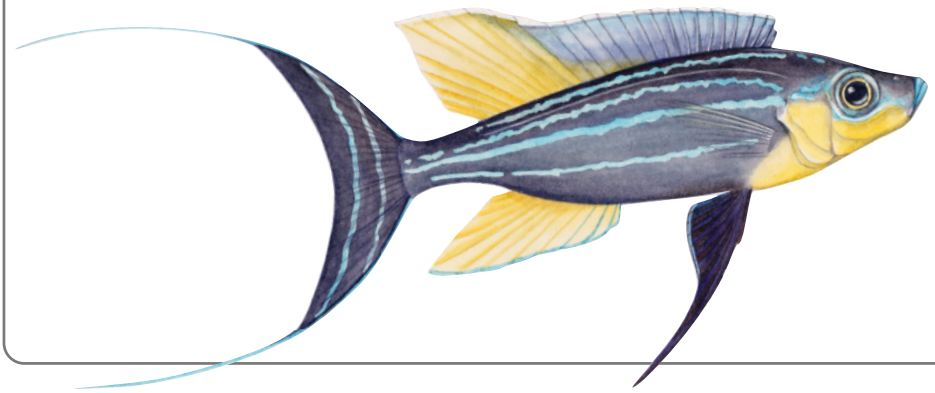
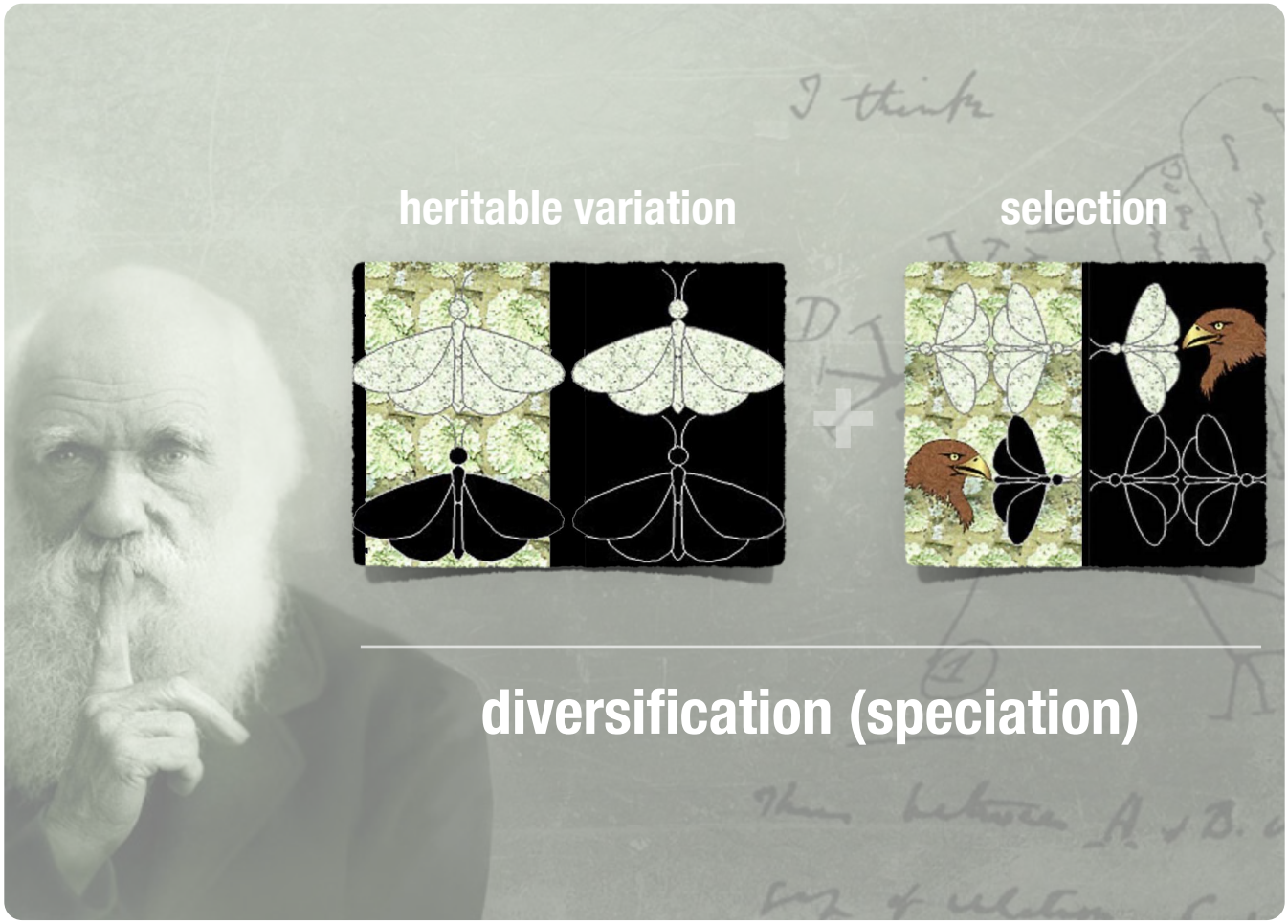
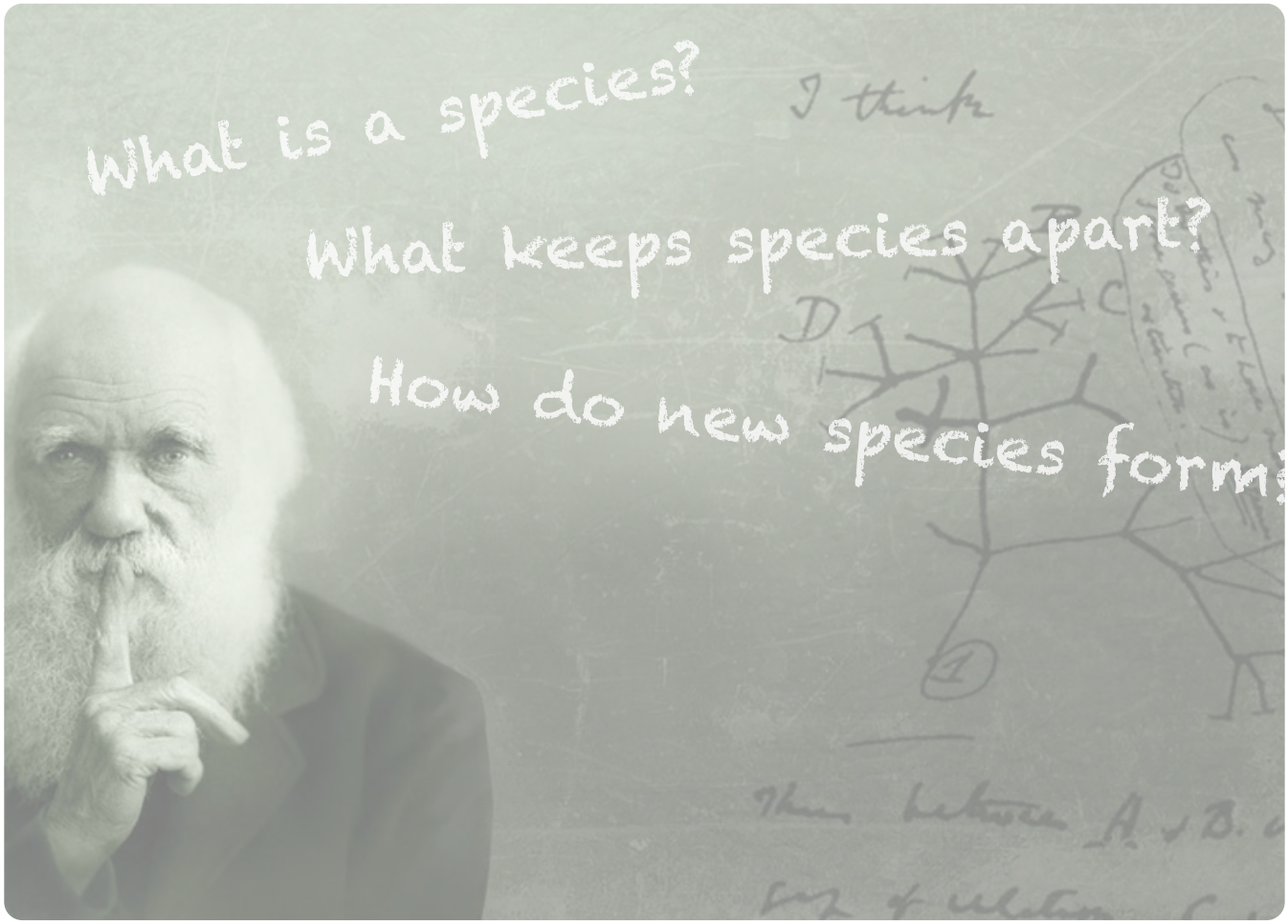
The genomics of organismal diversification



Walter Salzburger
Zoological Institute
Universität Basel



ⓘ Charles R. Darwin's journey onboard of the HMS Beagle lasted from 27 December 1831 until 2 October 1836



What is a species?

Poll (1946)

ⓘ Taxonomists describe species based on diagnostic characters and taxonomy guidelines

What is a species?

ⓘ Field guides and identification keys help in species identification

What is a species?

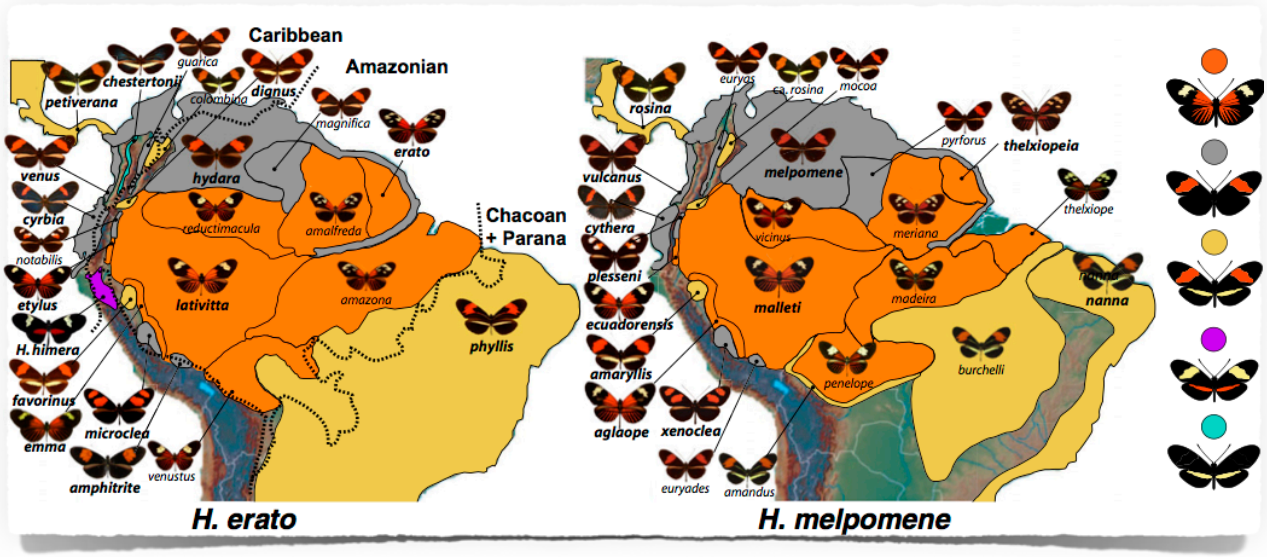
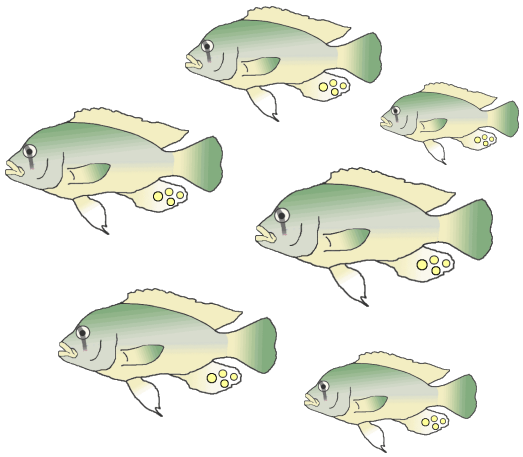


image: www.heliconius.org

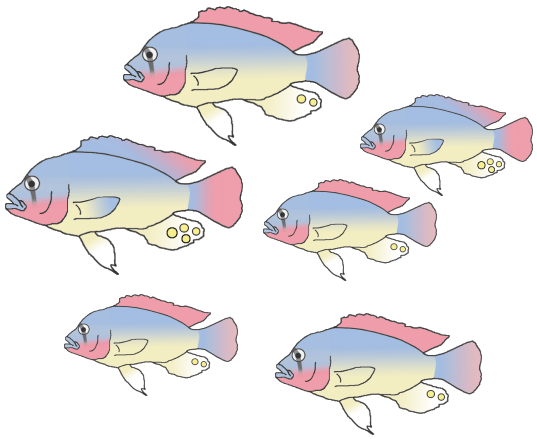
ⓘ Heliconius erato and H. melpomene are morphologically similar because of mimicry

What is a species?

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



species X



species Y

ⓘ Evolutionary biologists interpret species as independent evolutionary units

Species concepts

The category species is defined according to a species concept

biological species concept	A species is a group of interbreeding natural populations that is reproductively isolated from other such groups (Mayr 1963).
cohesion species concept	A species is the most inclusive populations of individuals having the potential for phenotypic cohesion through intrinsic cohesion mechanisms (Templeton 1989).
ecological species concept	A species is a lineages (or a closely related sets of lineages), which occupies an adaptive zone minimally different from that of any other lineage in range and which evolve separately from all lineages outside its range (Van Valen 1976).
evolutionary species concept	A species is a single lineage of ancestral-descendant lineages that evolve separately from other such lineages and have their own evolutionary tendencies and historical fate (Simpson 1961; Wiley 1978).
phylogenetic species concepts	A species is the smallest monophyletic group of common ancestry (de Querioz & Donoghue 1988). A phylogenetic species is a basal cluster of organisms that is diagnosably distinct from other such clusters (Cracraft 1989)

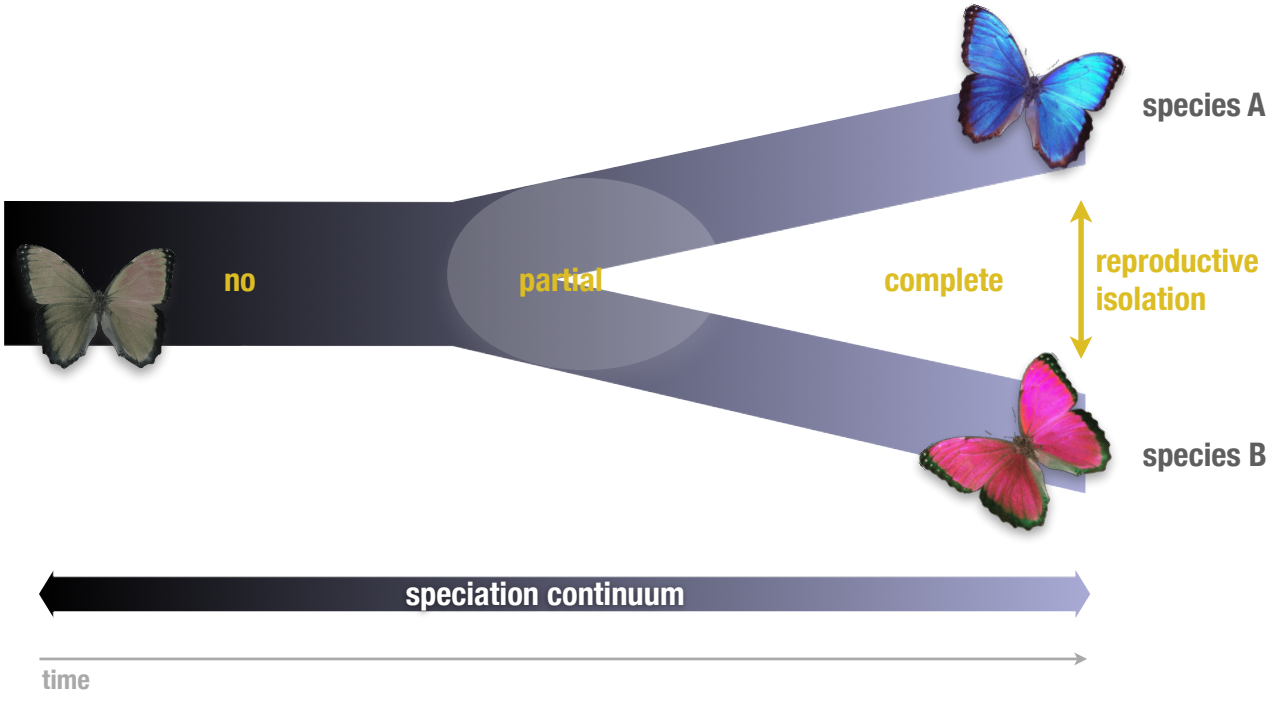
Coyne & Orr (2004); Zachos 2016

Biological species concept

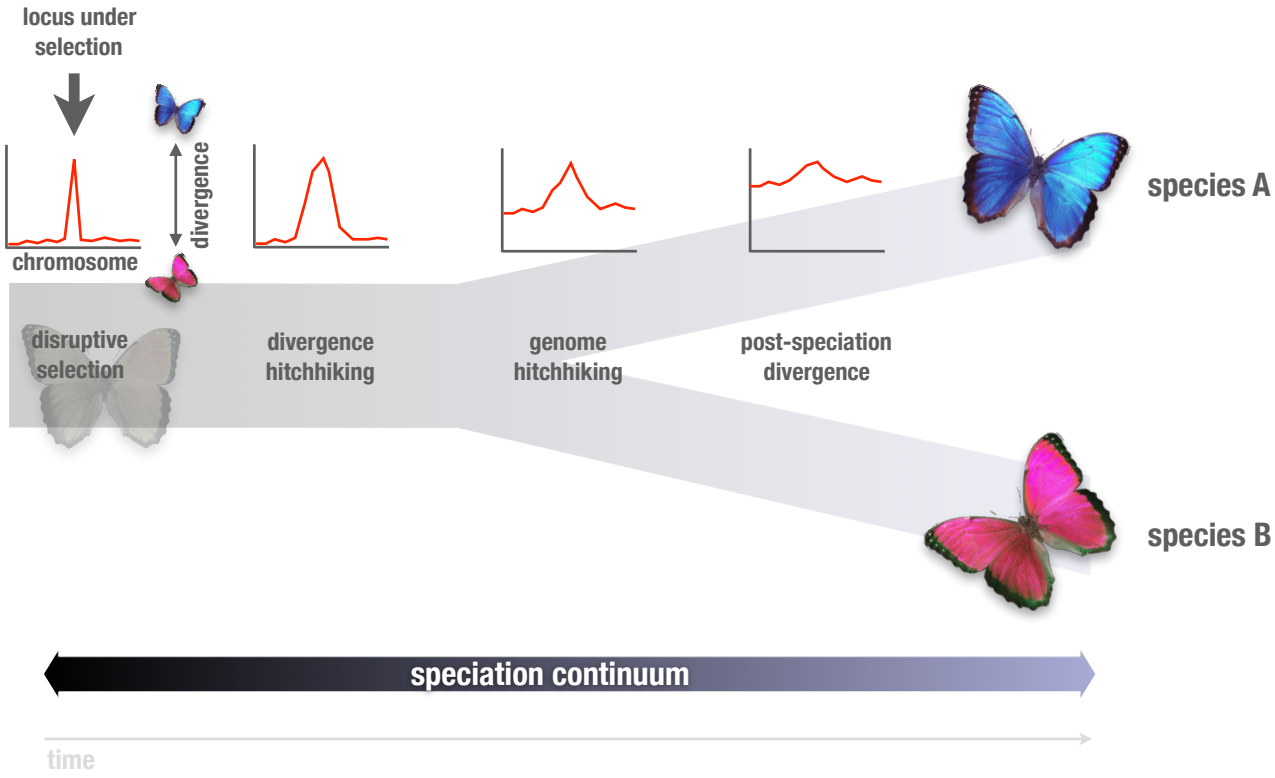
A species is a group of interbreeding natural populations that is reproductively isolated from other such groups (Mayr 1963).

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

Reproductive isolation

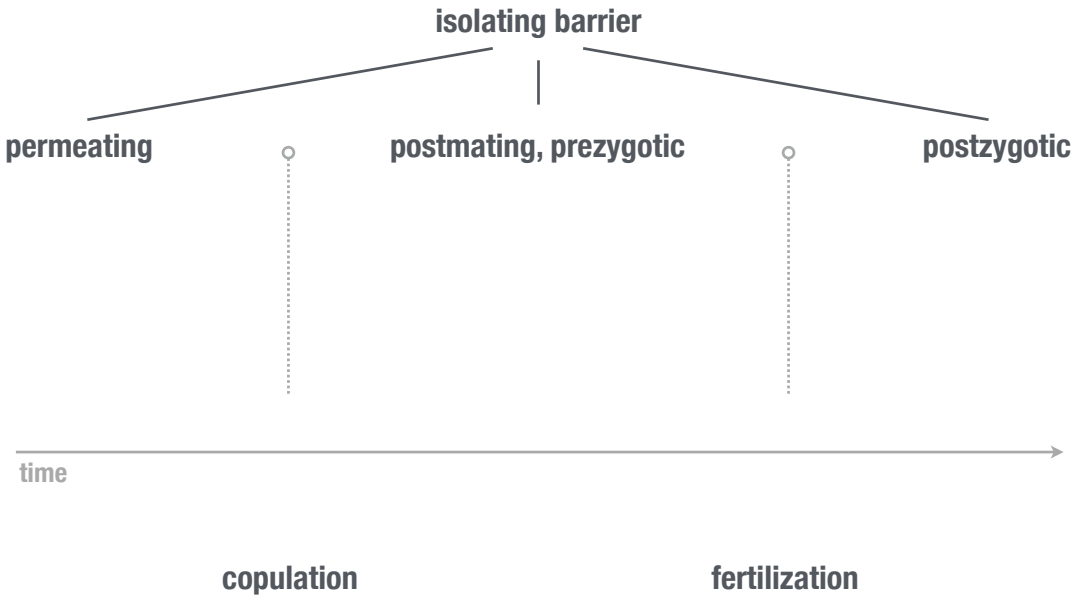


Reproductive isolation

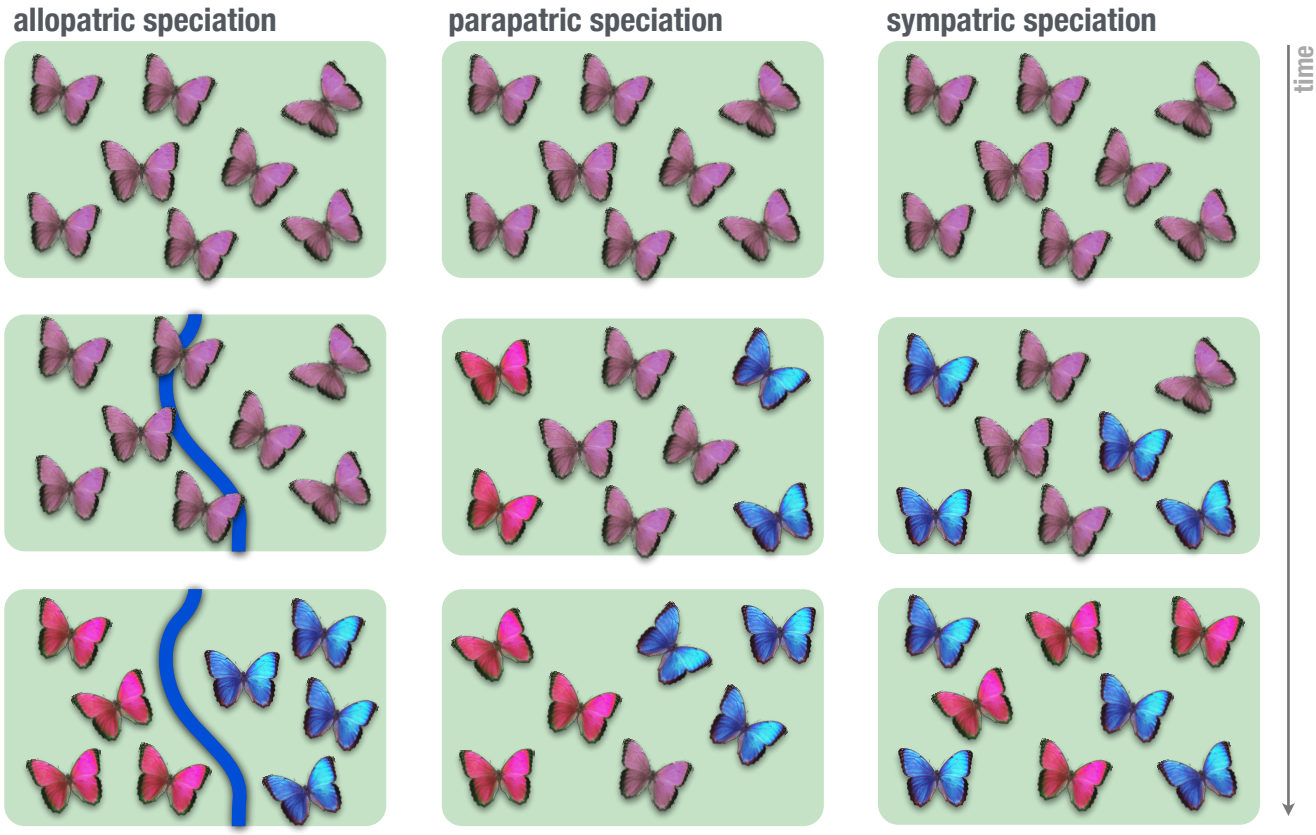


••• JL Feder, SP Egan & P Nosil (2012) TREE

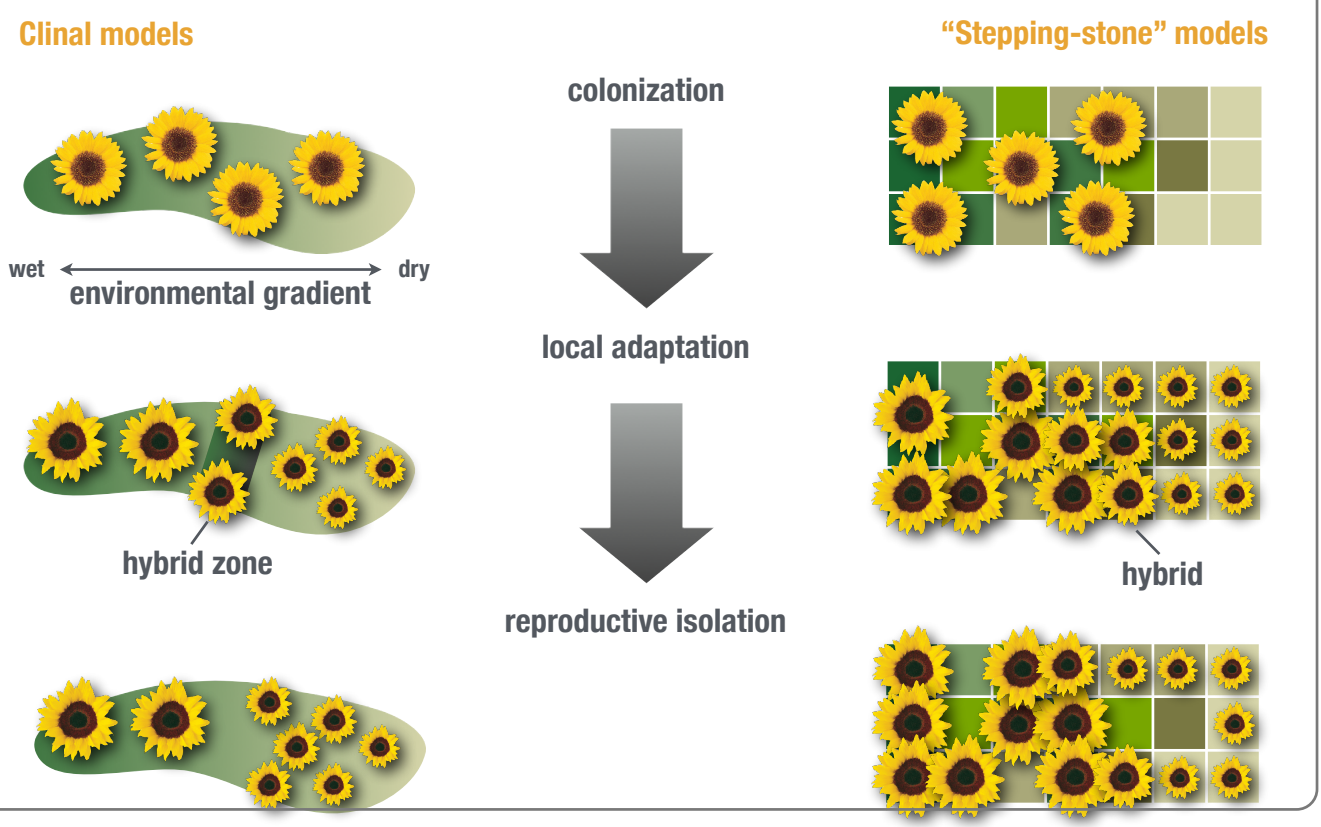
Reproductive isolation



Geographic conditions

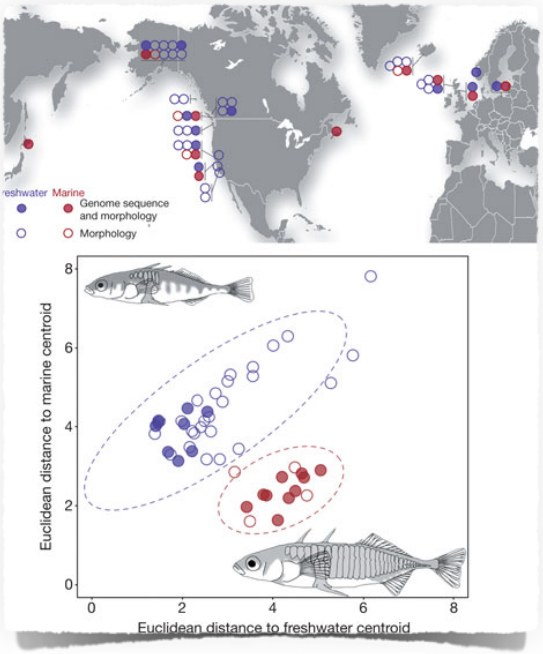


Parapatric speciation



Ecological speciation

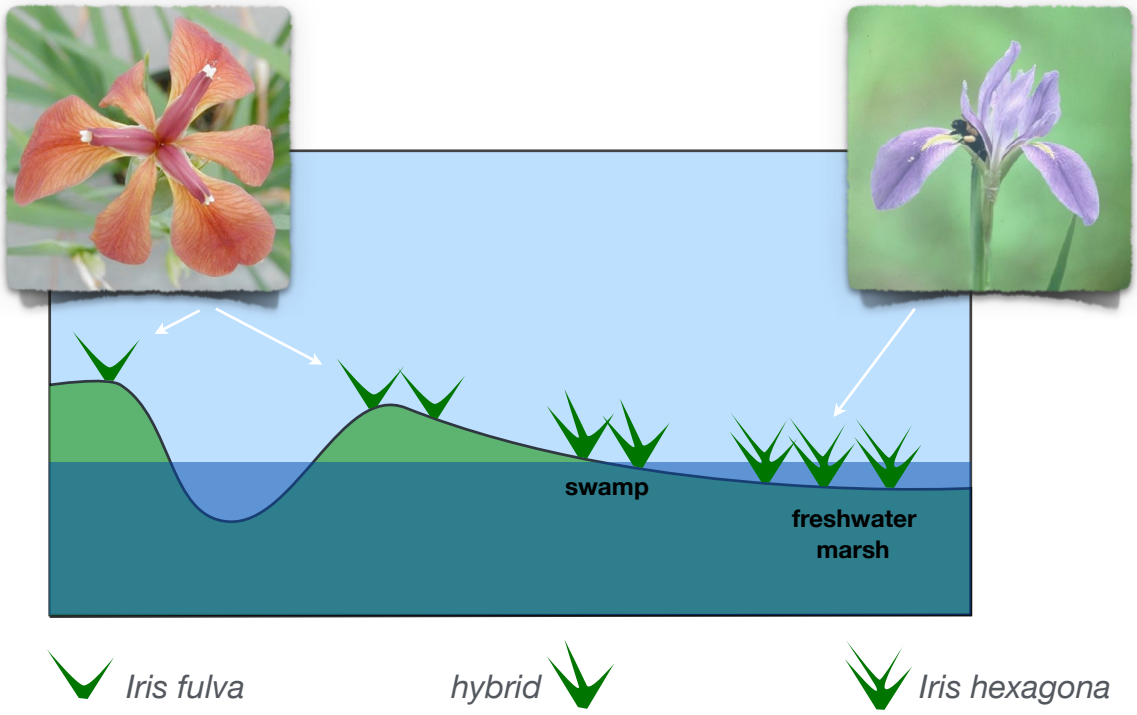
The evolution of reproductive isolation between populations by adaptation to different environments.



Jones et al. (2012) Nature

ⓘ Ecological speciation can happen in allopatry, parapatry and sympatry

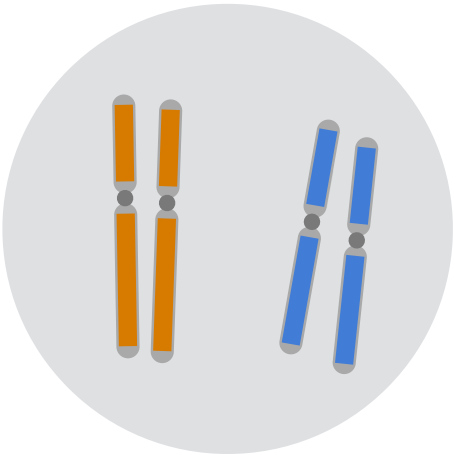
Hybrid speciation



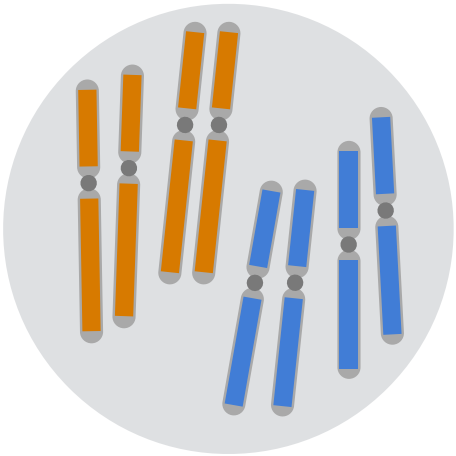
from: Arnold & Bennett (1993)

ⓘ Luisiana irises

Polyploid 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)

images: www.idscaro.net, www.wikipedia.com

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)

images: National Geographic, www.smh.com.au

Natural 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

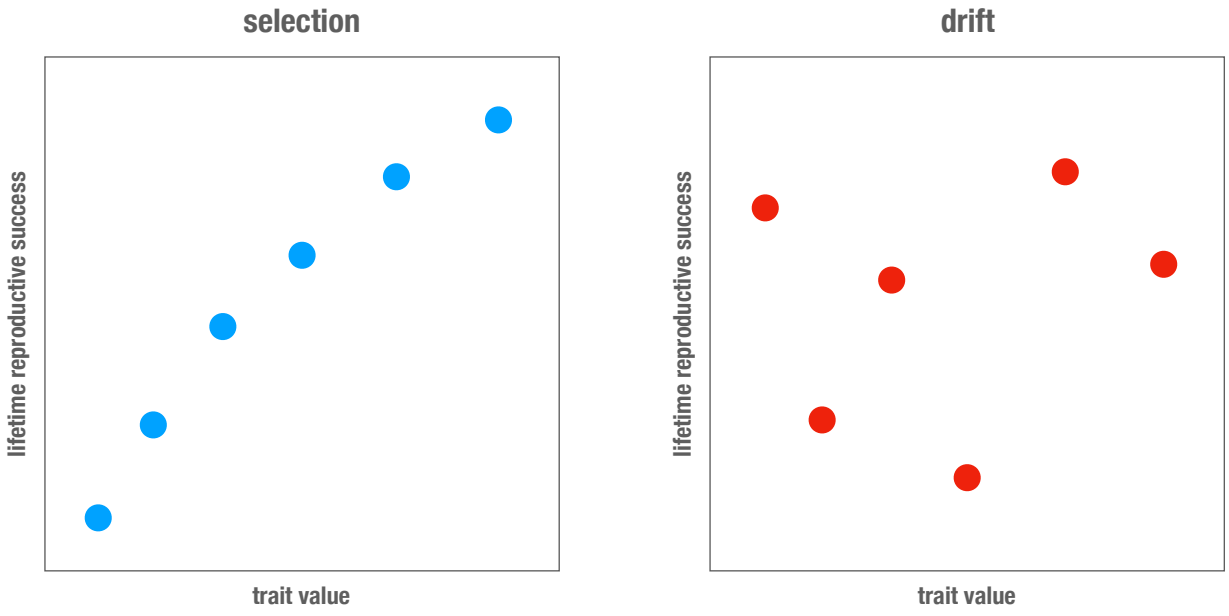
Sexual selection

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

(Natural) selection versus random drift



Natural variation

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

image: www.pbs.org

Natural variation

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

images: www.collective-evolution.com, N. Hunter/UC Davies

Natural variation

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

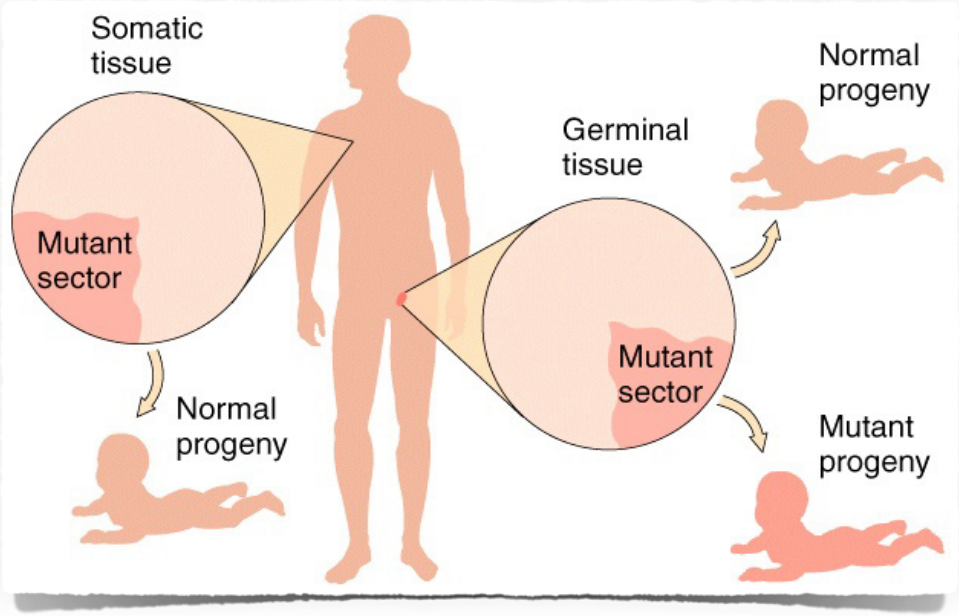
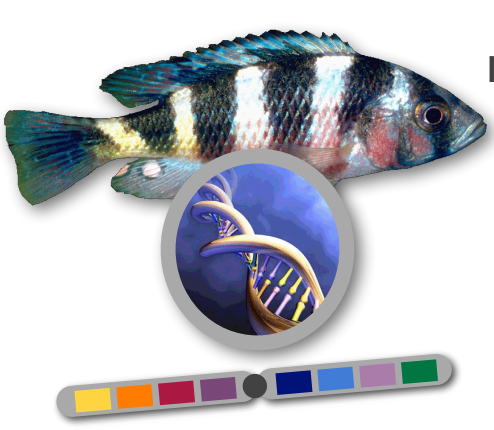


image: mun.ca

Phenotypic evolution

heritable variation in:

phenome



morphology
ecology
behavior

genome

genome structure

and/or

```
ATG AAC GTA TGG AGG...
Met Asn Val Trp Arg
```

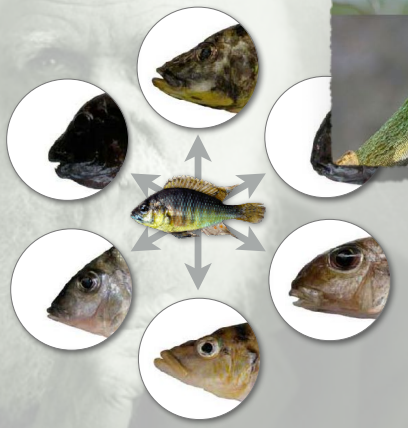
coding sequence

```
ATG AAC GCA TGG AGG...
Met Asn Ala Trp Arg
```

and/or

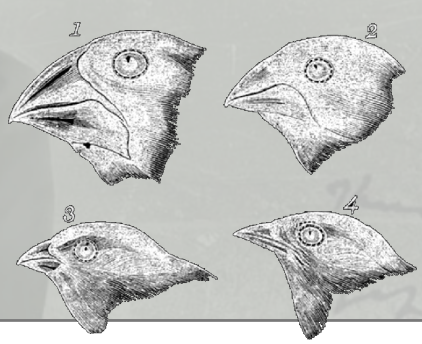
regulatory regions

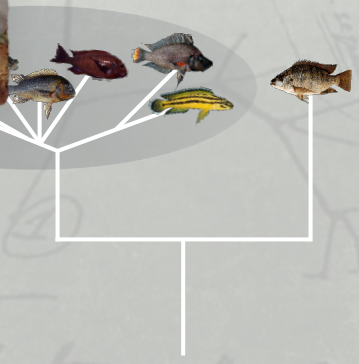
Adaptive radiation



common ancestry

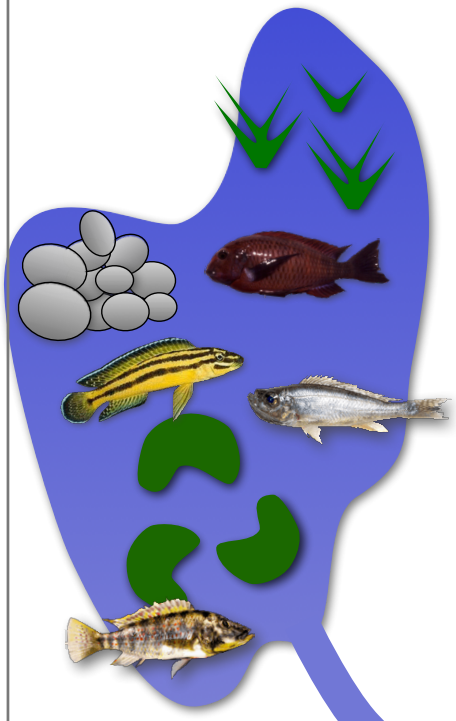
phenotype-environment correlation





rapid speciation

Ecological opportunity



colonization

extinction

innovation

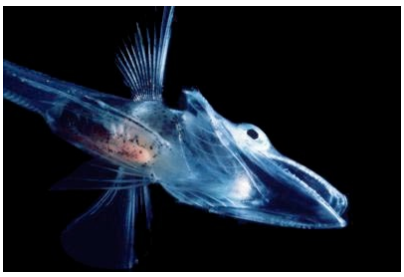
Ecological opportunity

- **Evolutionary key innovations permit a taxon to outcompete others or to exploit resources.**

Columbines

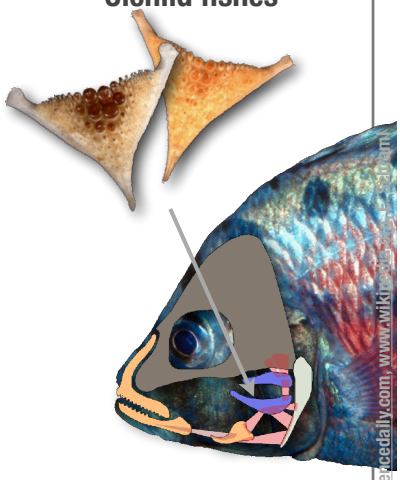
nectar spurs

Crocodile Icefishes



antifreeze glycoproteins

Cichlid fishes



pharyngeal jaw apparatus

images: www.sciencedaily.com, www.wikipedia.com

Cambrian explosion

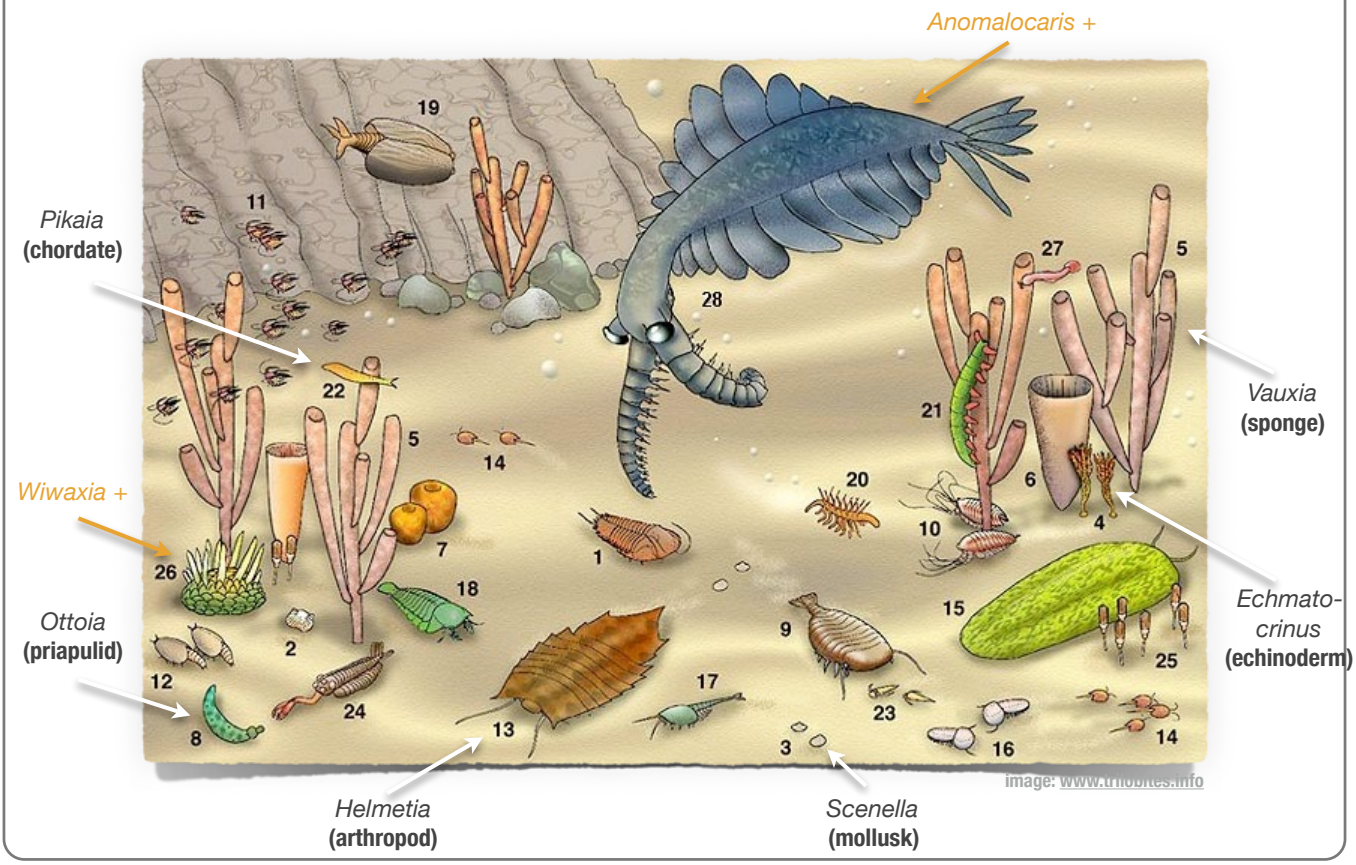
The 'Cambrian evolutionary radiation' most likely was an adaptive radiation.

trilobite

image: www.field.ca

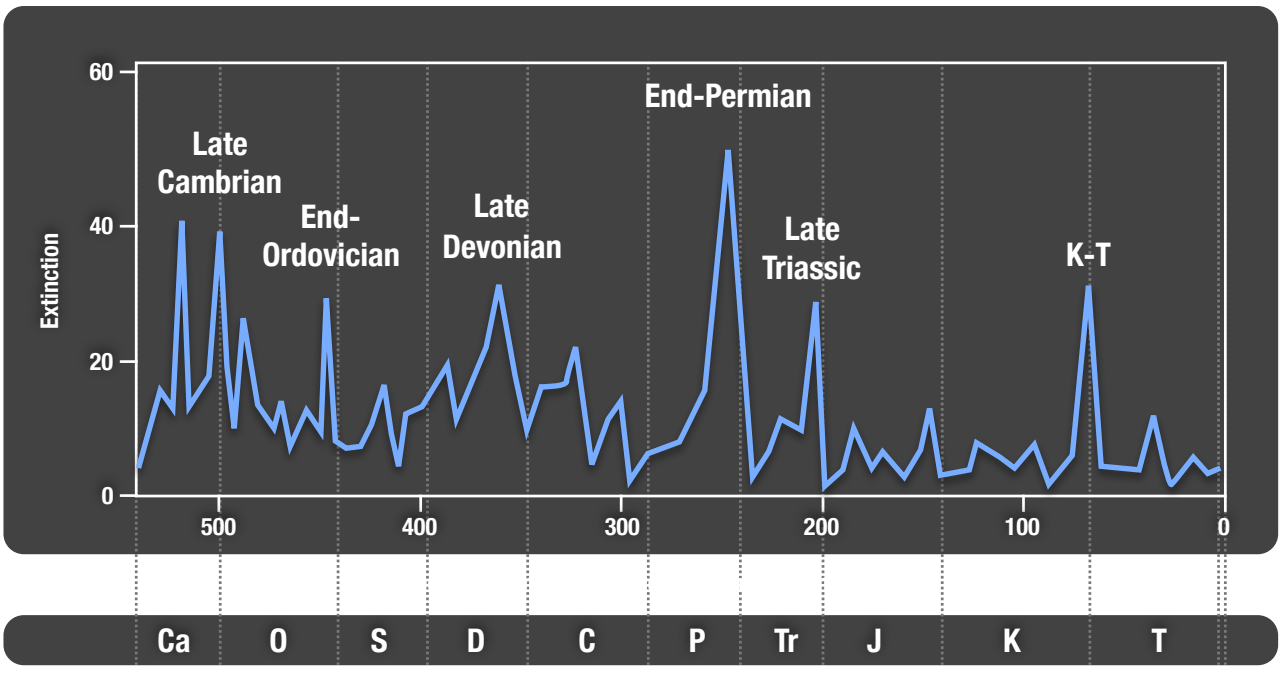
ⓘ The Burgess shale are fossil-rich deposits in the Yoho NP in British Columbia discovered by Charles D. Walcott in 1909

Cambrian explosion



Extinction

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



Sepkoski (1996), Rohde & Muller (2005)