

# The genomics of organismal diversification



Walter Salzburger  
Zoological Institute

A faded background image of Charles Darwin's face on the left, with his hand to his chin in a "shh" gesture. The background is filled with faint, handwritten text and sketches, including the phrase "I think" at the top and "There is a difference between A & B. a sort of selection" at the bottom.

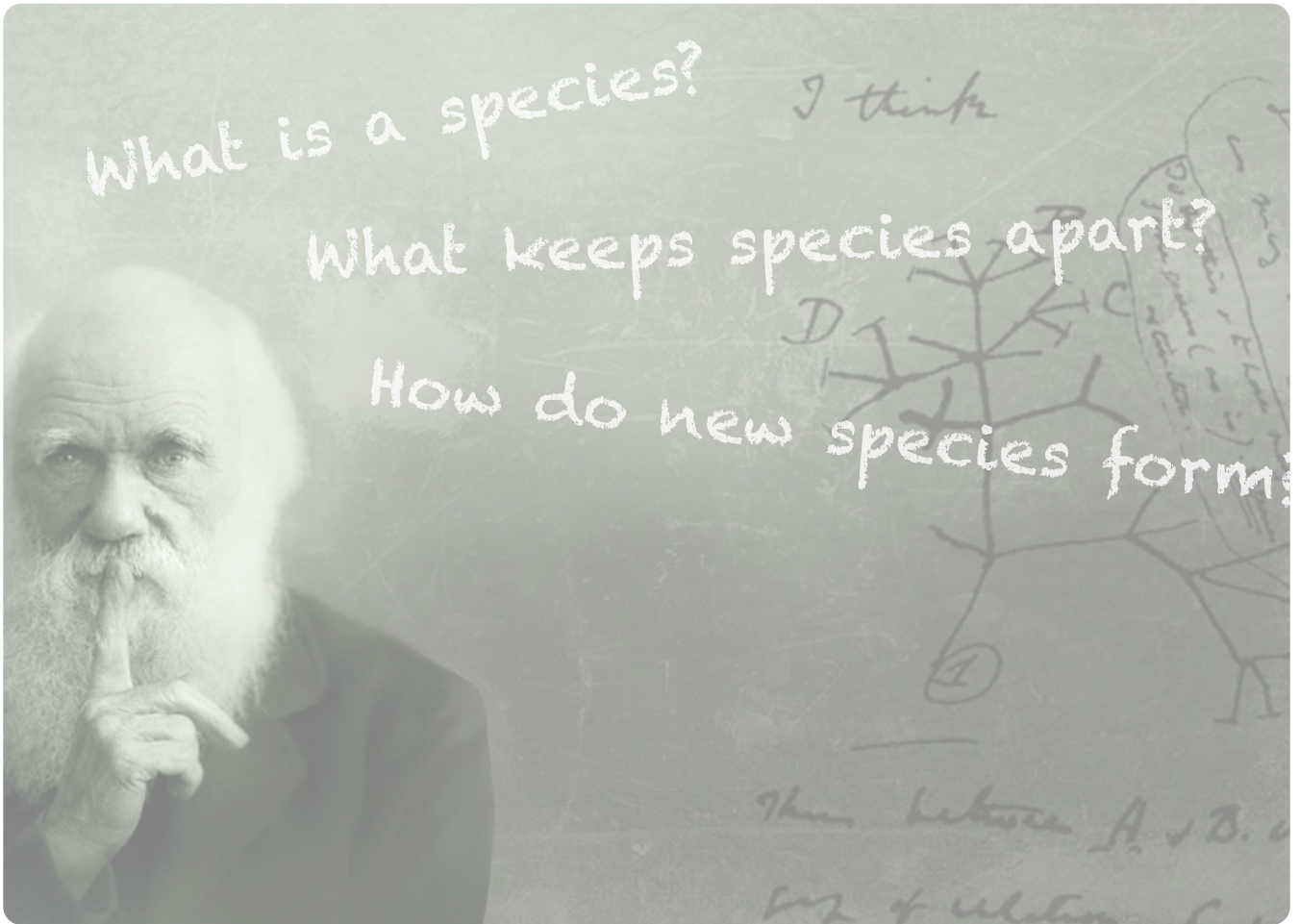
heritable variation

A diagram showing two pairs of moth wings. The left pair is on a green leaf background, showing a white moth with dark spots and a black moth with white spots. The right pair is on a black background, showing a white moth with dark spots and a black moth with white spots.

selection

A diagram showing two pairs of moth wings. The left pair is on a green leaf background, showing a white moth with dark spots and a black moth with white spots. The right pair is on a black background, showing a white moth with dark spots and a black moth with white spots, with a brown hawk head next to each, indicating predation.

diversification (speciation)



## What is a species?



Poll (1946)

① Taxonomists describe species based on diagnostic characters and taxonomy guidelines

# What is a species?

**STRÖMER**  
*Leuciscus souffia*

F: blageon, soufie  
Familie Karpfenfische (Cyprinidae)

**Kurzbeschreibung**  
Kleiner, relativ schlanker, seitlich nur wenig abgeflachter Fisch mit unterständiger Mundspalte und gelblich eingefärbter Seitenlinie.

**Merkmale**  
Gestreckter, im Querschnitt wenig abgeflachter Körper mit langem, stumpf endendem Kopf und unterständiger Mundspalte. Länge meist 12–18 cm, maximal 25 cm. Schuppen groß. Außenrand der Afterflosse in gespreiztem Zustand konkav. Rückenfärbung metallisch dunkelblau, Flanken silbrig, Bauch weiß. Seitenlinie schmal gelblich gerandet; zur Laichzeit mit dunkelviolettem Flankenband vom Auge bis zur Schwanzflosse. Alle Flossen leicht gelblich, Flossenansätze schwach gelblich bis kräftig orangefarben.

50–57 Schuppen entlang der Seitenlinie.  
Flossenstrahlen: Rückenflosse 10, Afterflosse 10–13, Brustflosse 14–15, Bauchflosse 10, Schlundzähne 2,5–5(4).2.

**Verwechslungsarten**  
Vom Hasel (*L. leuciscus*) durch den längeren Kopf und die Färbungsmerkmale zu unterscheiden, der ähnlich gefärbte Schneider (*Alburnoides bipunctatus*) besitzt eine viel längere Afterflosse.

**Lebensweise und Lebensraum**  
In der Lebensweise ähnelt der Strömer am ehesten dem Hasel. Im Gegensatz zu den meisten Cypriniden ist er an sauerstoff-

Strömer, *Leuciscus souffia*

reichtes, kühles Wasser angepaßt. So lebt er vor allem in schnellfließenden Gebirgs- und Mittelgebirgsflüssen bis in eine Höhe von ca. 900 m, aber auch in kühlen hochgelegenen Seen mit Kiesgrund, wo er die tieferen Wasserschichten bevorzugt. Er lebt gesellig, in Seen auch in größeren Schwärmen, und ernährt sich je nach Gewässertyp vorwiegend von im Wasser driftendem tierischen Plankton oder von bodenlebenden Kleintieren. Auch dicht über der Wasseroberfläche fliegende Insekten können im Sprung gefangen werden. Diese Fähigkeit haben Strömer mit den meisten Salmoniden (z. B. Äschen) gemein; sie stellt eine Anpassung an die Nahrungsarmut der oberen Fließwasserregionen dar. Strömer laichen von März bis Mai in schnellfließendem flachen Wasser über Kies.

Die Vorkommen dieses früher nicht seltenen Fisches sind innerhalb der letzten Jahrzehnte drastisch zurückgegangen. So ist er offensichtlich aus dem größten Teil seines deutschen Verbreitungsgebietes (das nördlich bis zum Main reichte) verschwunden. Als Grund für diesen Rückgang spielen neben der Gewässerverschmutzung sicherlich auch die Veränderungen eine Rolle, insbesondere die Zerstörung reich strukturierter Gewässerböden. Im Gegensatz zur Äsche, die unter denselben Einflüssen zu leiden hatte, kam der Strömer als sportlich „unattraktiver“ Kleinfisch nicht in den Genuß von Besatzmaßnahmen. Ganz im Gegenteil wird eine zu intensive Bewirtschaftung von Salmonidengewässern zumindest als Mitursache für die heutige Seltenheit dieser Fischart angesehen. So wurden und werden viele Bäche durch regelmäßiges Herausfangen von Cypriniden „entschuppt“ (teilweise unter Einsatz von E-Geräten), um lästige Konkurrenten oder Freilebende der Forellen zu entfernen;

222
223

① Field guides and identification keys help in species identification

# What is a species?

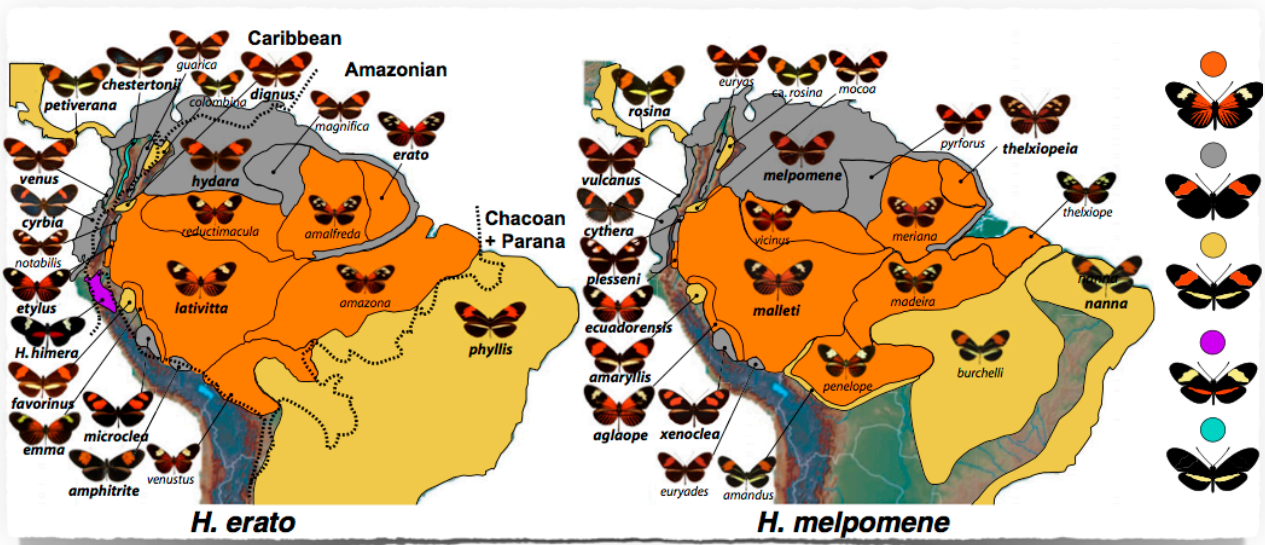
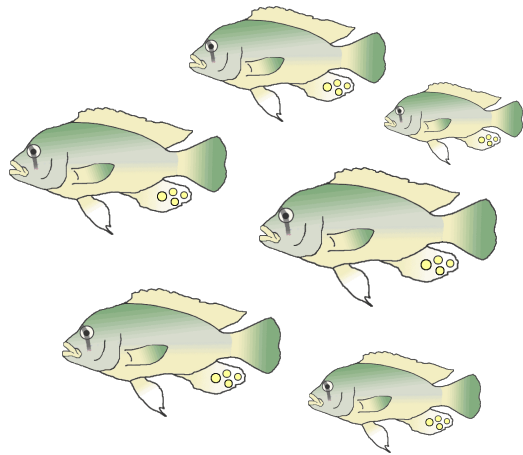


image: [www.heliconius.org](http://www.heliconius.org)

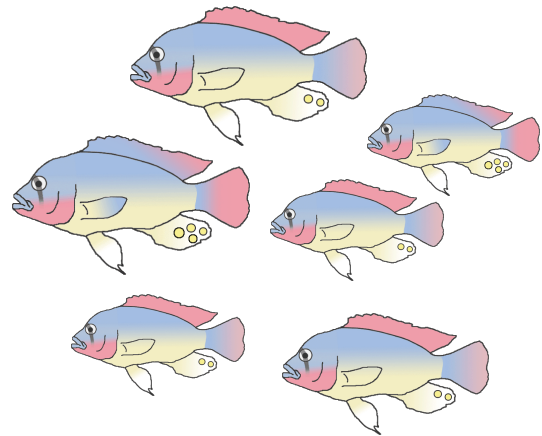
① Heliconius erato and H. melpomene are morphologically similar because of mimicry

# What is a species?

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



species X



species Y

① 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)

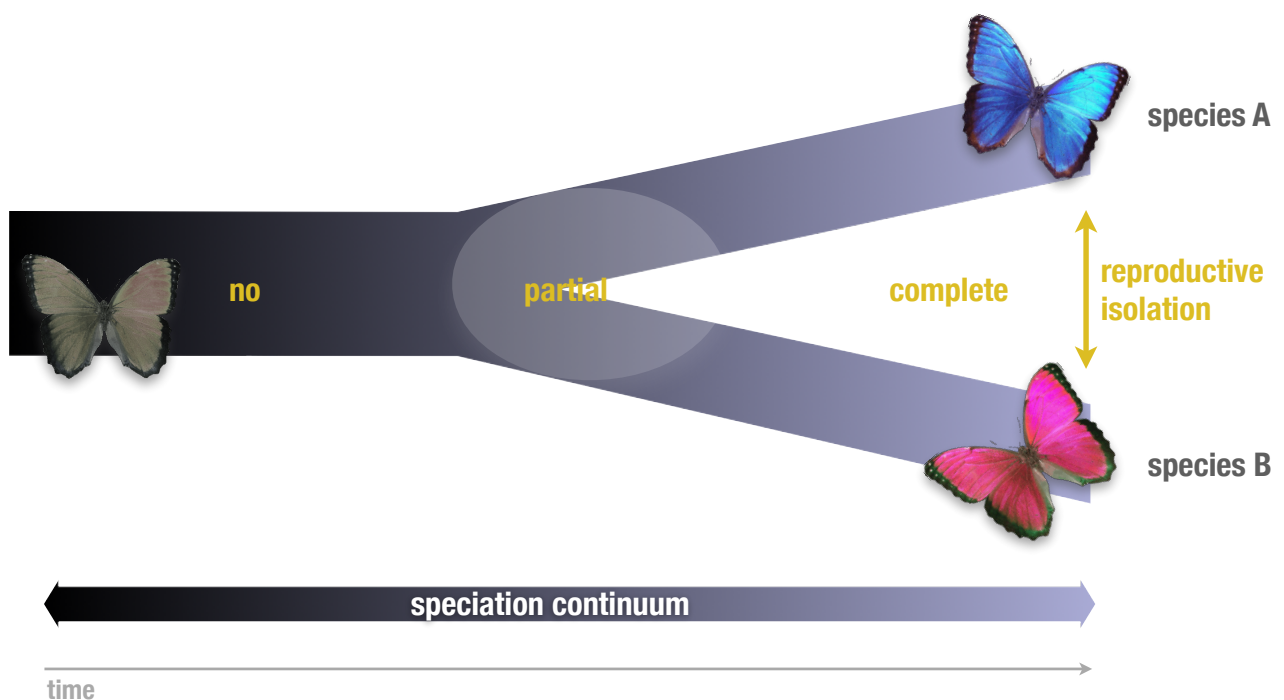
## Biological species concept

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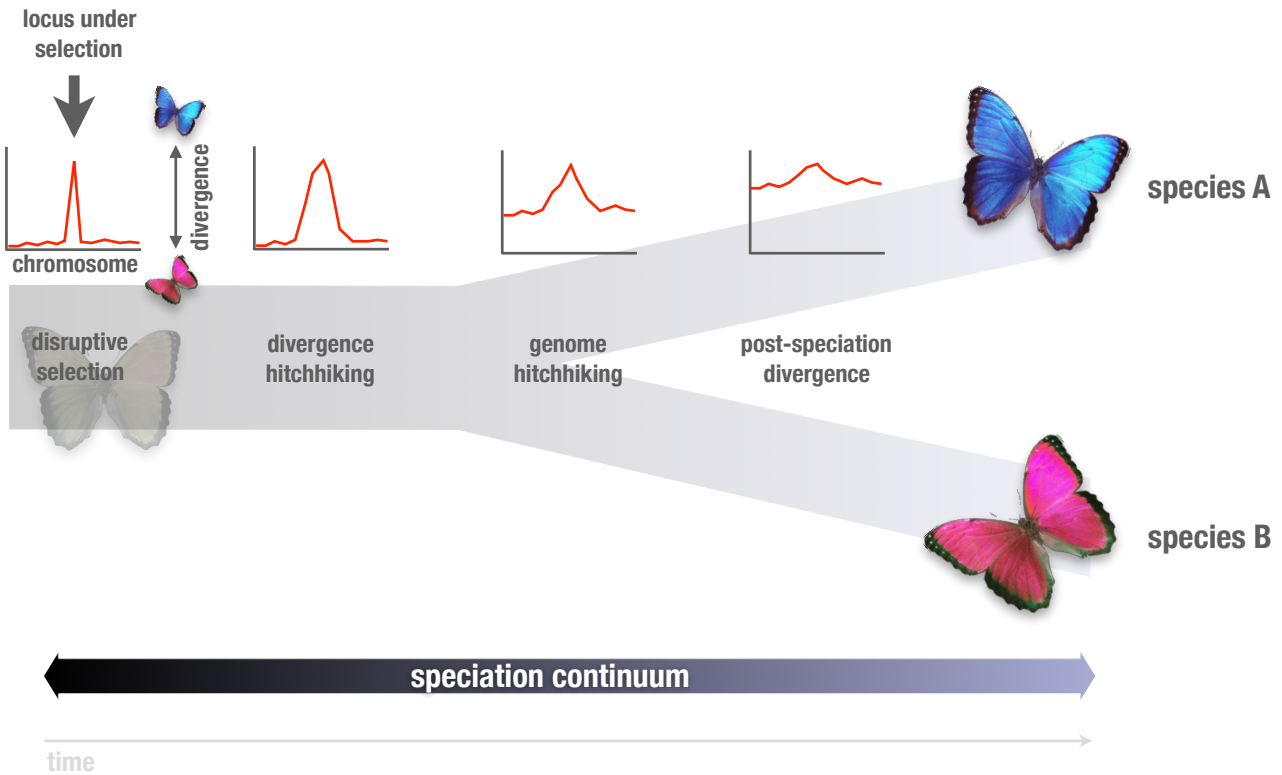


① The biological species concept places the category species within the framework of population genetics

## Reproductive isolation

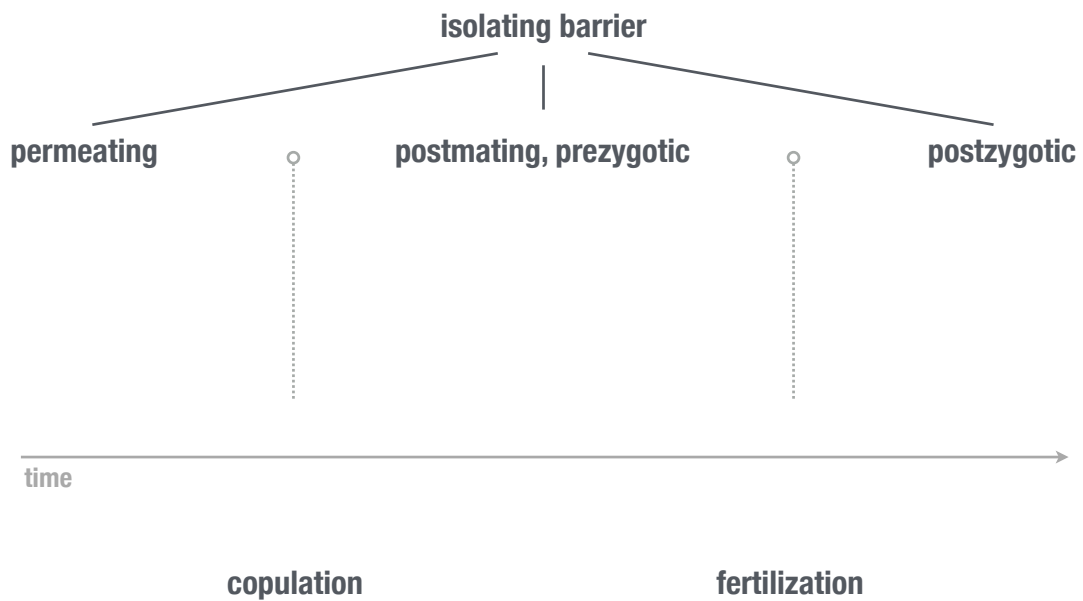


# Reproductive isolation



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

# Reproductive isolation

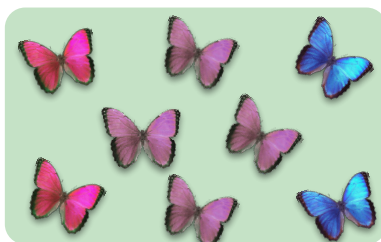


# Geographic conditions

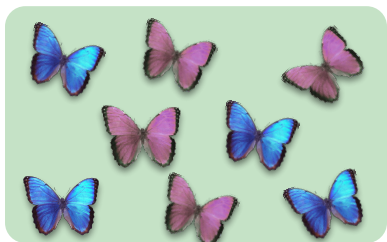
## allopatric speciation



## parapatric speciation



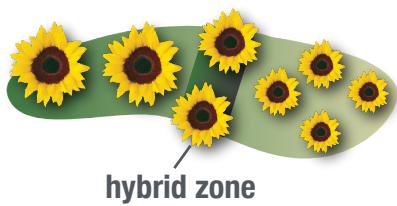
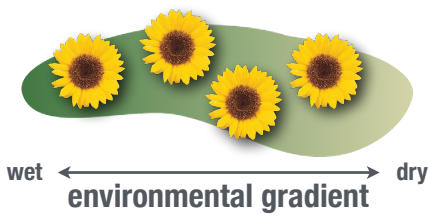
## sympatric speciation



time

# Parapatric speciation

## Clinal models



colonization

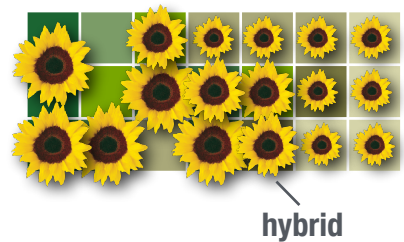


local adaptation



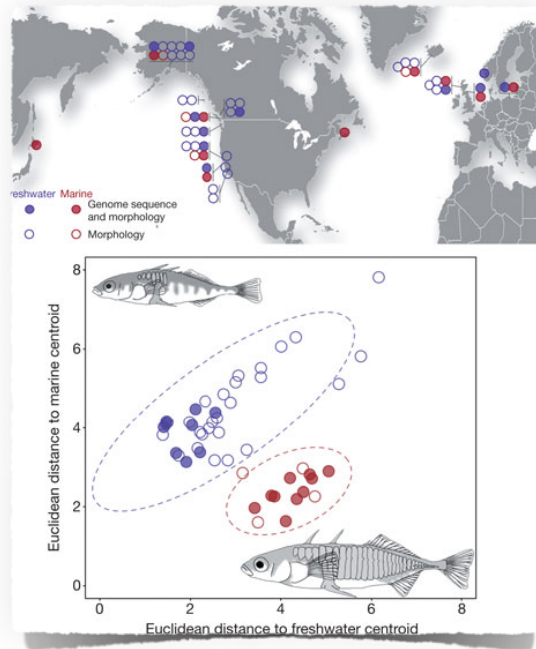
reproductive isolation

## "Stepping-stone" models



# Ecological speciation

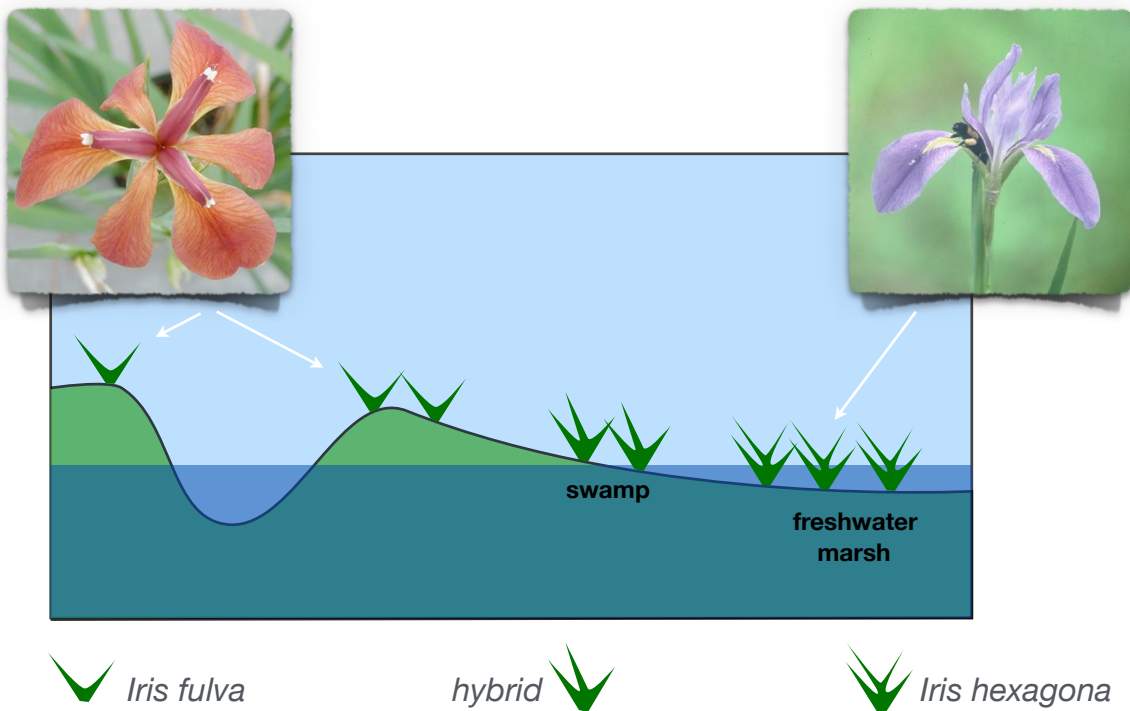
The evolution of reproductive isolation between populations by adaptation to different environments.



Jones et al. (2012) Nature

① Ecological speciation can happen in allopatry, parapatry and sympatry

# Hybrid speciation

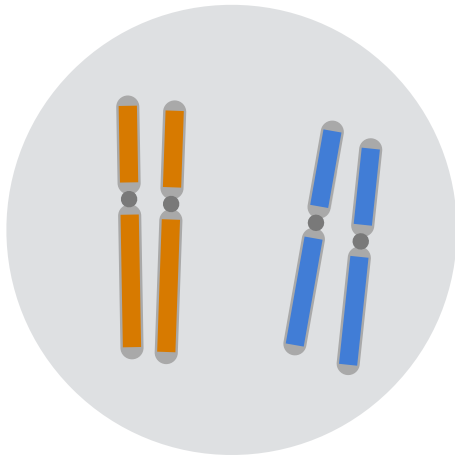


from: Arnold & Bennett (1993)

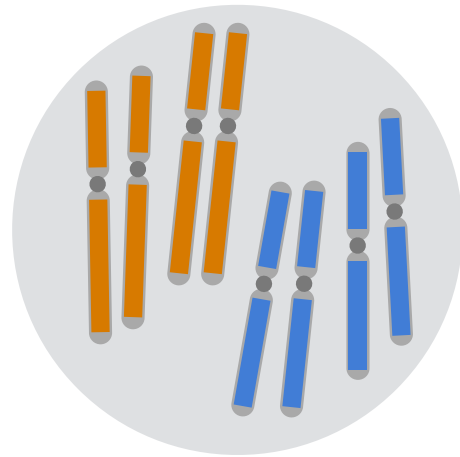
① Louisiana irises



## Ployploid speciation



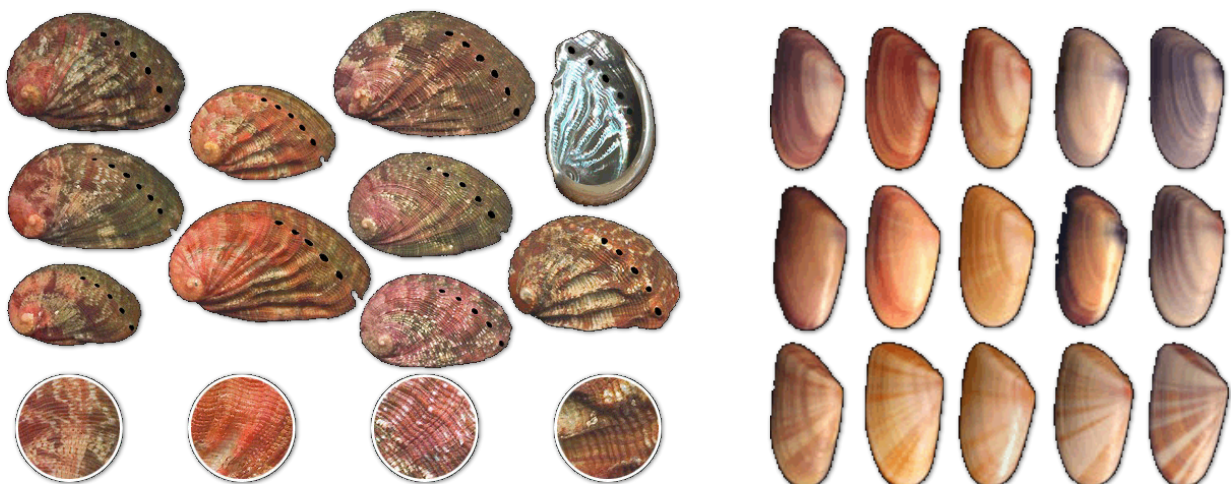
**diploid**  
( $2n=4$ )



**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)



images: National Geographic, www.smb.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

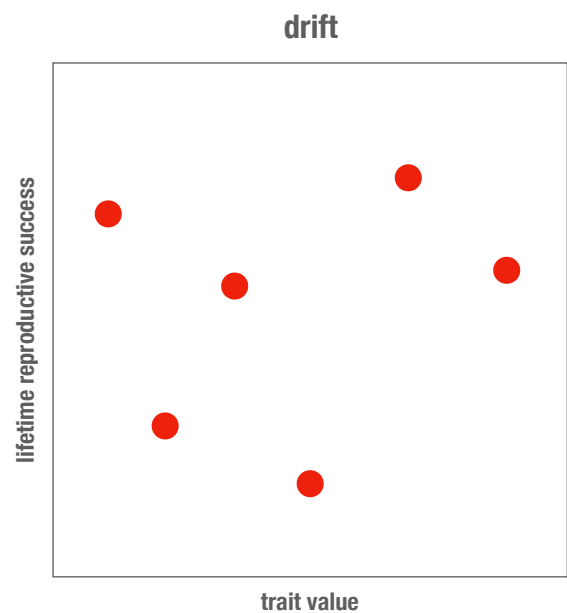
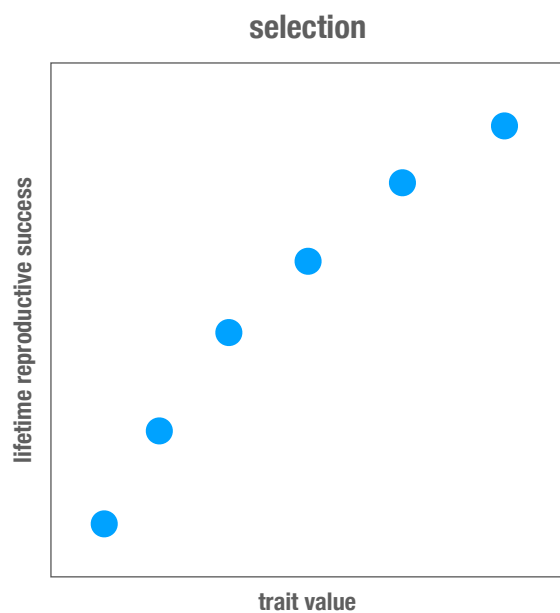
## Sexual selection

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.**

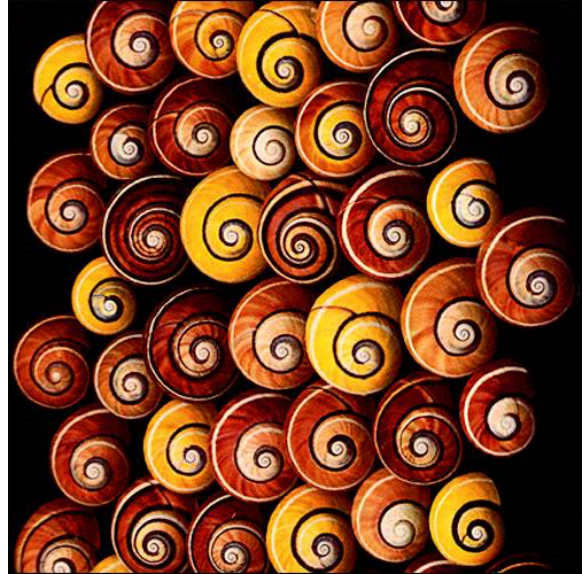


image: [www.pbs.org](http://www.pbs.org)

## Natural variation

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

images: [www.collective-evolution.com](http://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.

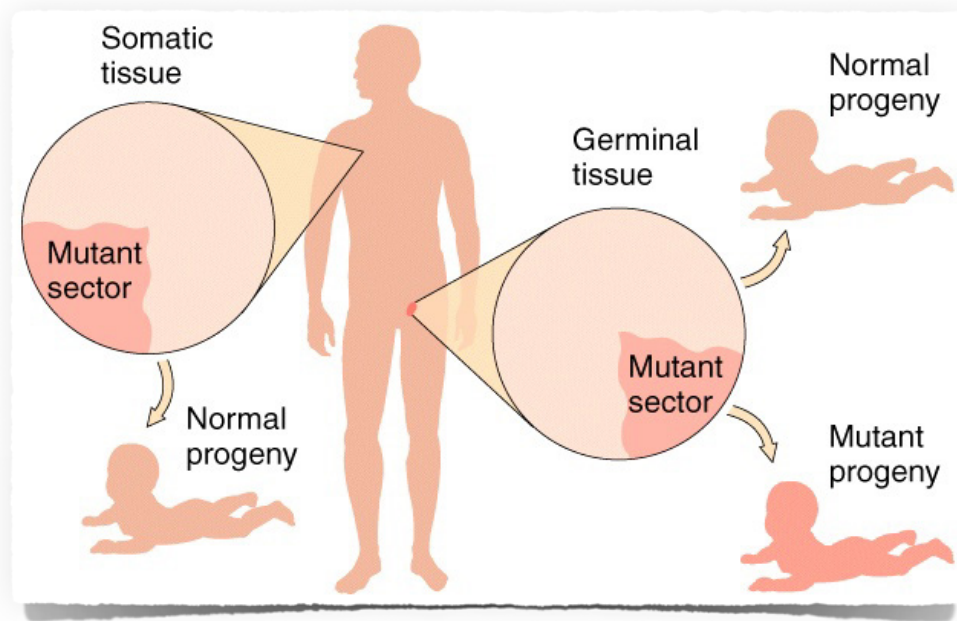
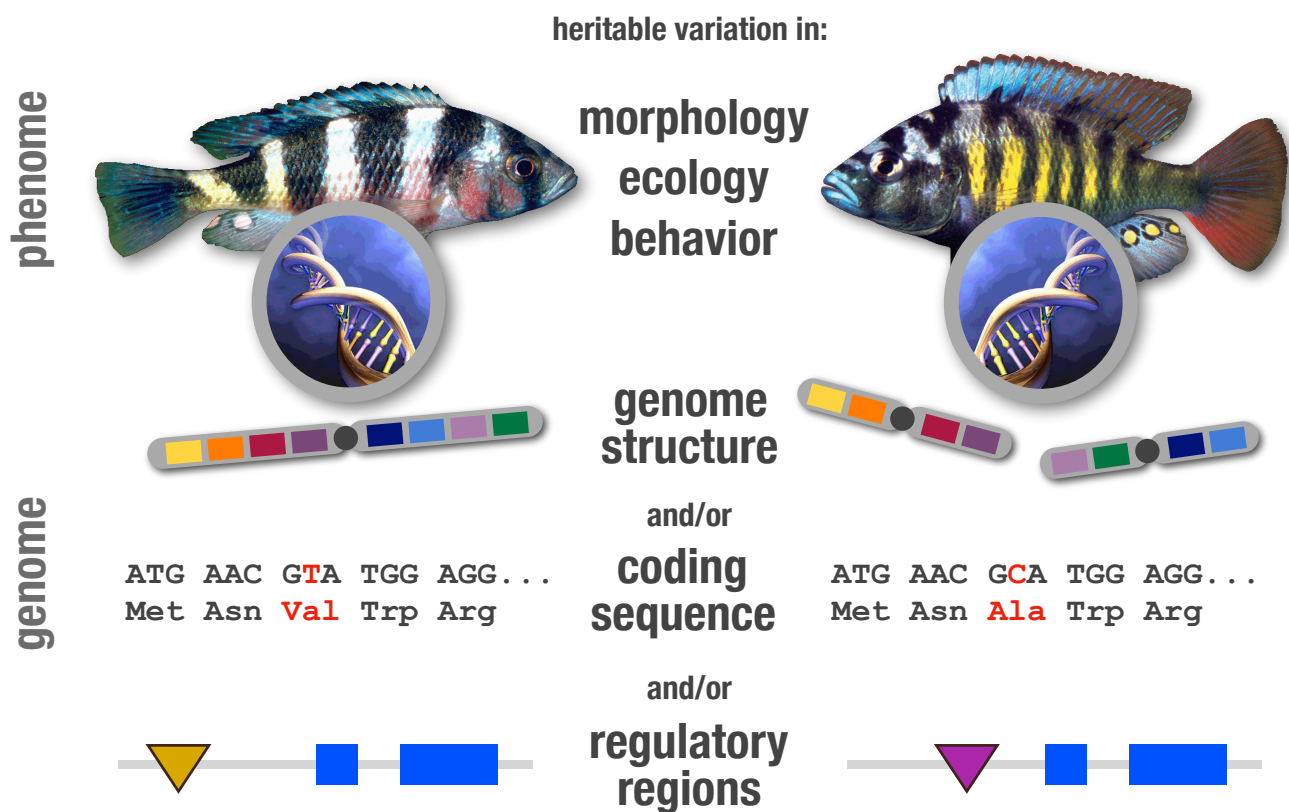
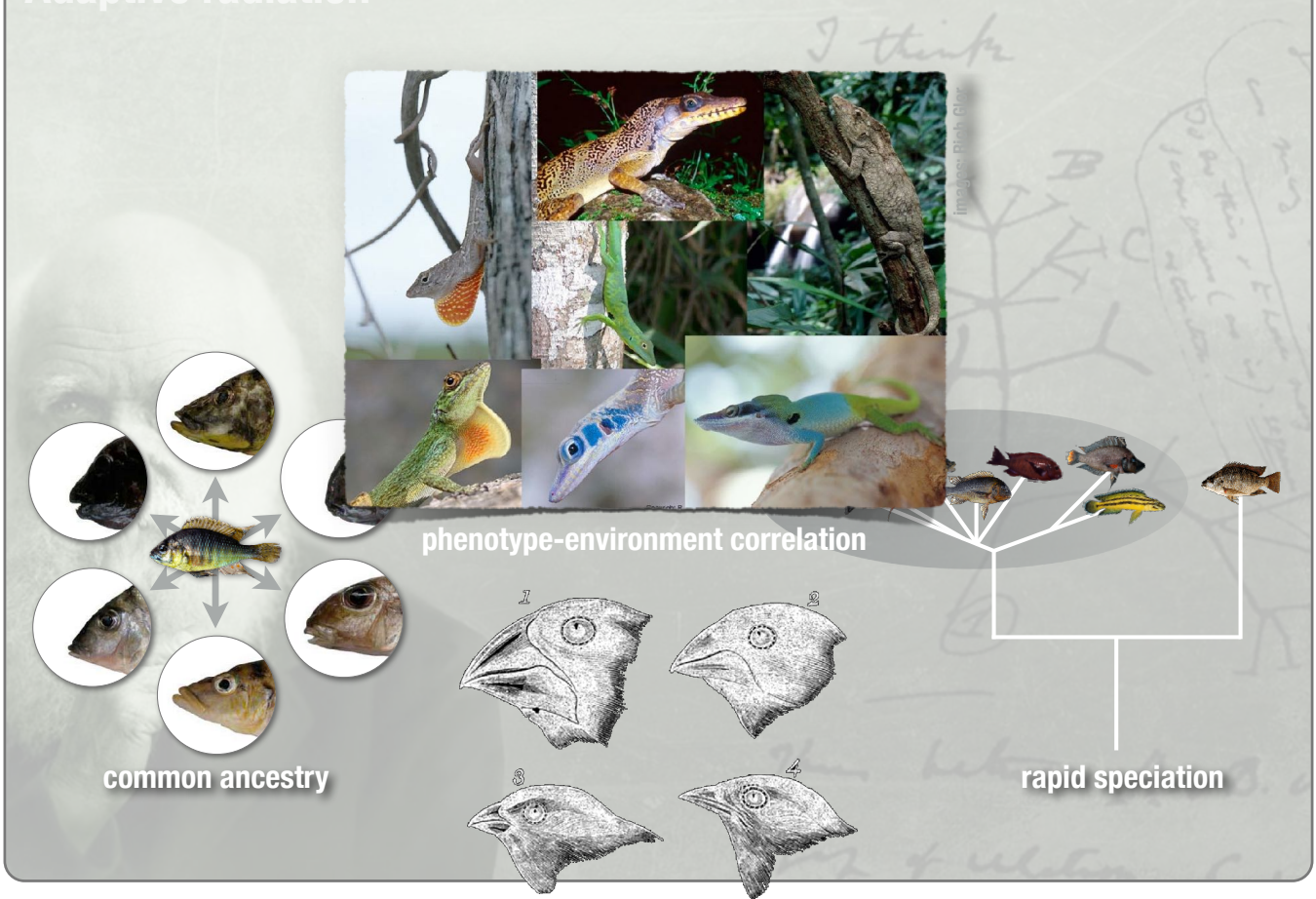


image: mun.ca

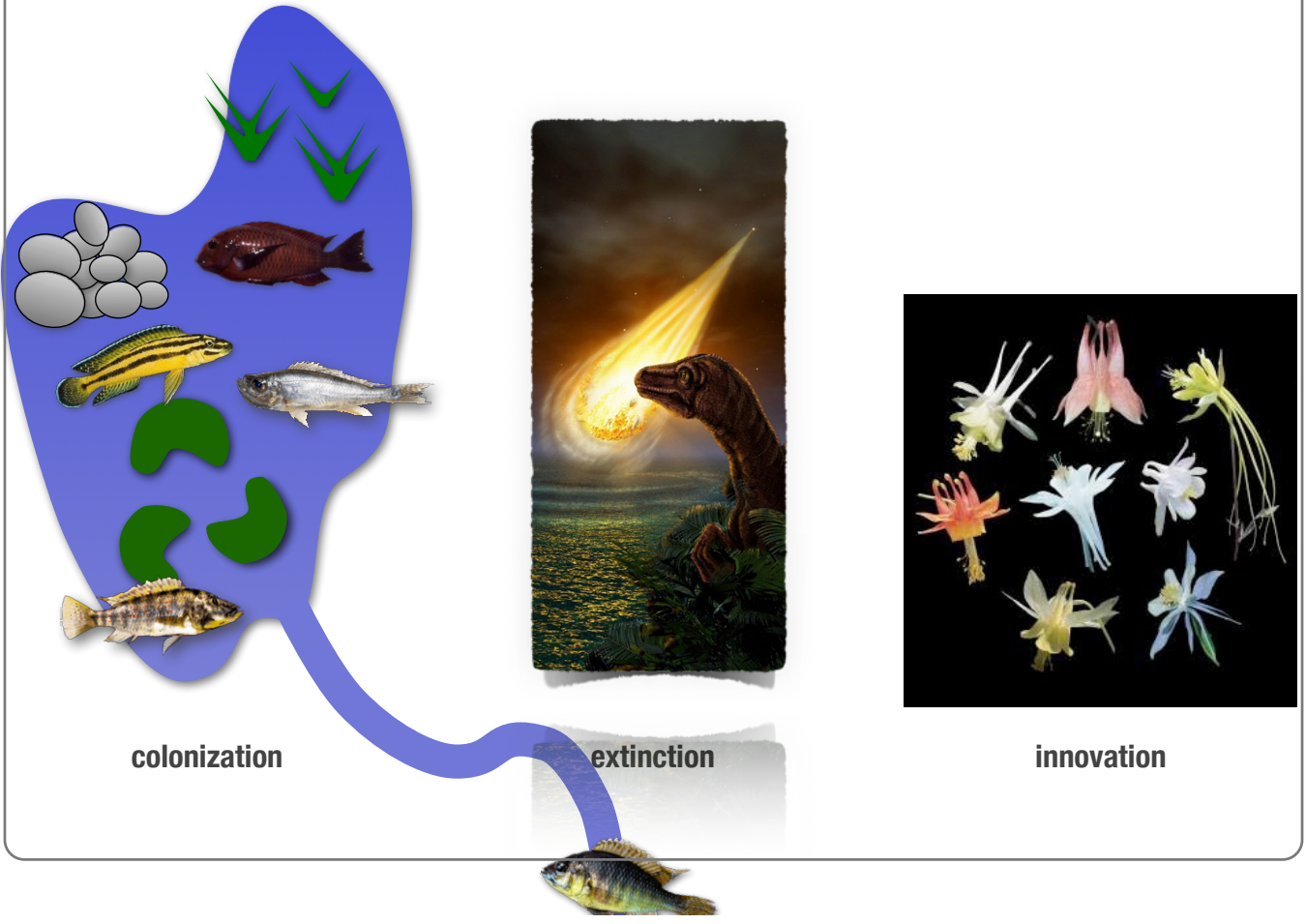
## Phenotypic evolution



# Adaptive radiation



# Ecological opportunity



## Ecological opportunity

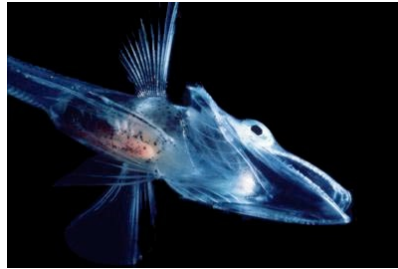
- ▶ Evolutionary key innovations permit a taxon to outcompete others or to exploit resources.

Columbines



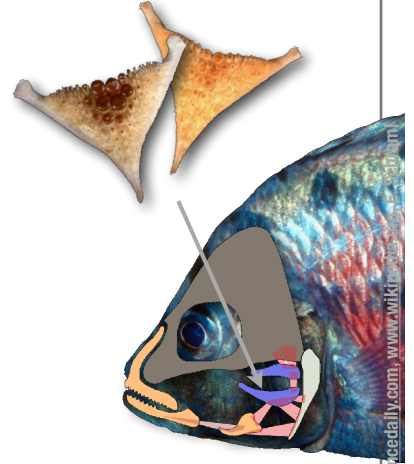
nectar spurs

Crocodile Icefishes



antifreeze  
glycoproteins

Cichlid fishes



pharyngeal jaw  
apparatus

images: www.scienceDaily.com, www.wiki.com

## Cambrian explosion

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

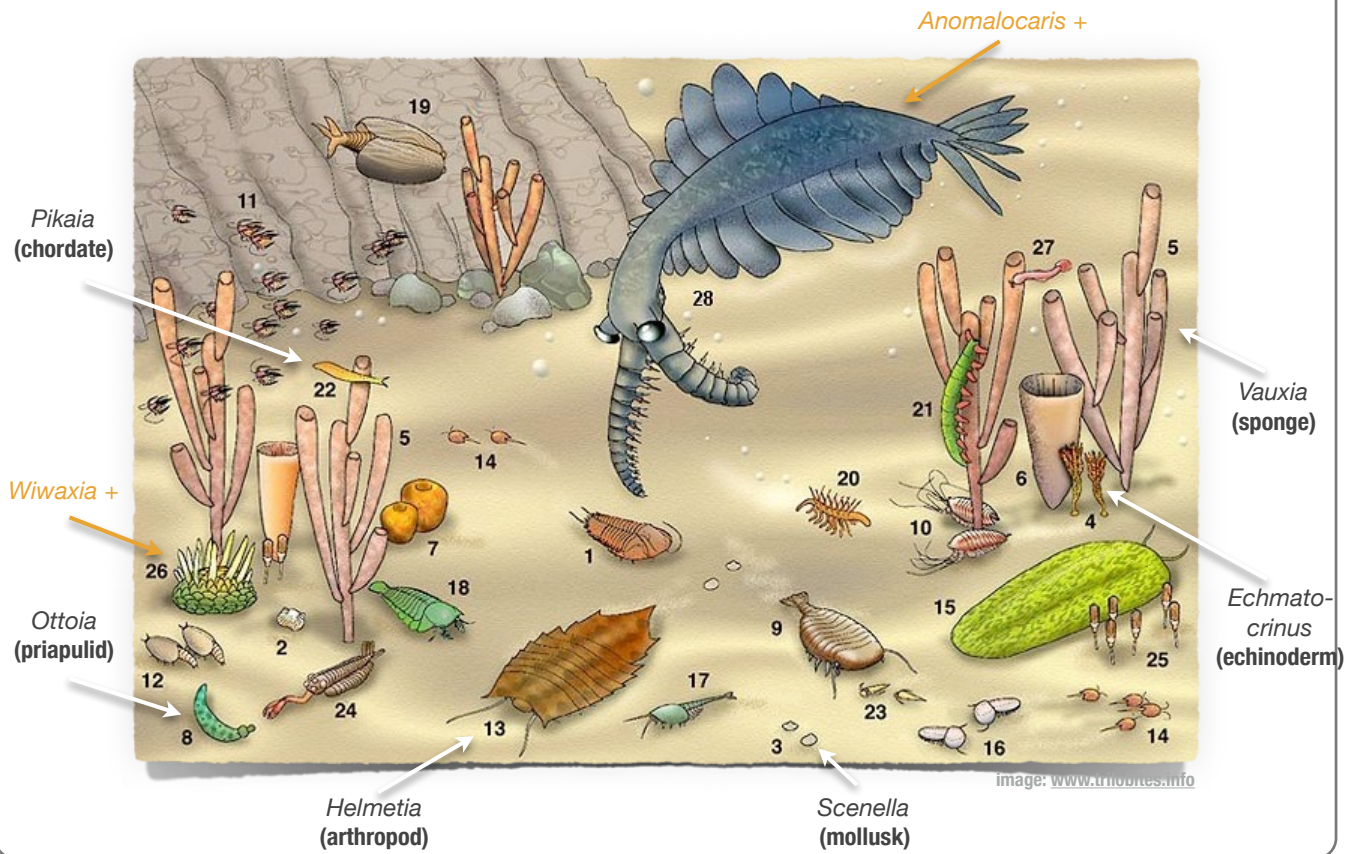


trilobite

image: www.field.ca

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)

