Molecular evolution



Molecular evolution



Molecular evolution

The rate of non-synonymous (dN) to synonymous (dS) substitution informs about the selective pressure that has acted on a protein coding gene:

$dN/dS \ll 1$: purifying selection

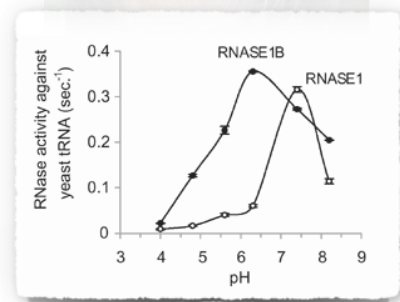
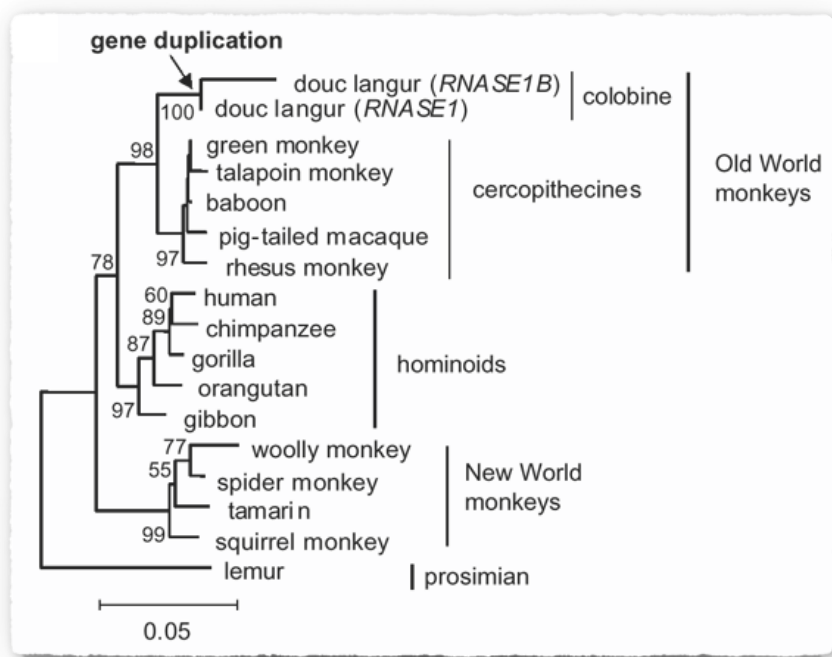
$dN/dS = 1$: neutrality

$dN/dS > 1$: positive selection (adaptive sequence evolution)

Molecular evolution

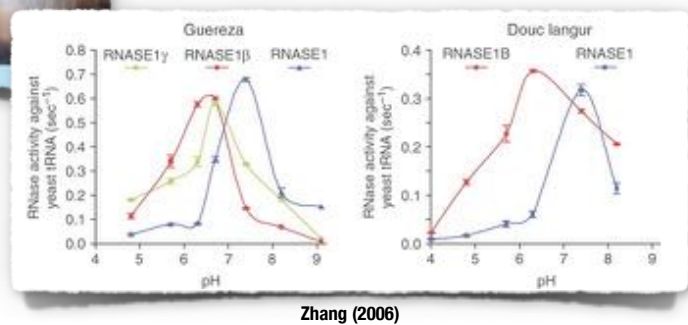
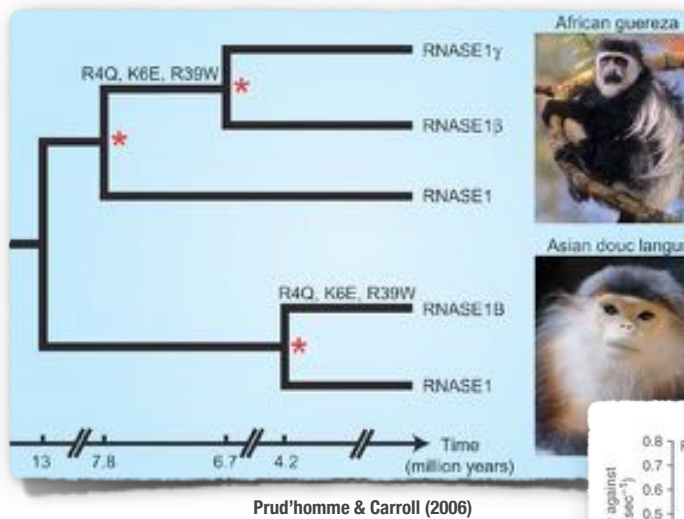
$Ka/Ks = 4.026$

Pancreatic ribonuclease in colobine monkeys



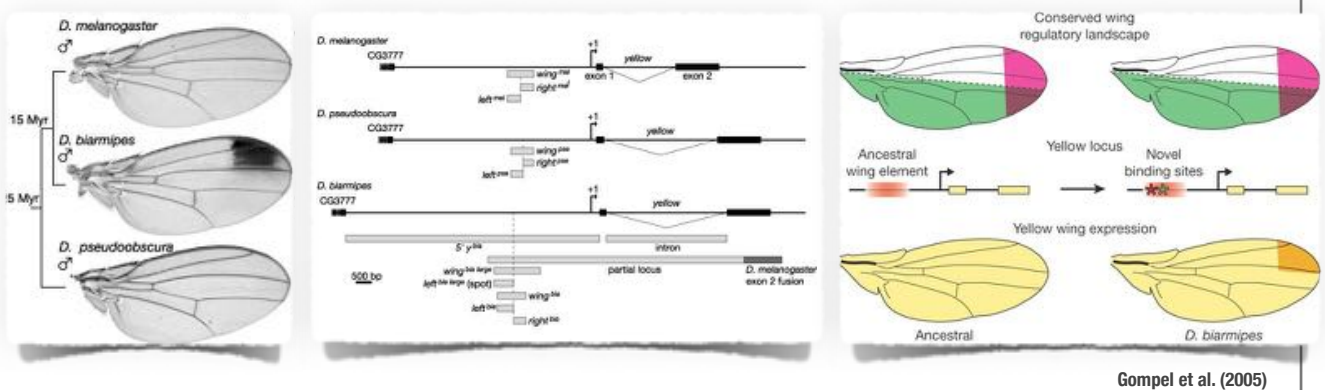
Molecular evolution

Pancreatic ribonuclease in leaf-eating monkeys



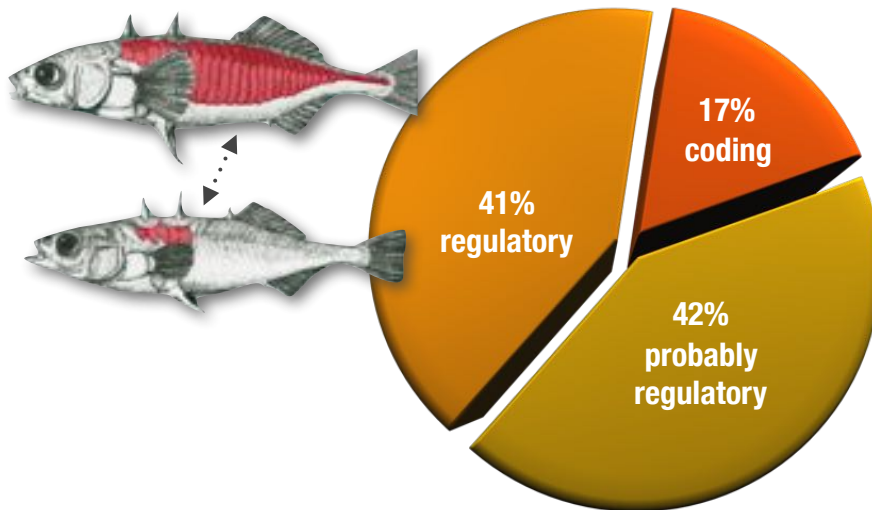
Molecular evolution

cis-regulatory evolution in fruitless



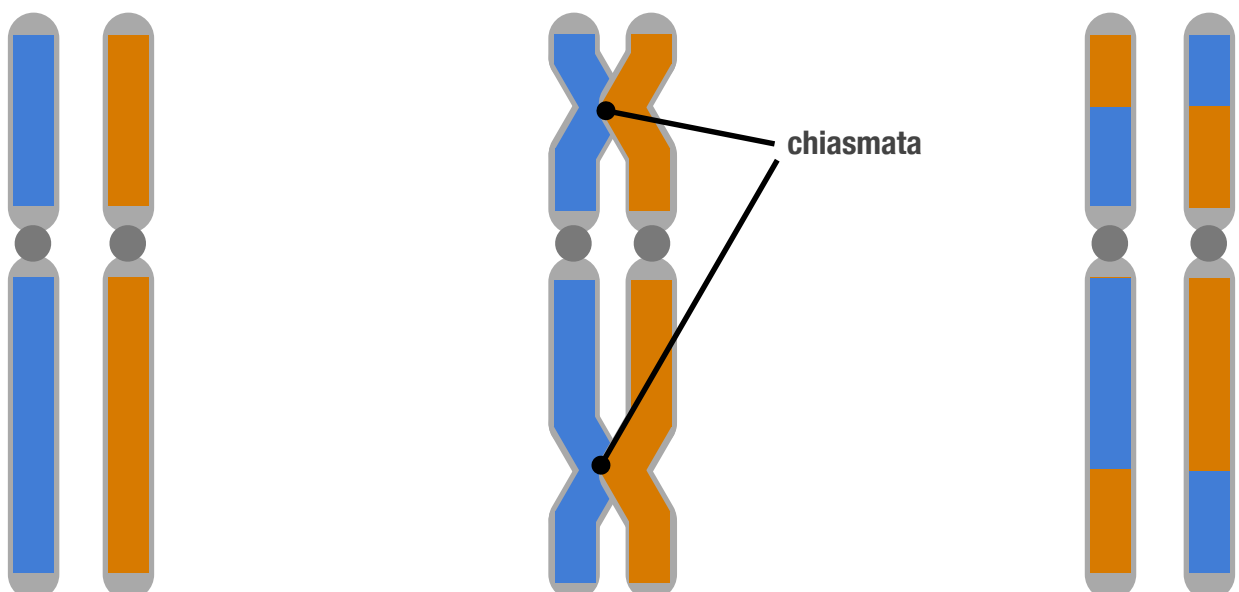
Molecular evolution

regulatory evolution in three spine sticklebacks

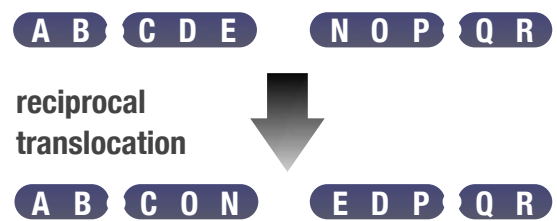
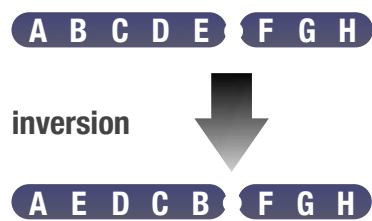
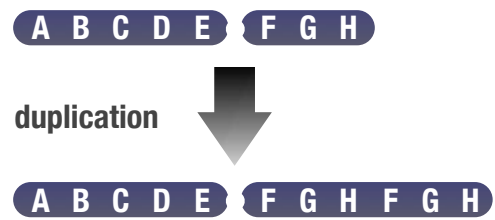
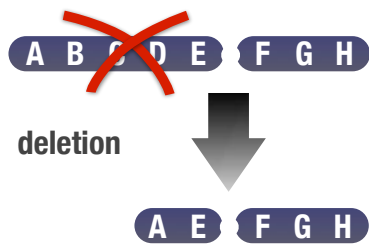


Chromosomal rearrangements

Recombination

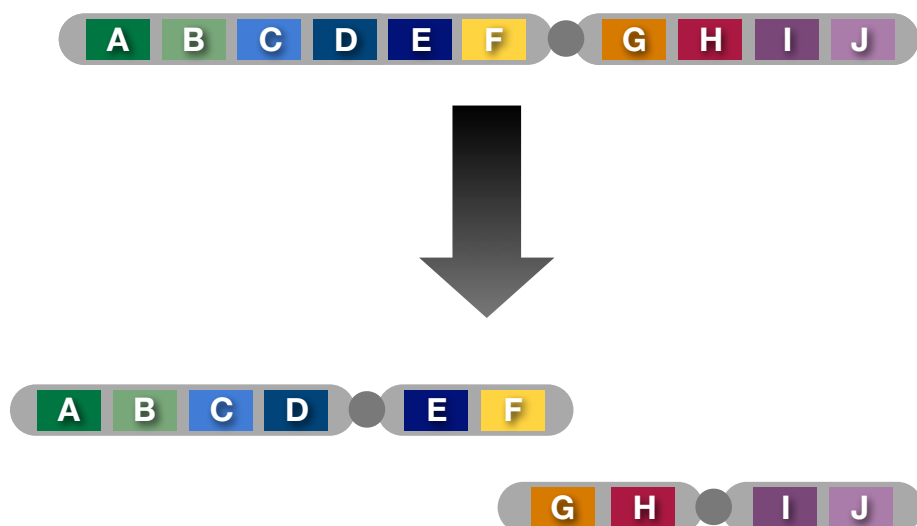


Chromosomal rearrangements



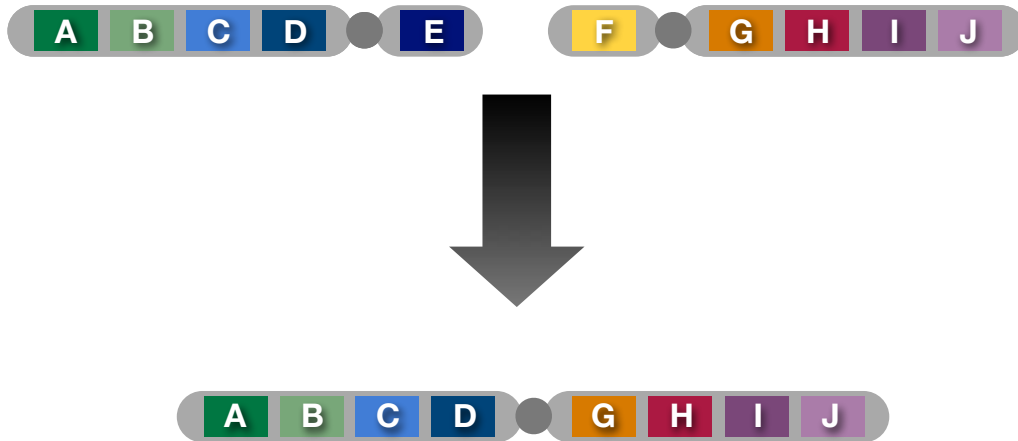
Chromosomal rearrangements

Chromosomal fission



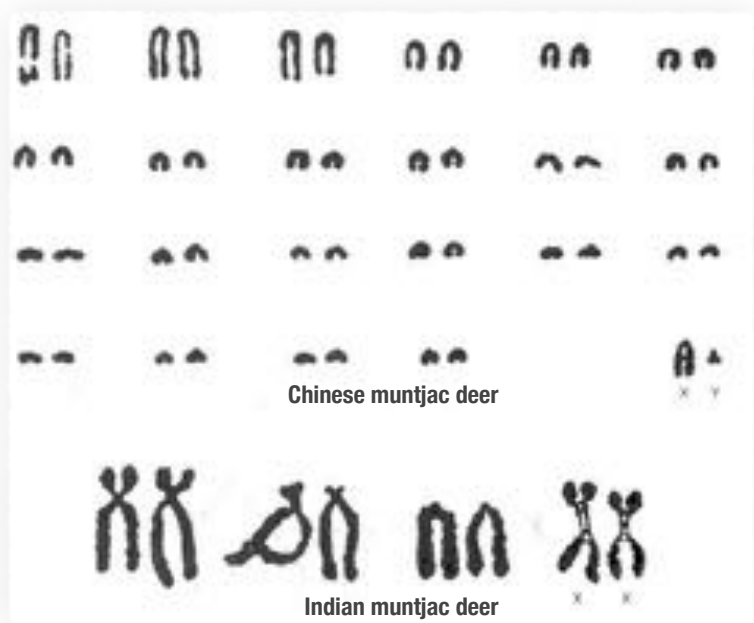
Chromosomal rearrangements

Chromosomal fusion



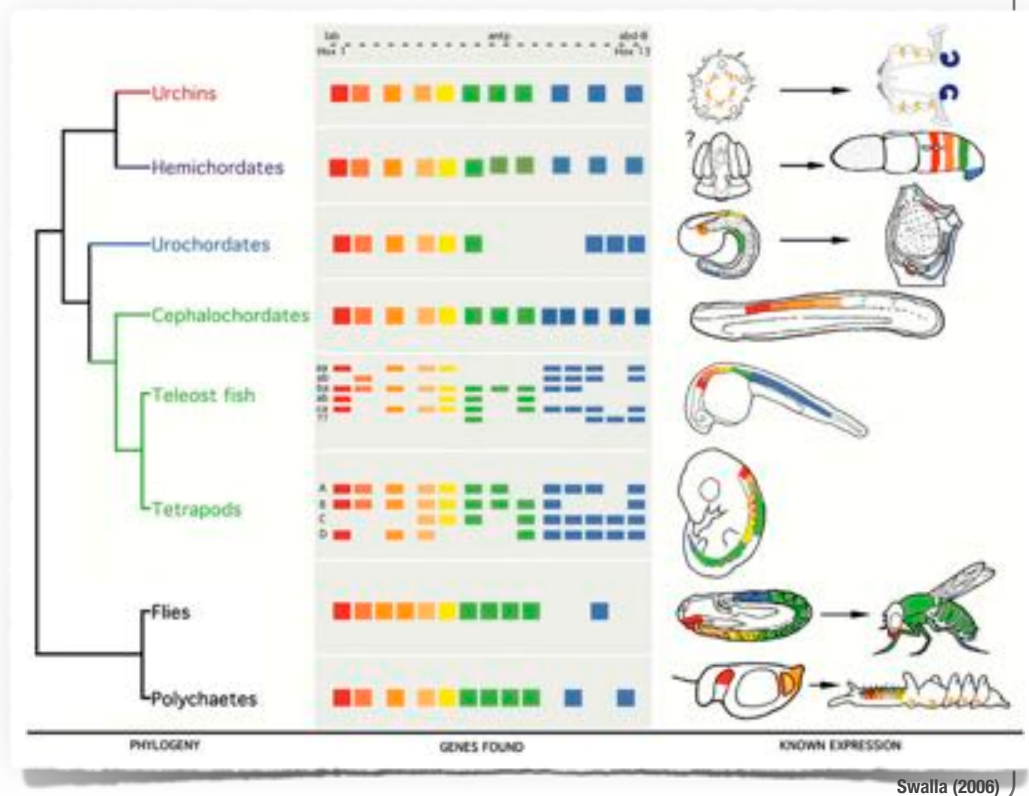
Chromosomal rearrangements

Chromosomal rearrangements in muntjac deers



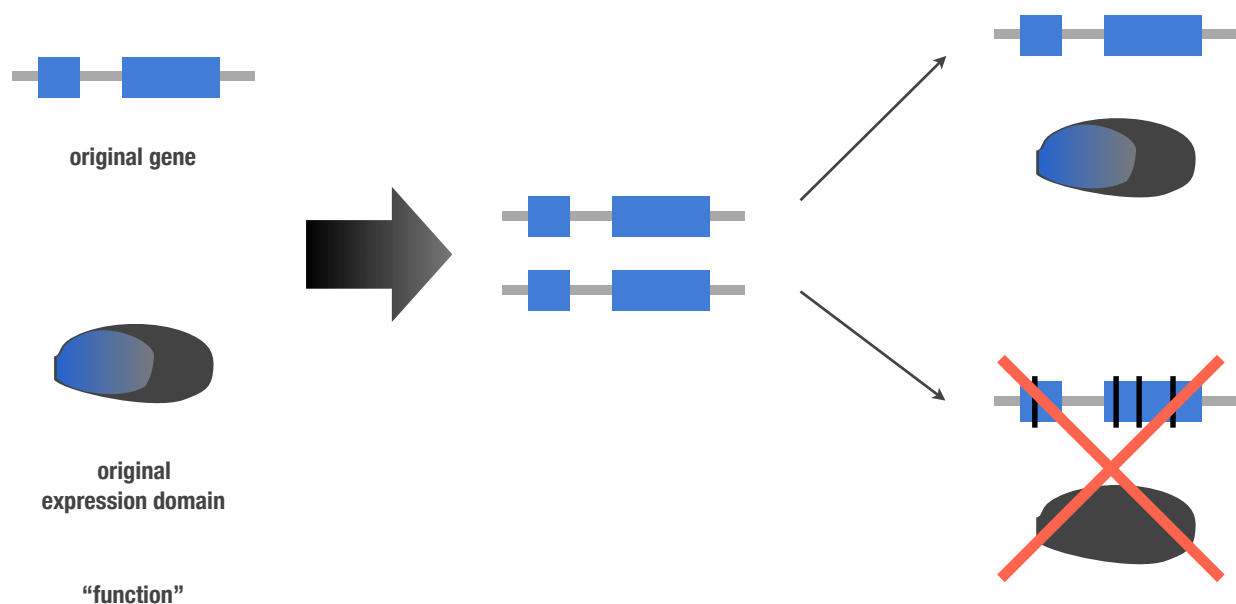
Gene and genome duplications

Hox gene clusters

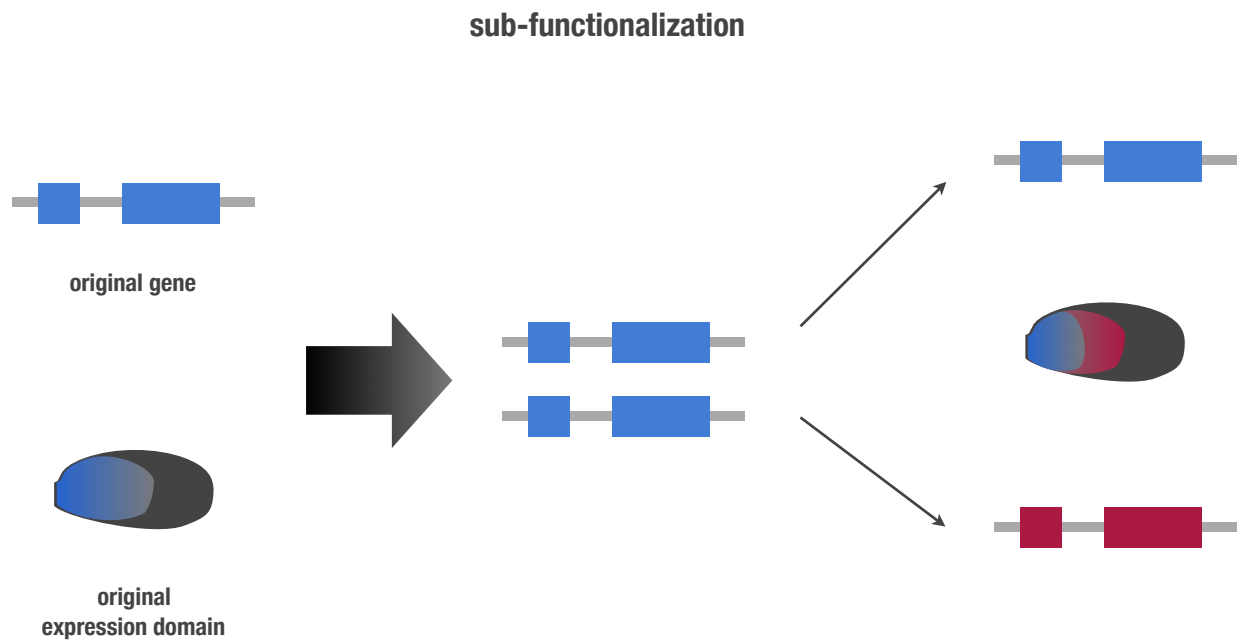


Gene and genome duplications

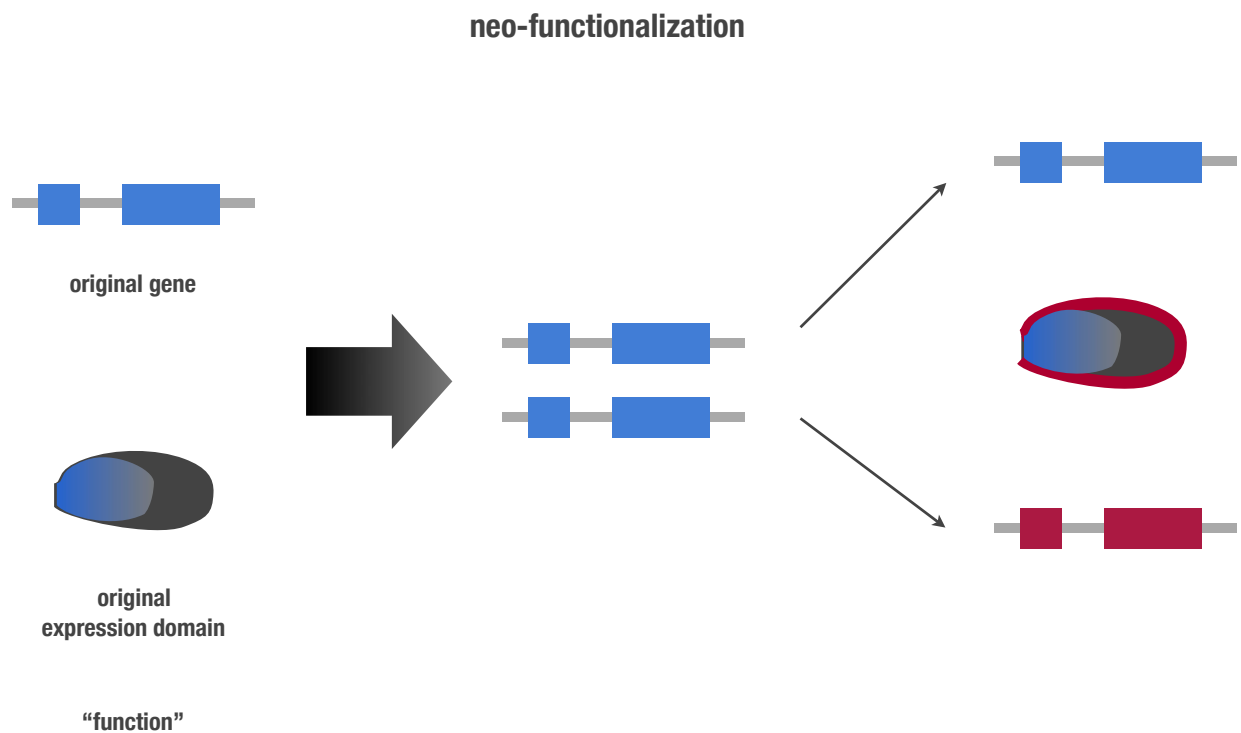
non-functionalization



Gene and genome duplications

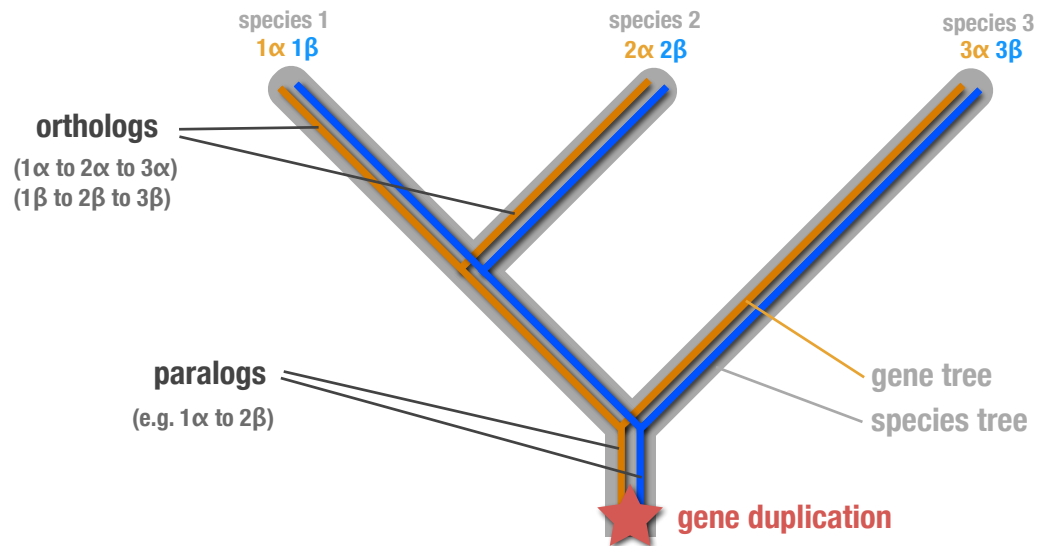


Gene and genome duplications

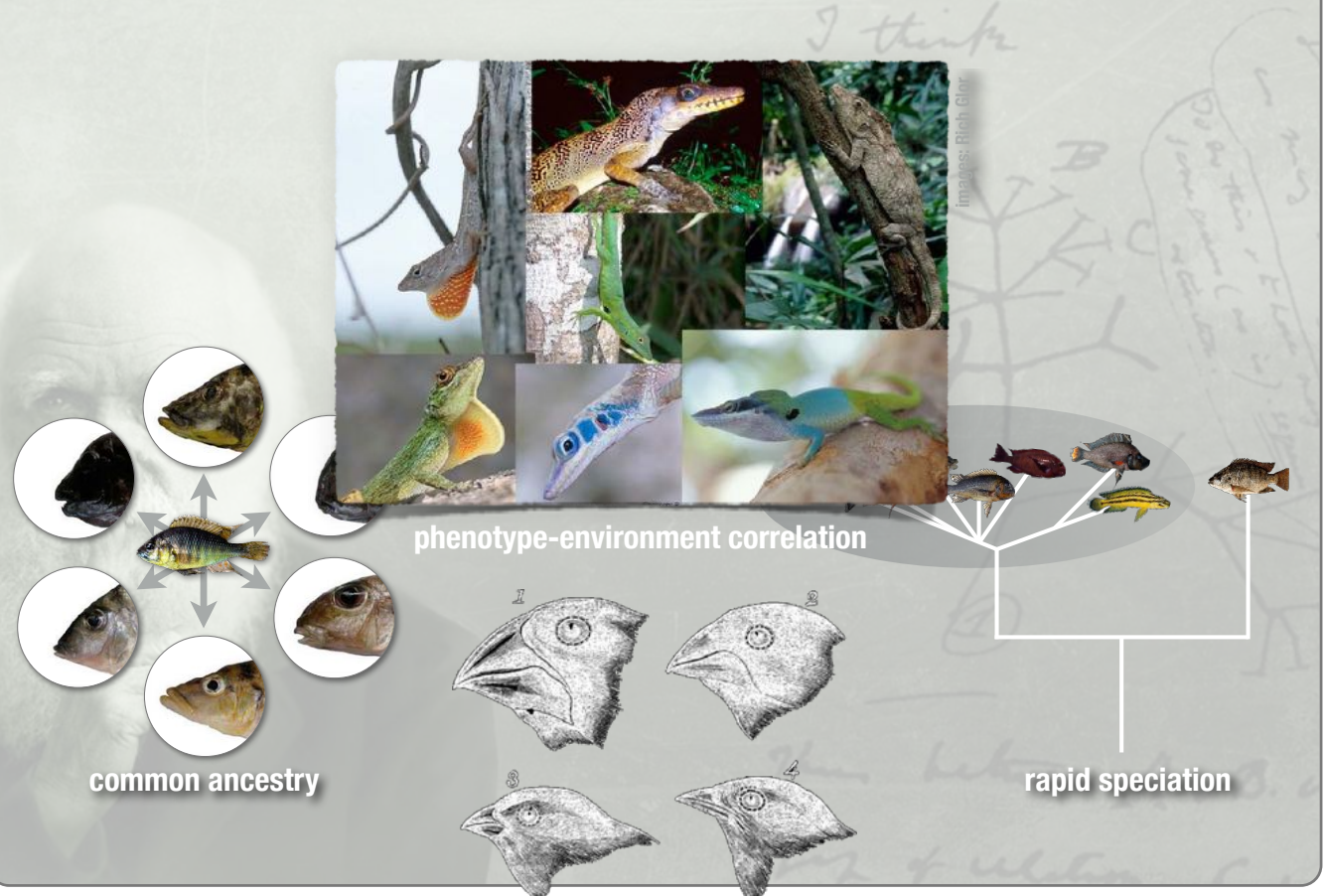


Gene and genome duplications

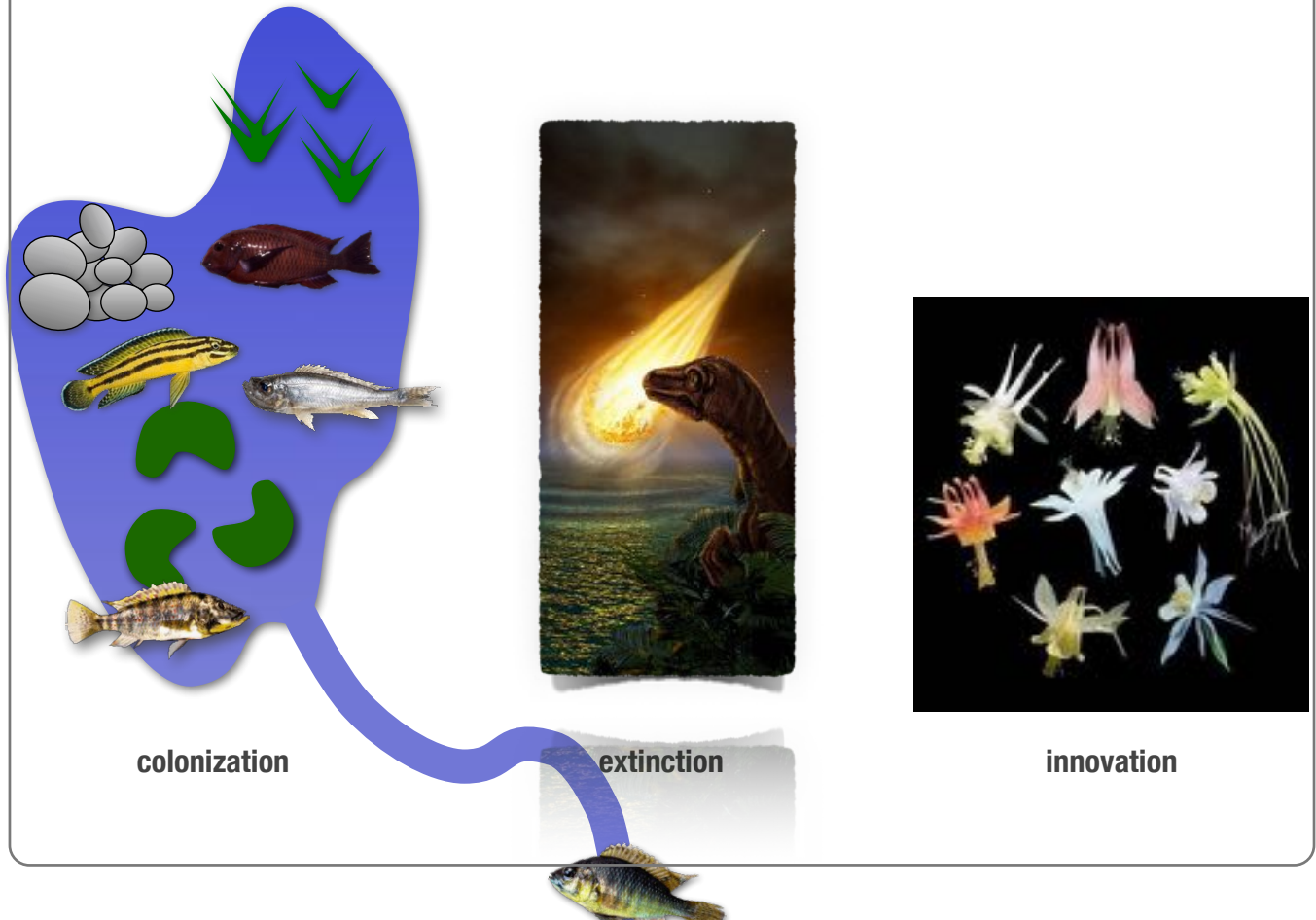
Caveats and pitfalls in phylogenetic inference: mixing paralogs with orthologs



Adaptive radiation



Ecological opportunity



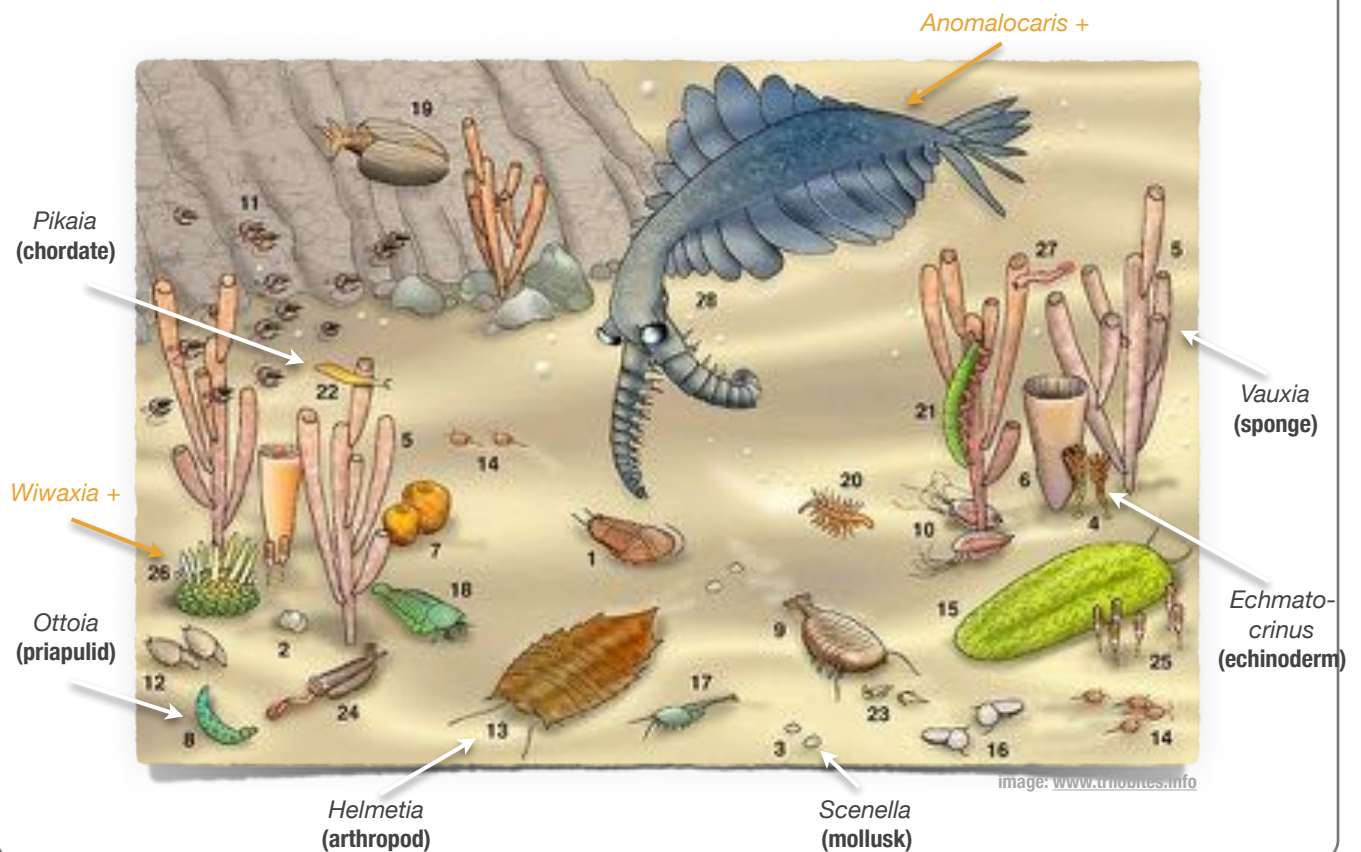
Cambrian explosion

The 'Cambrian evolutionary radiation' most likely was an adaptive radiation.



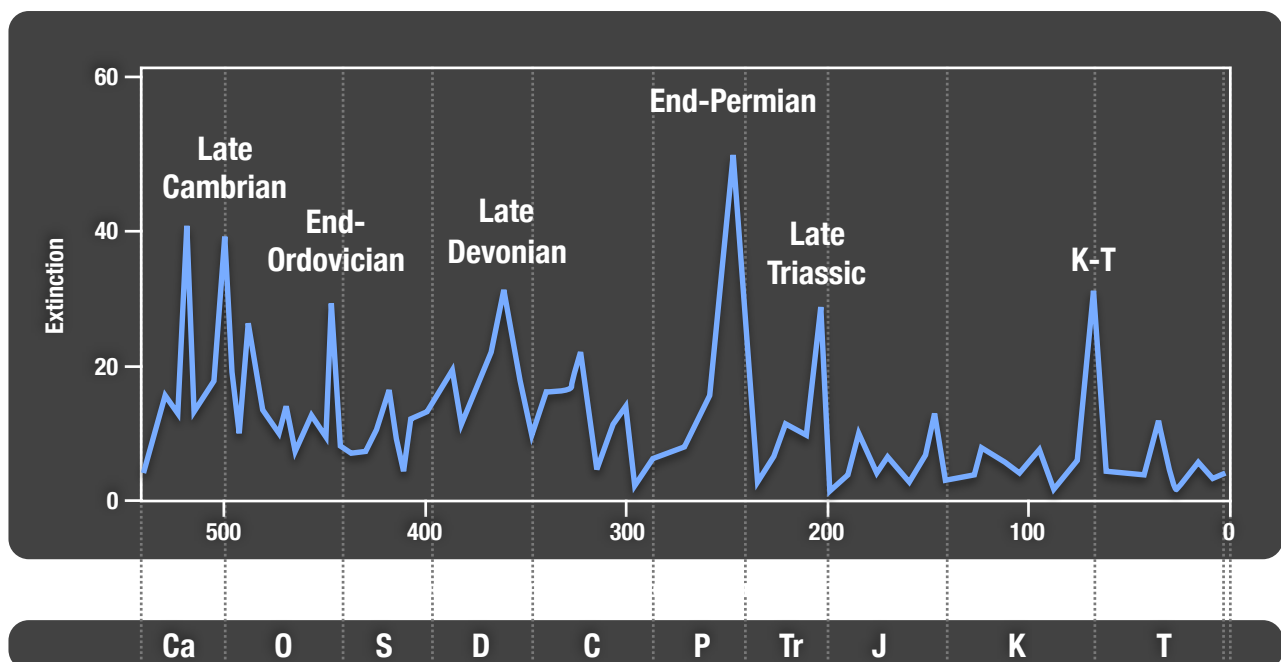
① The Burgess shale are fossil-rich deposits in the Yoho NP in British Columbia discovered by Charles D. Walcott in 1909

Cambrian explosion



Extinction

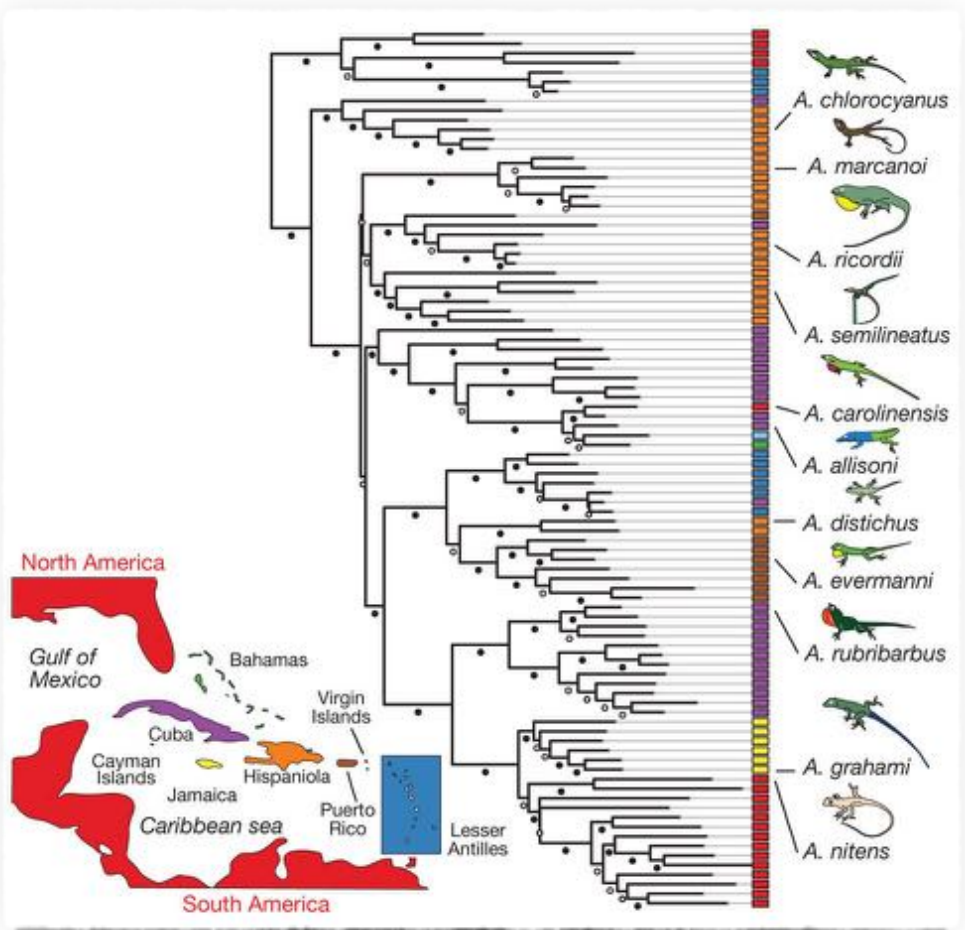
The 'big five' mass extinctions (based on marine fossils)



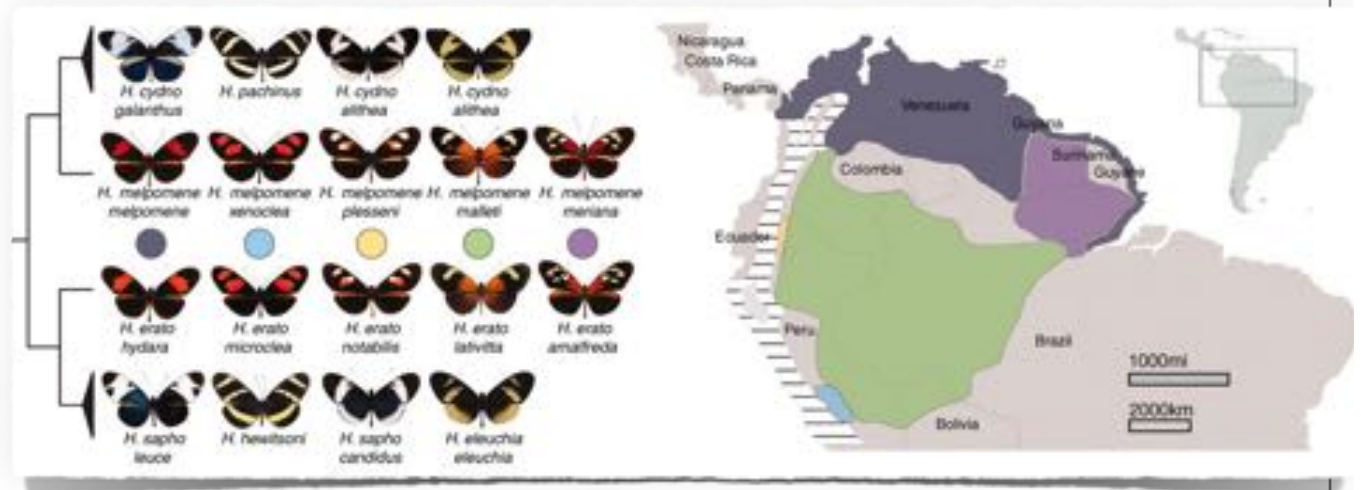
Radiating Genomes



Anolis

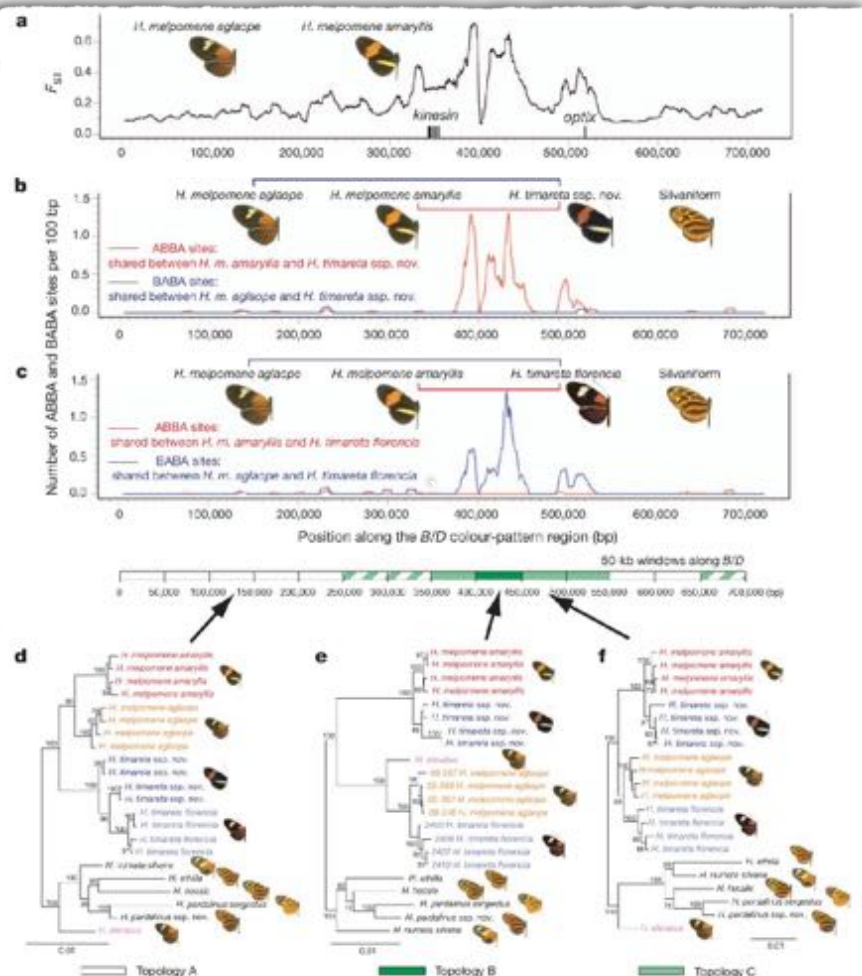


Heliconius



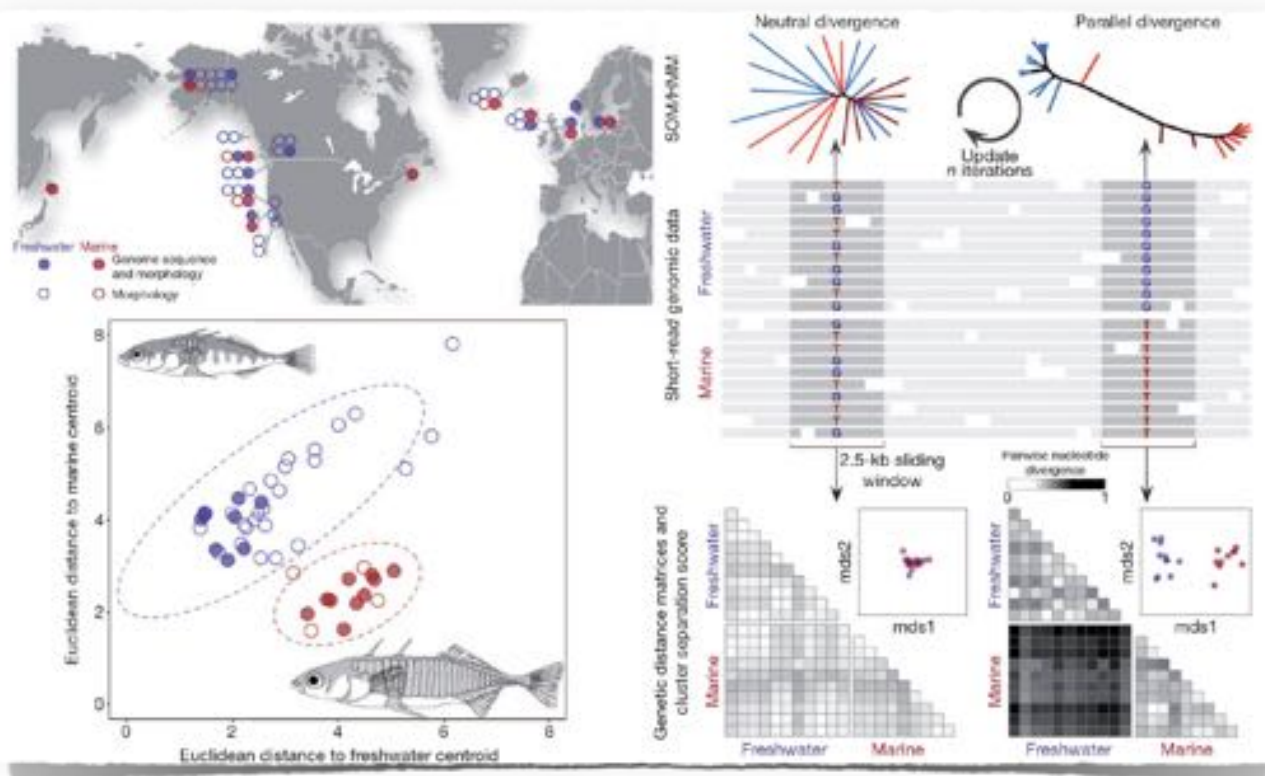
... R Reed et al. (2011) Science

Heliconius



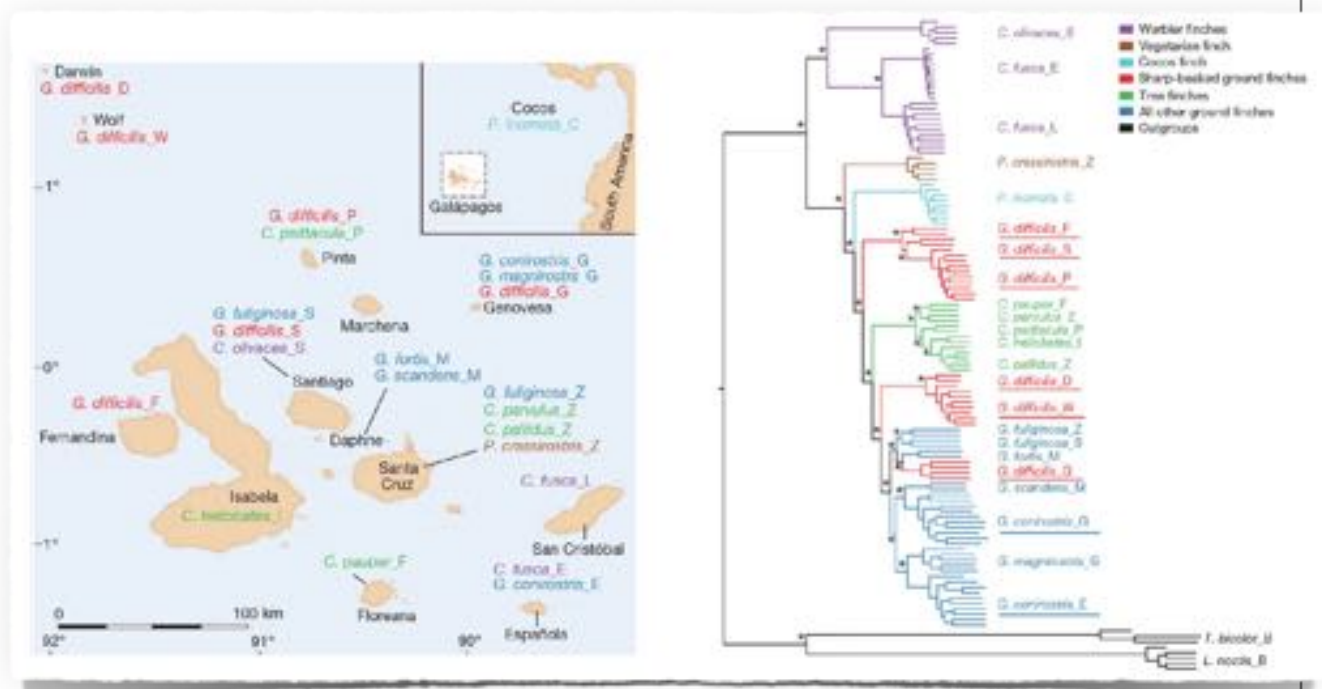
... The Heliconius Genome Consortium (2012) Nature

Stickleback



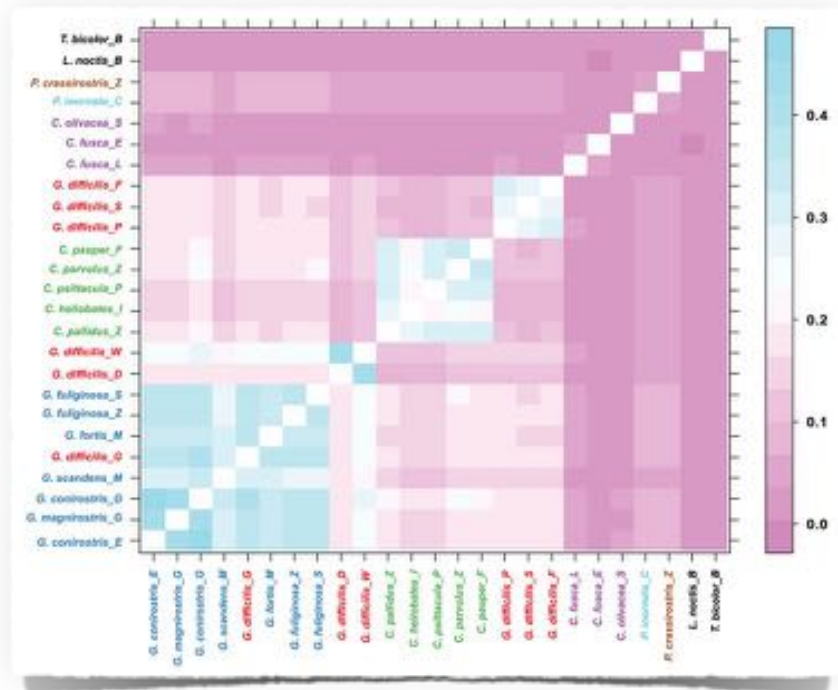
••• FC Jones et al. (2012) Nature

Darwin's finches



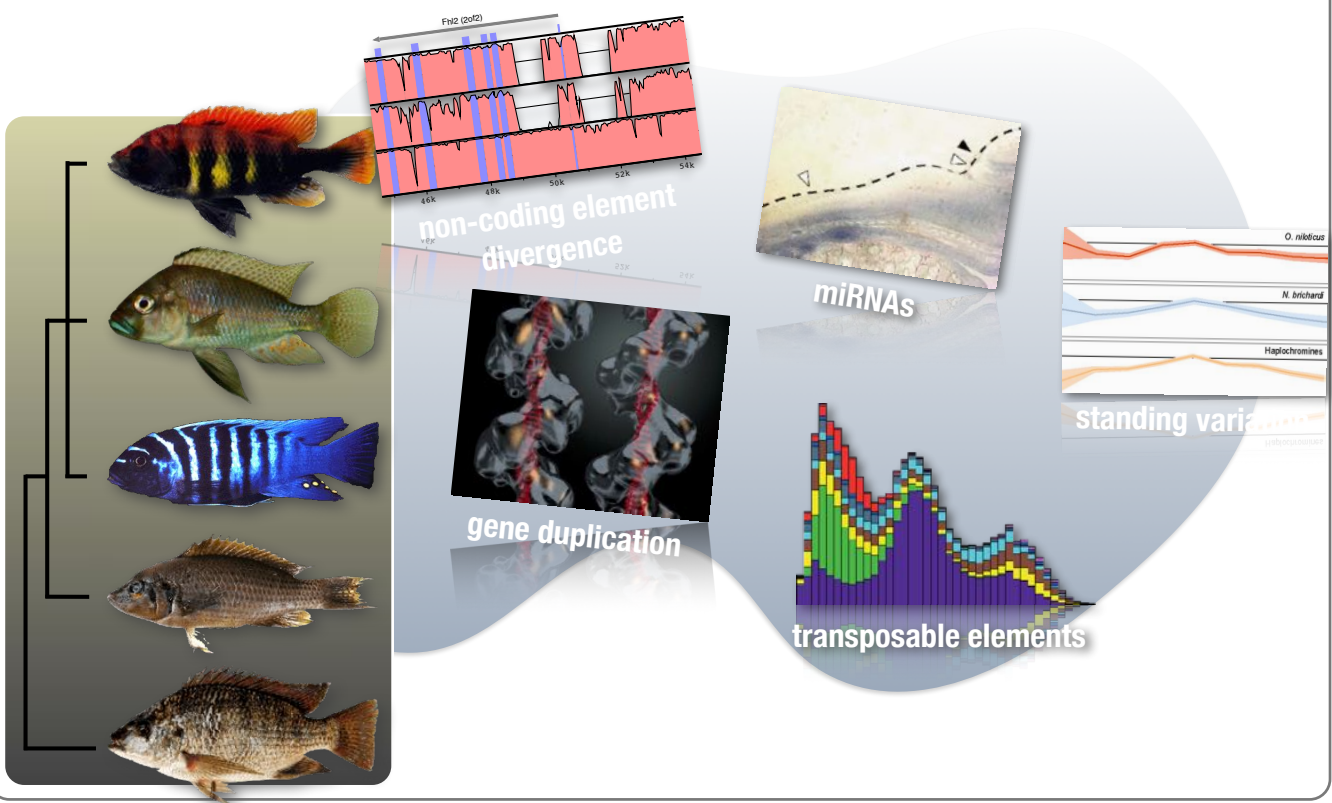
••• S Lamichhane et al. (2015) Nature

Darwin's finches



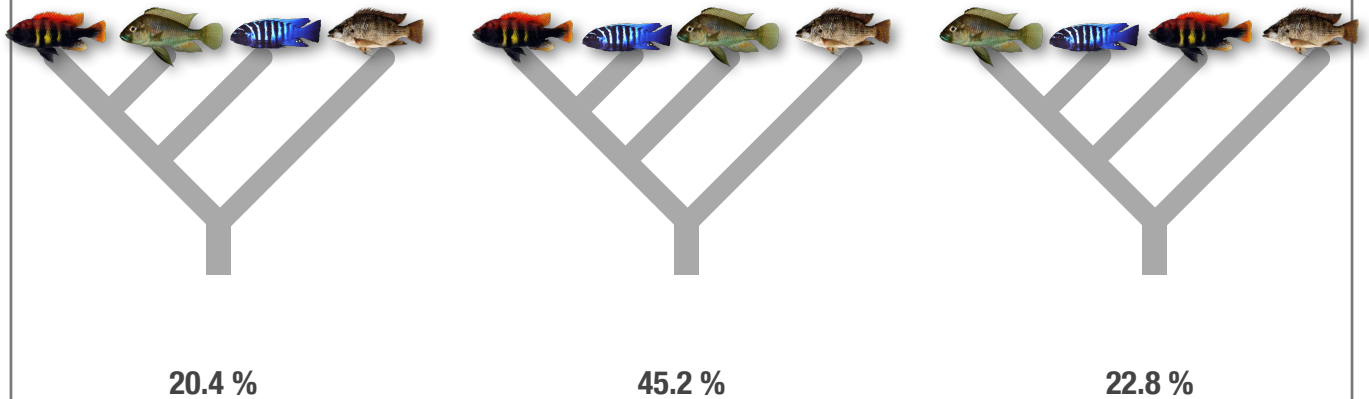
••• S Lamichhane et al. (2015) Nature

cichlids








●●● D Brawand et al. (2014) Nature

cichlids



... D Brawand et al. (2014) Nature

radiating genomes

	genomes	gene duplications	mobile elements	regulatory changes	accelerated coding evolution	miRNAs	inversions	hybridization introgression ILS
	1	n/r	YES	maybe	n/r	n/r	n/r	n/a
	5 (>100)	YES	YES	YES	YES	YES	n/r	YES
	1 (>100)	n/r	n/r	n/r	n/r	n/r	n/r	YES
	1 (>100)	n/r	YES	maybe	n/r	YES	n/r	YES
	1 (>100)	n/r	n/r	YES	n/r	n/r	YES	YES

... D Berner & W Salzburger (2015) Trends in Genetics