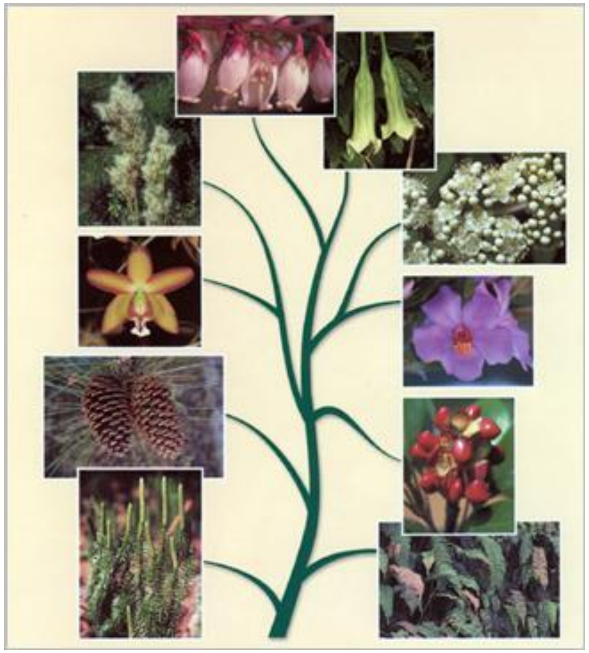
Plant

"Nothing in biology makes sense except in the light of evolution."

- T. Dozhansky



Evolutionary Processes in Plants

Chapter 11

So What is Evolution?

Evolution is changes in allelic or genotypic frequencies from one generation to the next

1. Microevolution: changes in allelic or genotypic frequencies within **a population** from one generation to the next

- occurs below the species level

2. Macroevolution: evolutionary change on a grand scale, involving major evolutionary trends

- occurs on a scale at or above species level

Forces that drive Microevolution – 1. Natural Selection

Darwin's theory of **natural selection** has four key observations

Taraxacum sp. (dandelion)

Observation 1: **Overproduction**

– All species tend to produce excessive numbers

Observation 2: **Resources are limited**

– This leads to a **"struggle for existence"**

Darwin's Theory of Natural Selection

Observation 3: **Individuals vary**

- Variation exists among individuals in a population

- Much of this variation is heritable

Flower colour variation in *Cylindropuntia sanfelipensis* (cactus)

Observation 4: **Differential reproductive success**

- Those individuals with traits most successful in the local environment will **leave more fertile offspring**

This leads to **Adaptation**

Microevolution – 2. Mutations

2. Mutation: the ultimate source of all genetic variation within species and populations

Two different Morning Glories in my garden this year

Mutation: a heritable change in the genotype

Microevolution – 2. Mutations

2. **Mutation:** the rate of mutation may be influenced by environmental factors, but the specific mutations produced are independent of the environment

The radioactive daisies near Fukushima - Fact or twitter fiction?

Microevolution – 3. Gene Flow

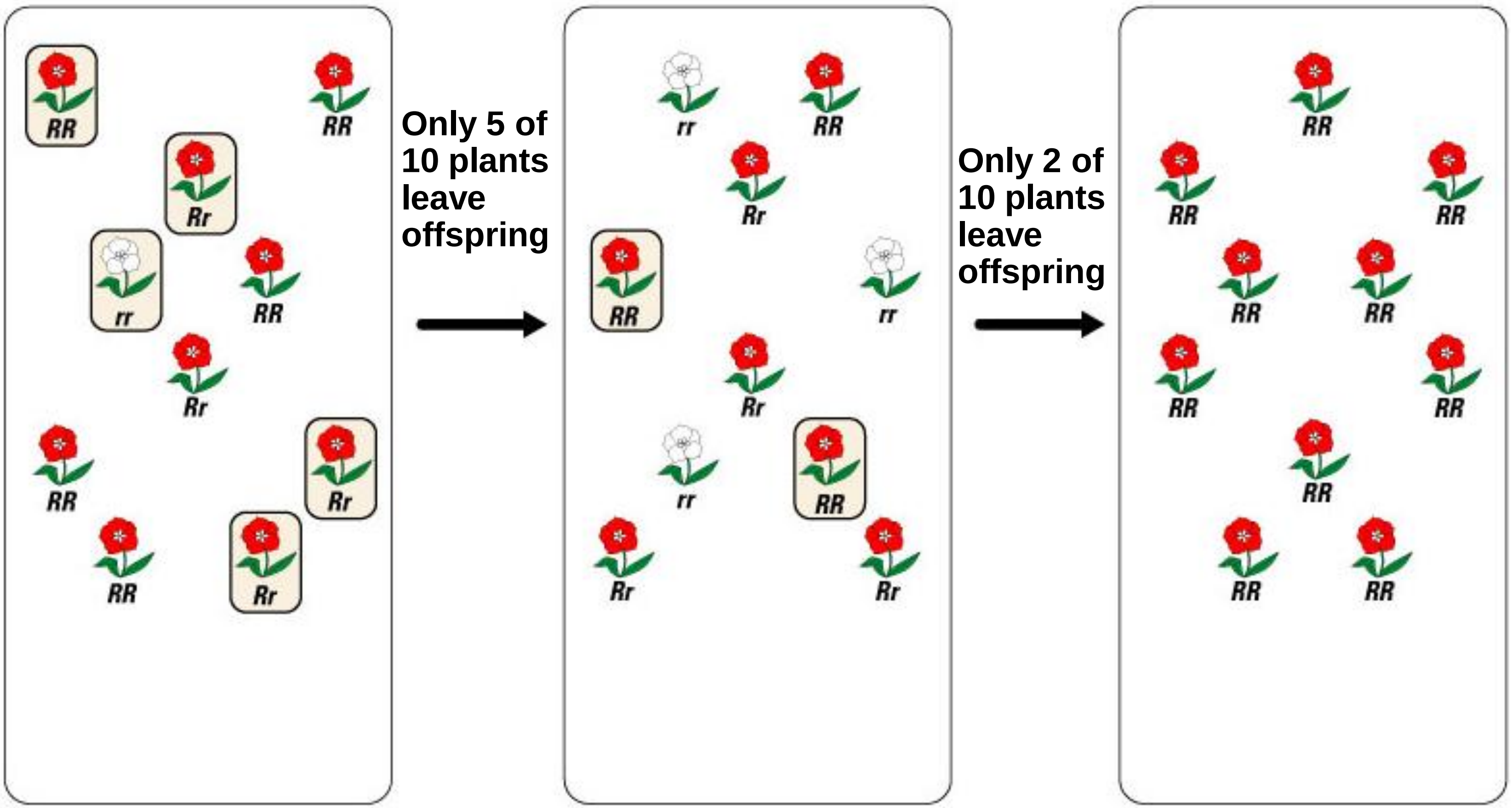
3. Pollen is an important contributor to Gene Flow

- Populations exchange alleles – hence **allelic frequencies change**
- can counteract natural selection by decreasing differences between populations




Microevolution – 4. Genetic Drift

4. Genetic Drift: change in allelic frequency due to CHANCE (i.e., random)



Generation 1
***p* (frequency of *R*) = 0.7**
***q* (frequency of *r*) = 0.3**

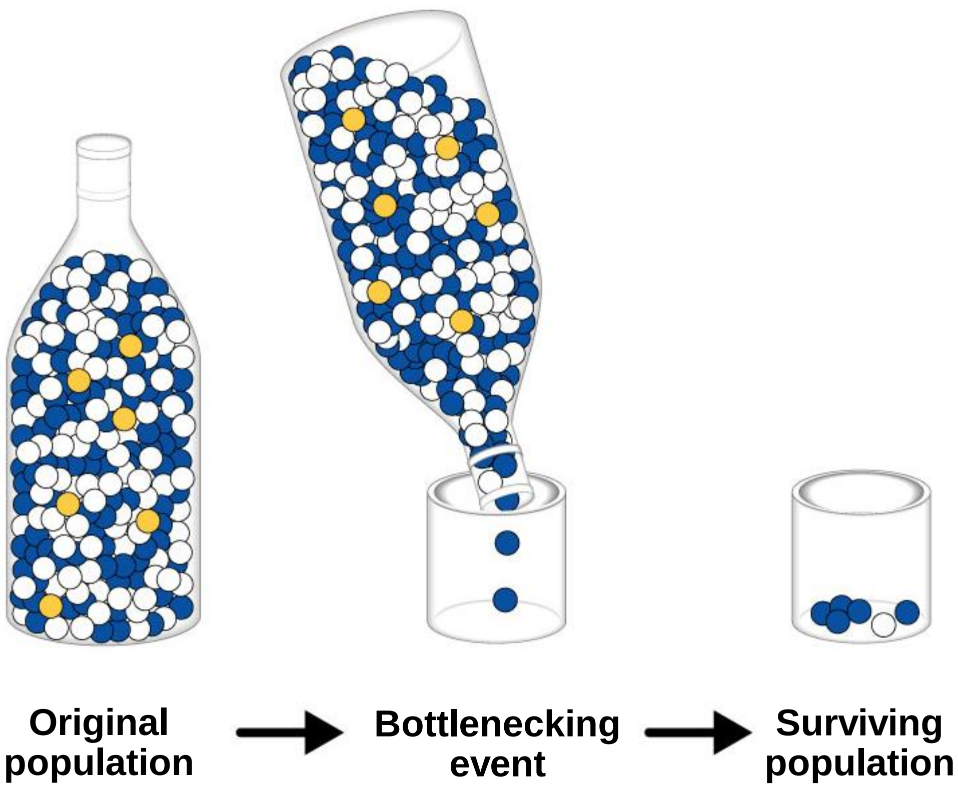
Generation 2
***p* = 0.5**
***q* = 0.5**

Generation 3
***p* = 1.0**
***q* = 0.0**

Microevolution

4. Genetic Drift:

a. Bottleneck effect



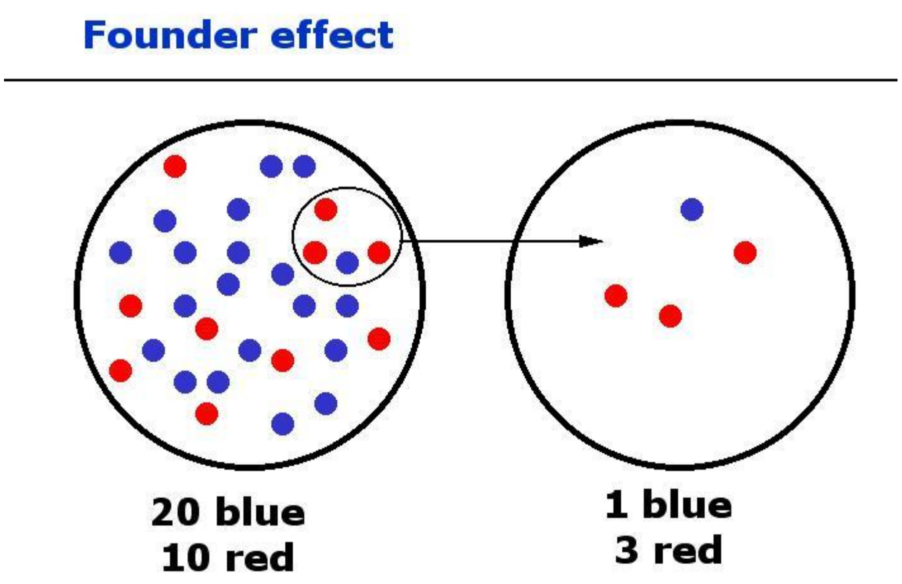
Wollemia nobilis (Wollemi Pine)

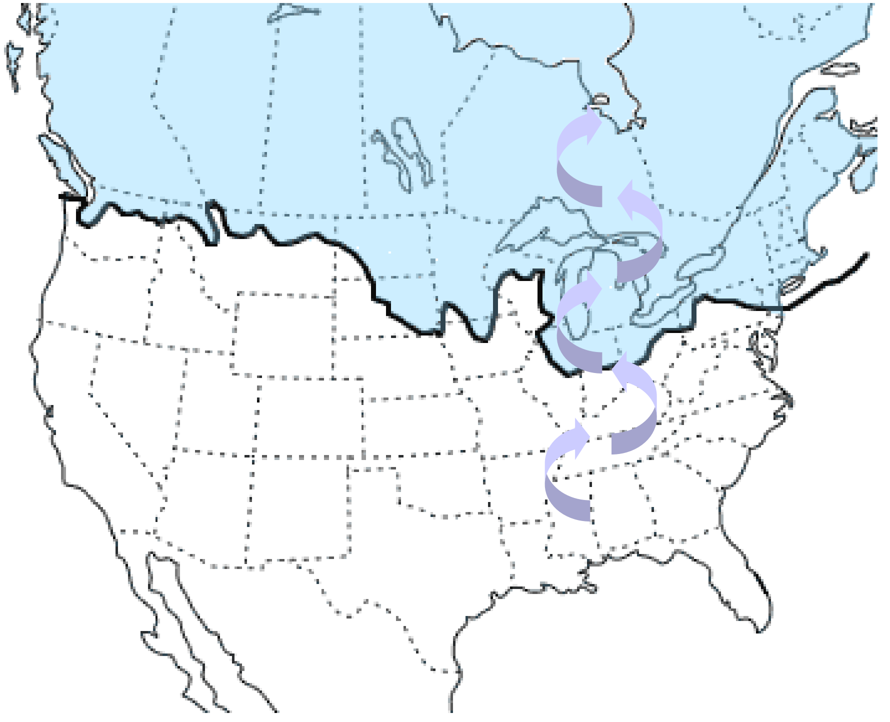
All known individuals are nearly genetically identical – population may have fallen to 1 or 2 plants

Microevolution

4. Genetic Drift:

b. **Founder effect** – new arrivals do not represent the genetic diversity from whence they came





Populations and species south of the glacial maximum are more genetically diverse than those north of the maximum

Microevolution – 5. Non-random mating

5. Non-random mating:

Self-pollination or selfing: the individual fertilizes itself

↓

Lead to inbreeding – frequency of homozygotes increases

Inbreeding: also common due to fact that plants do not move – individuals mate with neighbours

THE ORIGIN OF PLANT SPECIES

- *Species* is a Latin word meaning “kind” or “appearance”
- Morphological species concept – differentiation of species based on anatomical and morphological criteria (ie, appearance)

So, what is a species?

The **biological species concept:** a species is a group of interbreeding natural populations that are entirely **reproductively isolated** from other such groups

Sister species of Mimulus “monkey-flower”

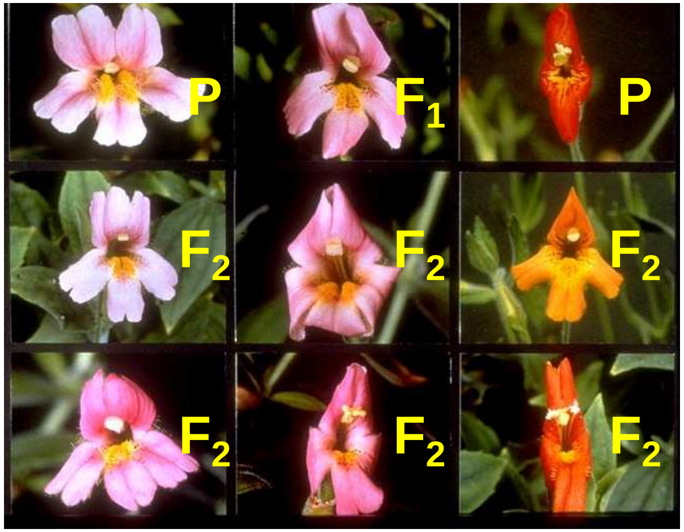
M. lewisii *M. cardinalis*

M. lewisii and *M. cardinalis* have overlapping habitat ranges but do not interbreed in nature

So, what is a species?

Biological species concept - implies that two individuals of different species cannot produce fertile young…

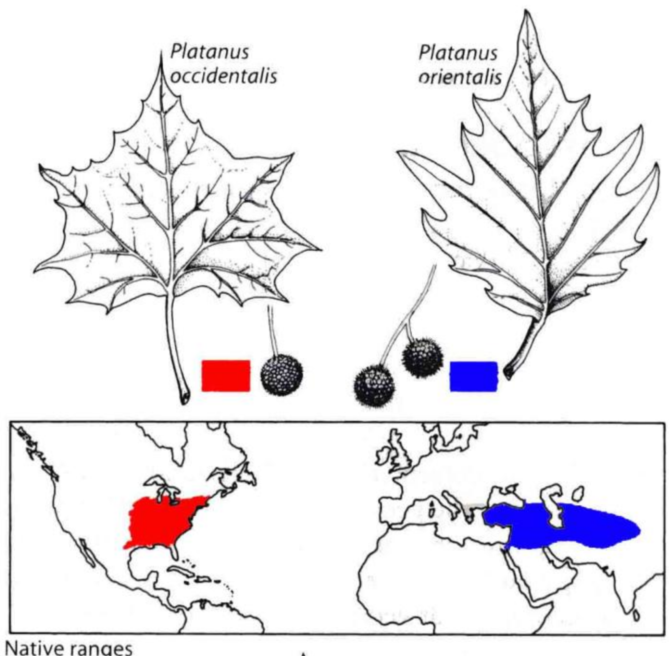
M. lewisii *M. cardinalis*



These sister species may be cross-fertilized in a lab and produce fertile offspring…so are these distinct species?

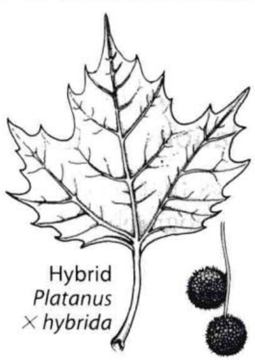
Plants Hybridize Widely!

Hybridization: the crossing of unlike parents (could be individuals within a species or even different species)



Populations of *P. orientalis* and *P. occidentalis* were isolated for 50MY

Hybridization in Europe produced fertile offspring



London Plane Sycamore

NYC Parks

So, what is a species?

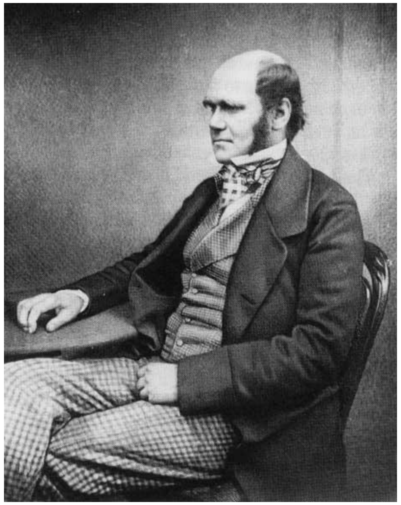
Phylogenetic species concept: a population whose members are descended from a common ancestor and who all possess a combination of certain defining, or derived, traits

- This implies genetic isolation but **does not** require a breeding test or **complete** genetic isolation to determine whether two things are species

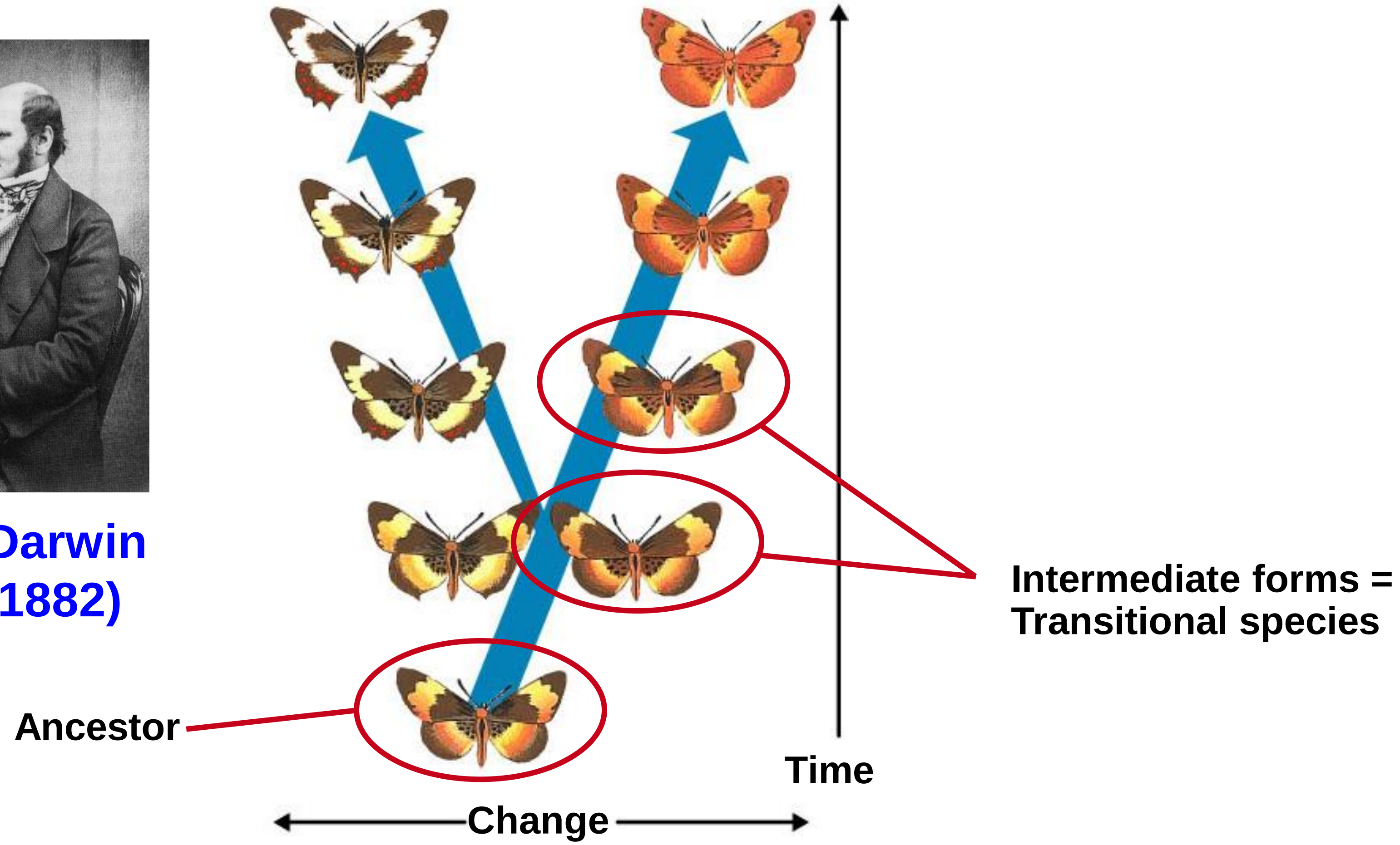
M. lewisii *M. cardinalis*

What Is the Tempo of Speciation?

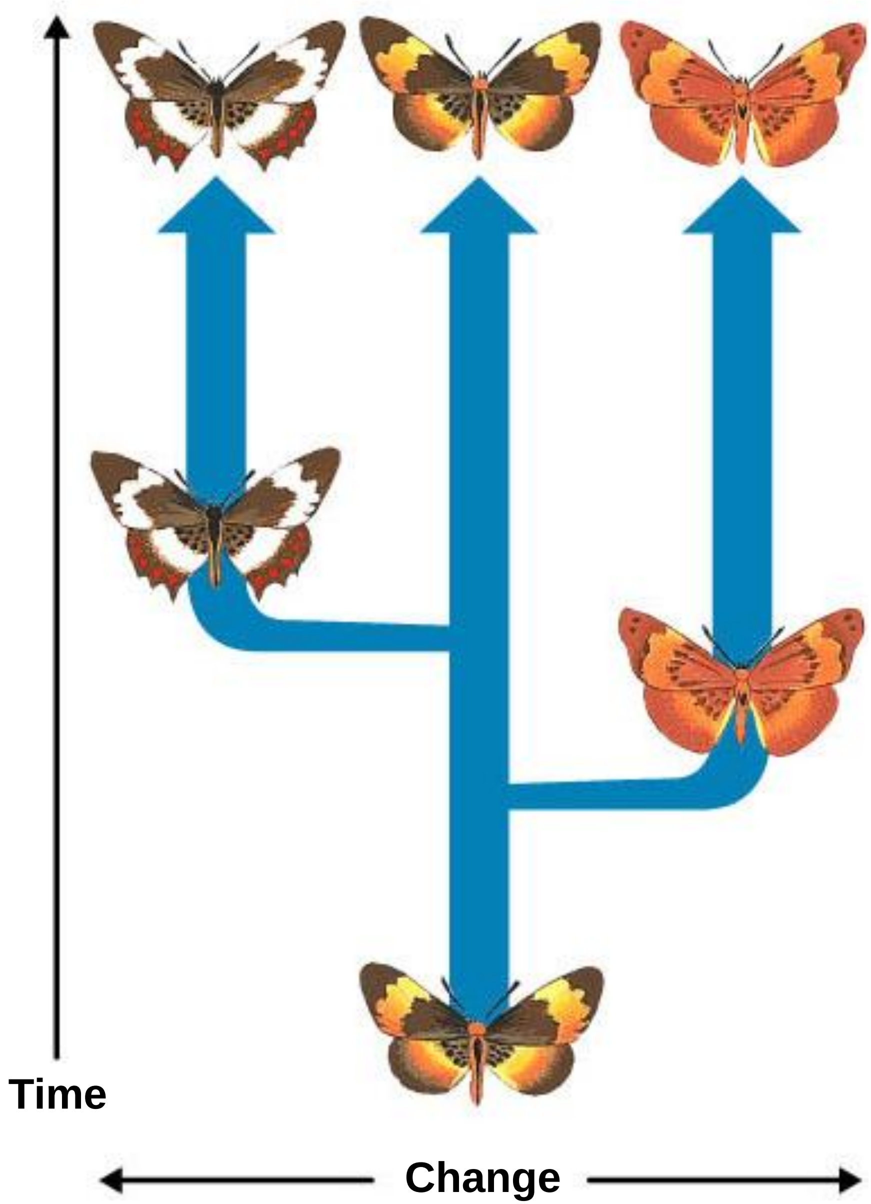
- The **gradualistic model** is an extrapolation of microevolution



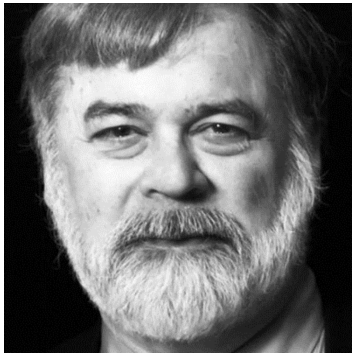
Charles Darwin
(1809 – 1882)



Punctuated equilibrium model



Stephen J. Gould
(1941 – 2002)



Niles Eldredge
(1943)

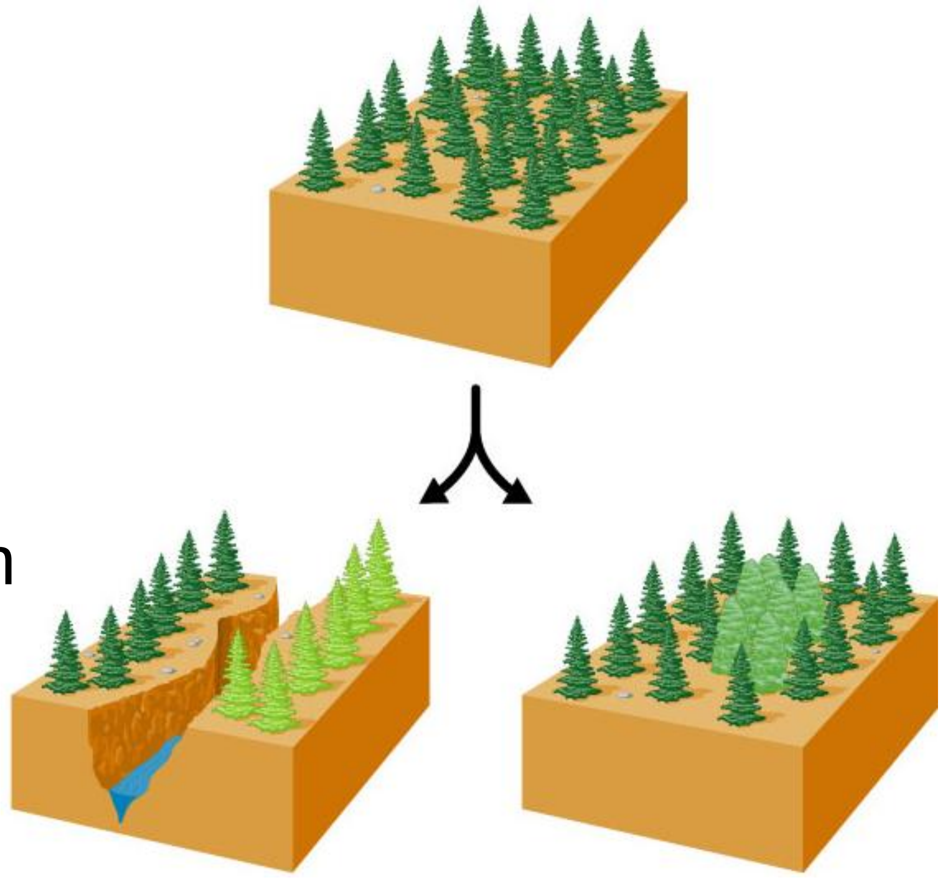
Mechanisms of Speciation

- For a species to evolve, there needs to be the creation of a **reproductive barrier** **(we need genetic isolation)**

- The two modes of speciation are

1. Allopatric speciation

2. Sympatric speciation



(a) Allopatric speciation **(b) Sympatric speciation**

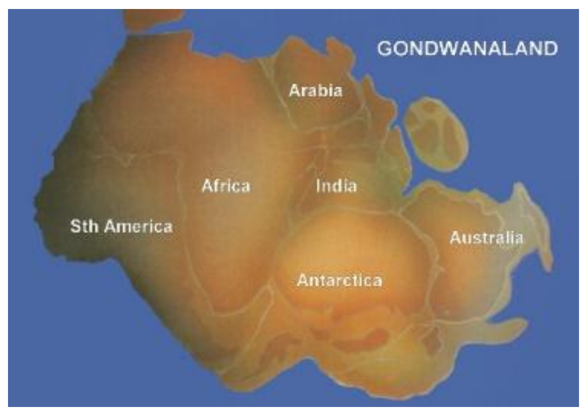
Speciation

1. Allopatric speciation: a population becomes **geographically separated**, then evolves through **natural selection** and/or **genetic drift**

– This is considered to be the most common method of speciation

Allopatric Speciation – Southern beeches

Nothofagus is native to the Southern Hemisphere in southern South America (Chile, Argentina) and Australasia



Nothofagus antarctica

Allopatric Speciation & Adaptive radiation

Creation of geographic barriers sets the stage for:

Adaptive radiation - Evolution of new species with a variety of ecological roles and adaptations, from a single ancestor

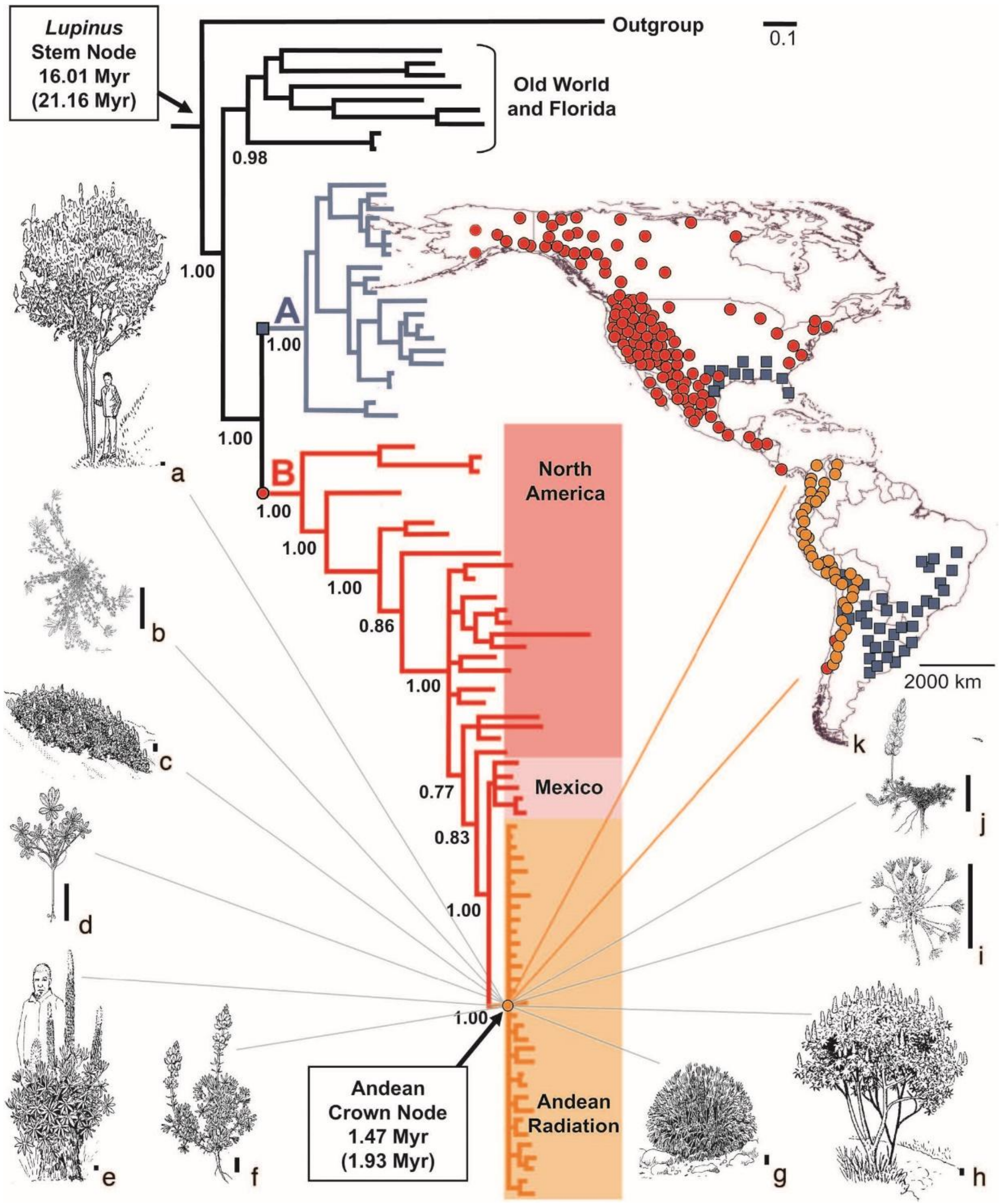
Islands are particularly important sites for adaptive radiation

Adaptive radiation in silverswords in Hawaii

Adapted to alpine habitat on volcanoes

Adapted to arid areas

- More than 28 species evolved from a single sunflower family ancestor in Hawaii
- Because of a lack of competition they adapted to widely different habitats on different islands



Adaptive Radiation

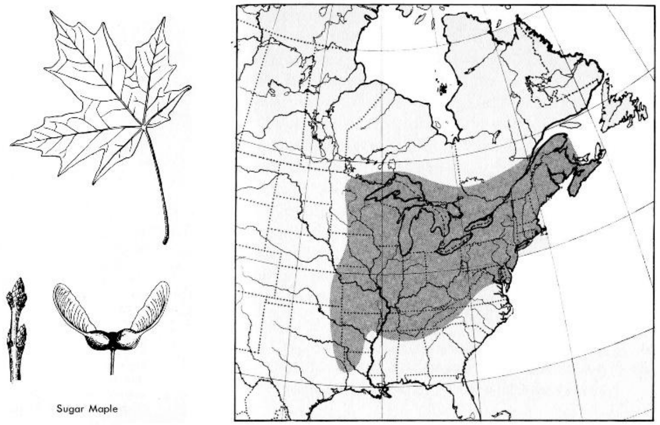
Island radiation on a continental scale: Exceptional rates of plant diversification after uplift of the Andes

Colin Hughes* and Ruth Eastwood

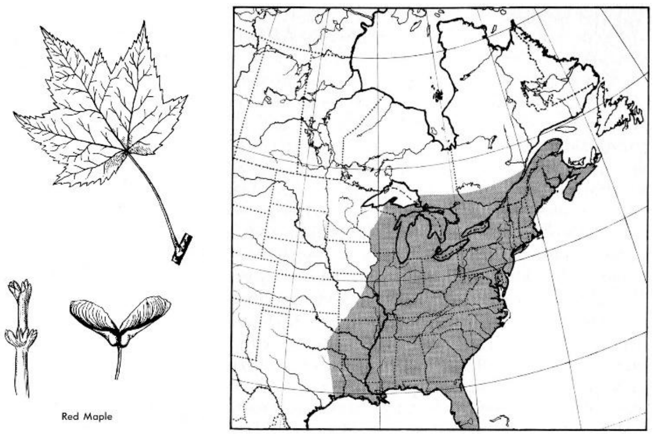
Proc Natl Acad Sci USA. 2006. 103(27): 10334–10339.

Examined patterns of species diversification in the high-altitude flora of the northern Andes…colonization of the emerging high Andes was comparable to colonization of a newly formed island or island archipelago

Allopatric Speciation – with genetic isolation

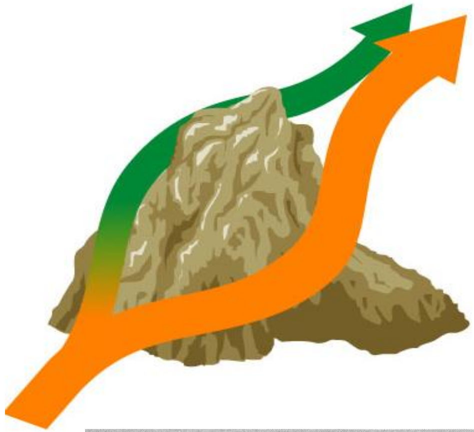


Acer saccharum
"sugar maple"

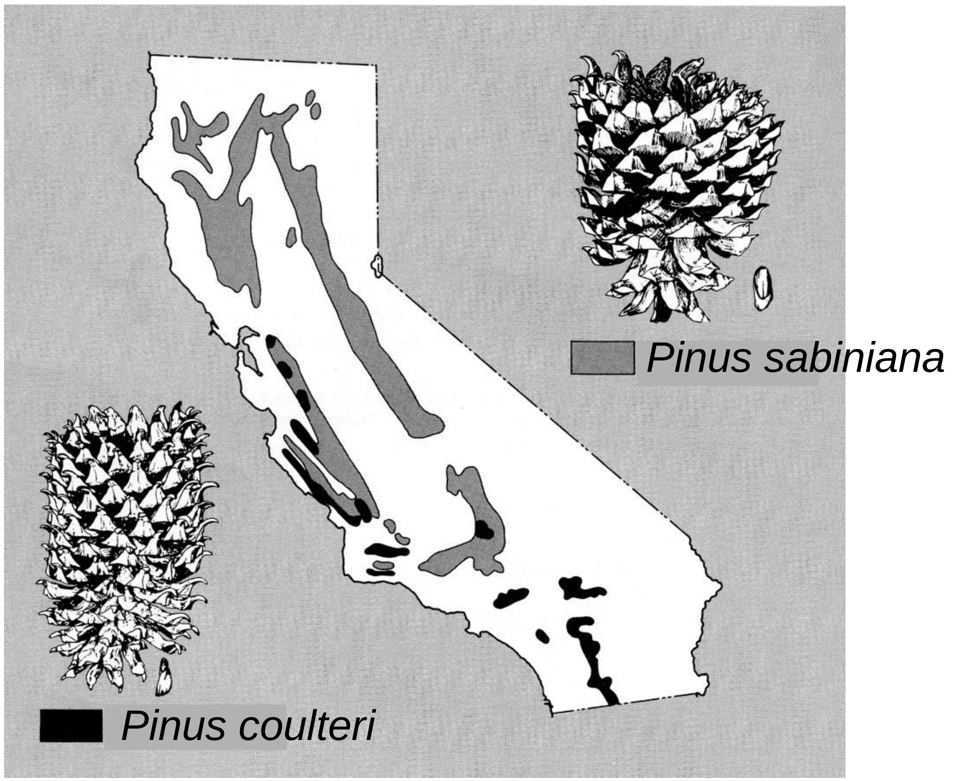


Acer rubrum
"Red maple"

Sympatric Distributions

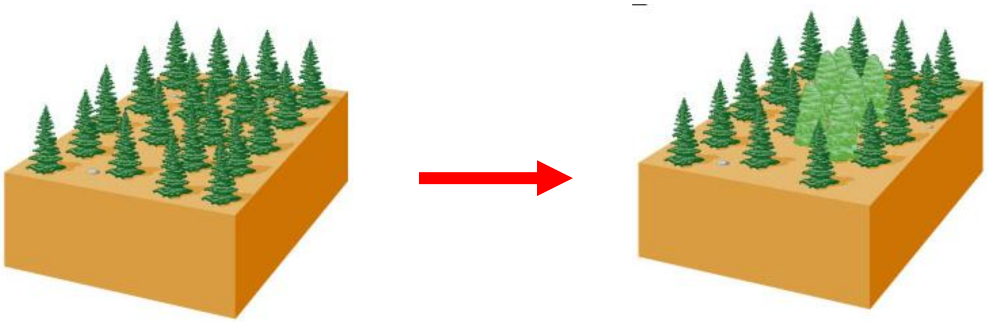


Populations become sympatric again but do not interbreed



2. Sympatric Speciation

Sympatric speciation occurs if a genetic change produces a reproductive barrier between **mutants** and the **parent population**



Especially prevalent in **plants**…less so in animals

The major process is…

Polyploidy

Polyploidy

Polyploidy = presence of three or more chromosome sets in an organism (i.e., greater than the diploid number, 2n)

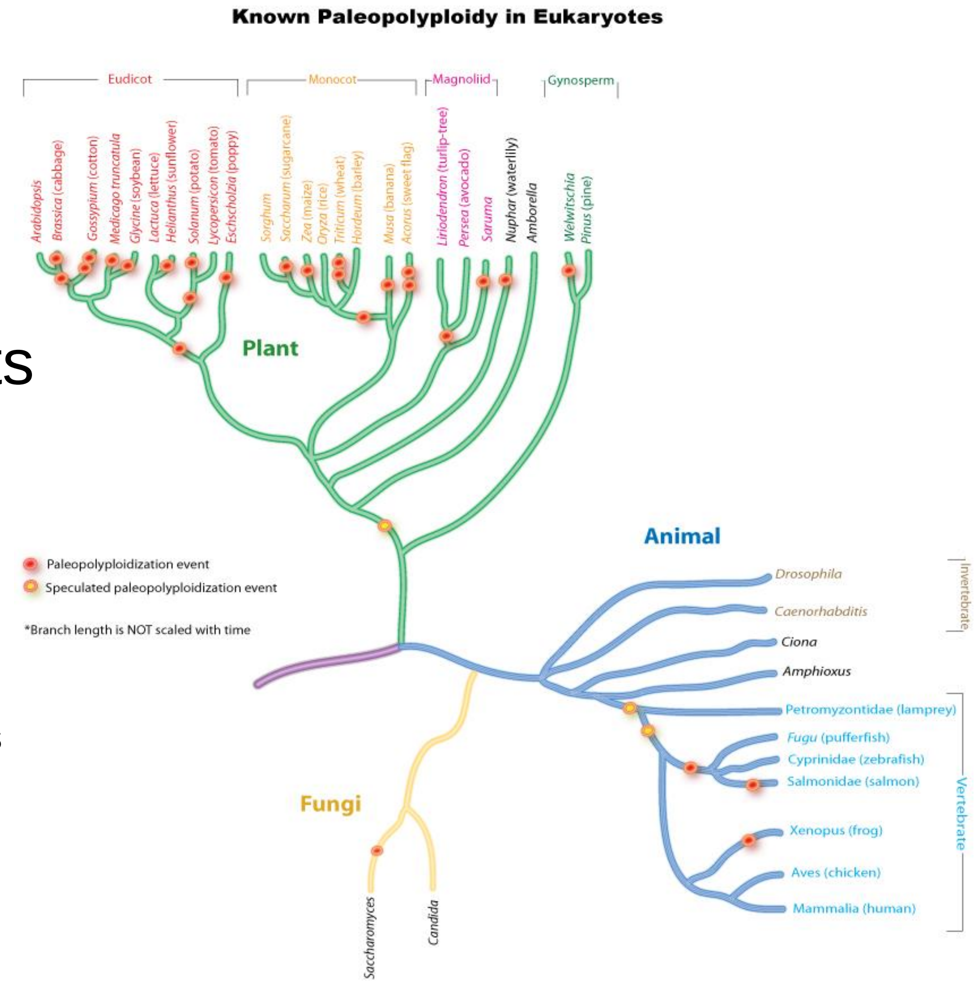
Very common in plants

Up to 80% of flowering plants

Some strawberries are decaploids

Seedless watermelons
Triploids

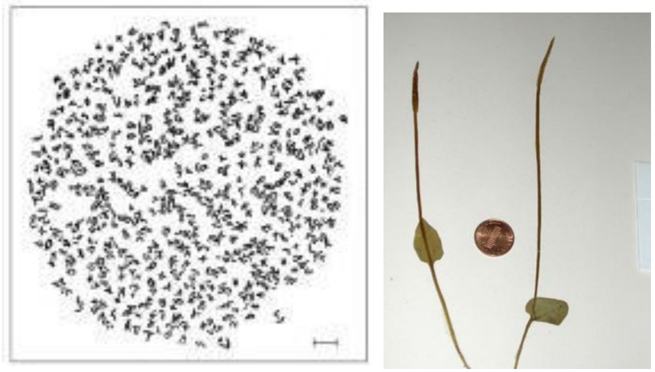
Kiwifruit
hexaploid



https://en.wikipedia.org/wiki/Polyploidy

Polyploidy

Polyploidy = presence of three or more chromosome sets in an organism (i.e., greater than the diploid number, 2n)



Ophioglossum reticulatum

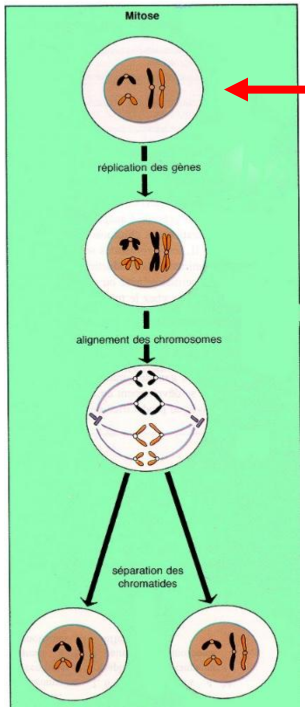
630 chromosome pairs or 2n = 1260 chromosomes per cell!

Haploid, diploid, polyploidy…what does it all mean again??

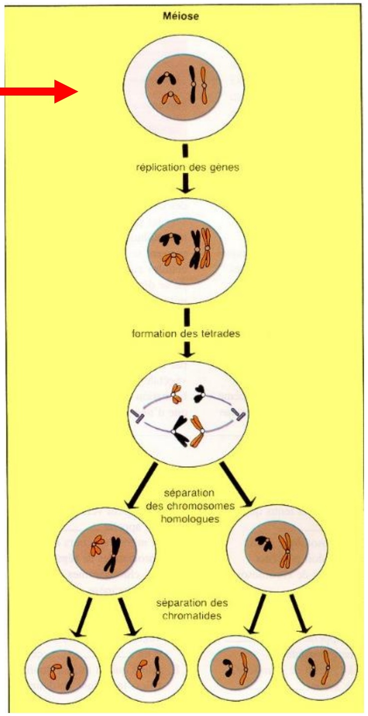
Growth & Repair

Reproduction

Mitosis



Meiosis



2n Cell

Divisions

2 cells identical to the mother cell

2n

Diploid

4 cells different from the mother cell

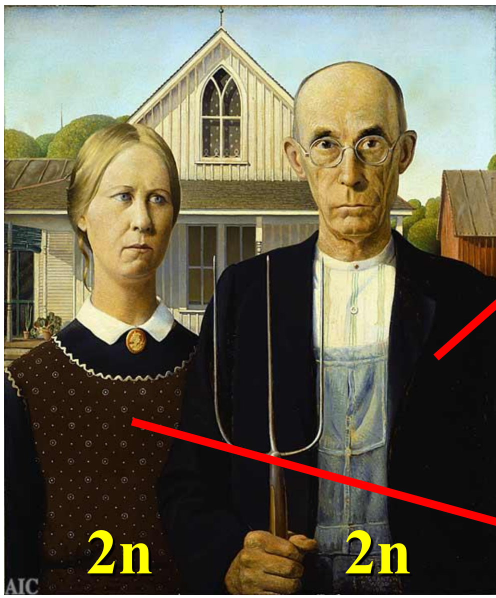
1n

Haploid

Diploid and Haploid

Sex cells
(gametes)

Mama + Papa

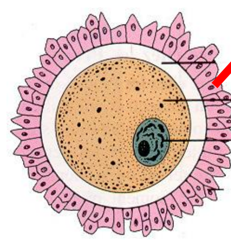


Diploid

2 genomes = 2n

1n

Sperm Cell



1n

ovule

Haploid

1 genome = 1n

= baby!

Diploid

2 genomes = 2n

Plant Evolution: Polyploidy

Polyploid types are termed according to the number of chromosome sets in the nucleus:

- triploid (three sets; 3x) → INFERTILE

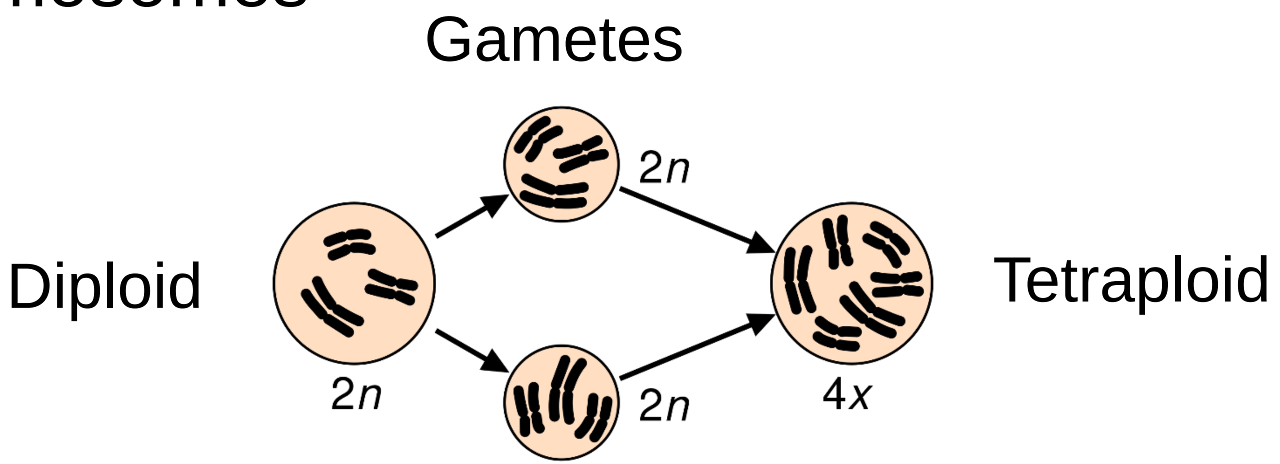
- tetraploid (four sets; 4x) → FERTILE

- pentaploid (five sets; 5x) → INFERTILE

- hexaploid (six sets; 6x) → FERTILE

2. Sympatric Speciation

Polyploidy = the possession of more than two sets of chromosomes

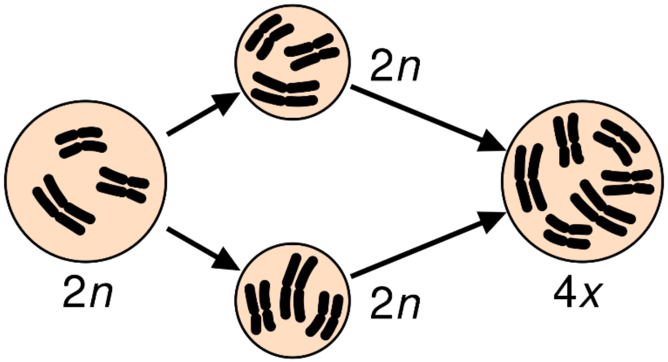


Speciation via (auto)polyploidy: A diploid cell undergoes failed meiosis, producing diploid gametes, which self-fertilize to produce a tetraploid zygote.

2. Sympatric Speciation

Polyploidy = the possession of more than two sets of chromosomes

"Instant Speciation"
genetic isolation
is immediate



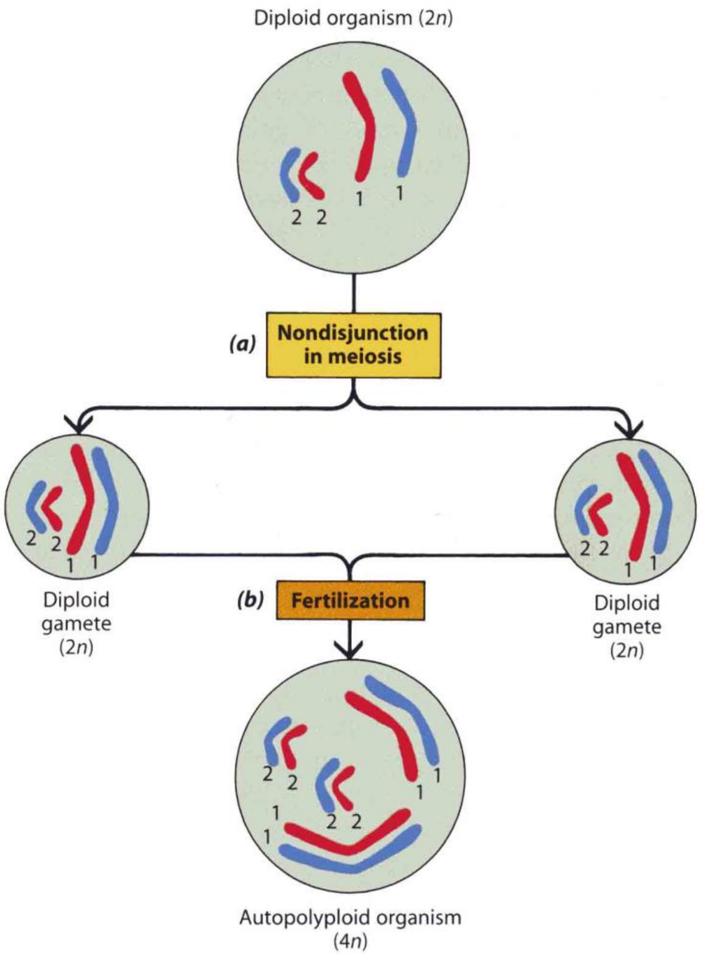
Two kinds:

1. **Autopolyploidy** = multiple sets of chromosomes from a single species

2. **Allopolyploidy** = multiple sets of chromosomes from different species (two or more)

   - More common

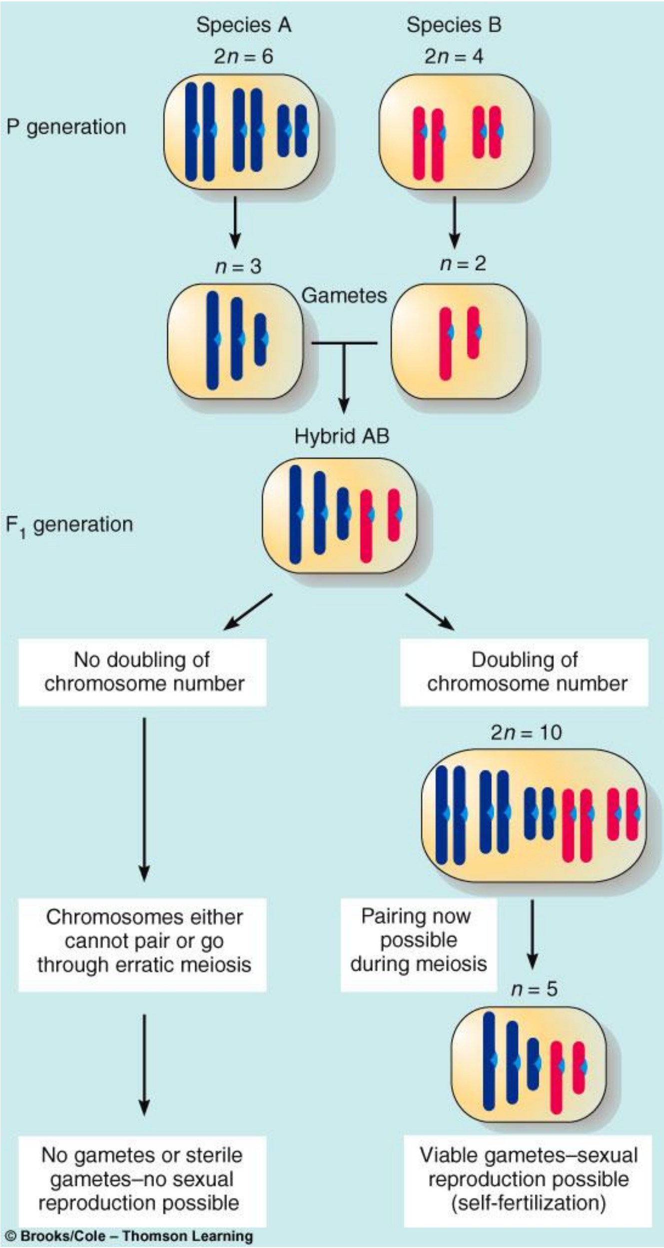
2. Sympatric Speciation - Autopolyploidy



Oenothera (Onagraceae)
"Evening Primroses"

Note that polyploids are often larger than their diploid ancestors → Cells have twice the DNA, twice the size

2. Sympatric Speciation - Allopolyploidy



"Instant Speciation" **genetic isolation** is immediate

Originate from a cross between 2 species to produce a (sterile) hybrid

↓

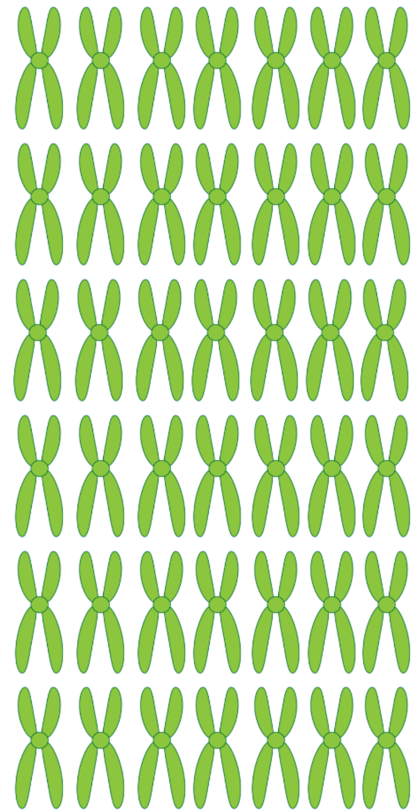
Autopolyploidy

↓

Allopolyploidy

Note: Allopolyploidy is an example of **Hybrid Speciation**

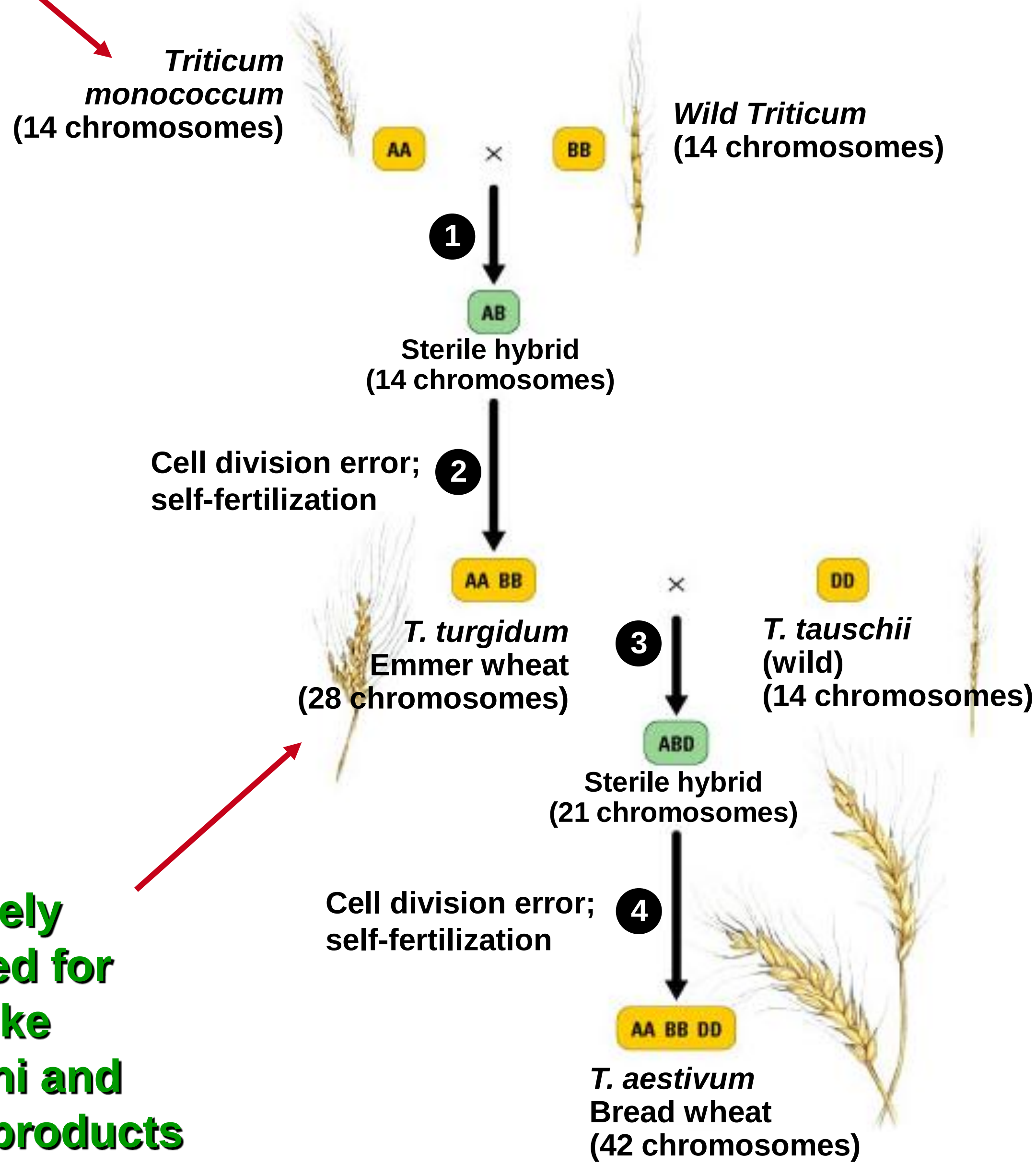
6. Some plants have very large genomes



6 x 7 chromosomes
14.5 Gb; 107,891 genes
~90% repetitive

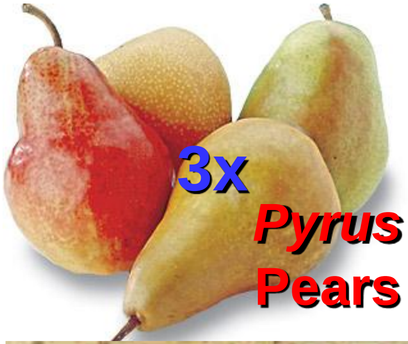
First domesticated Wheat

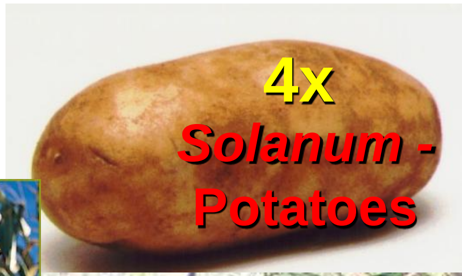
Many **domesticated plants** are the result of **sympatric speciation** (accompanied by artificial selection)



Still widely cultivated for things like macaroni and noodle products

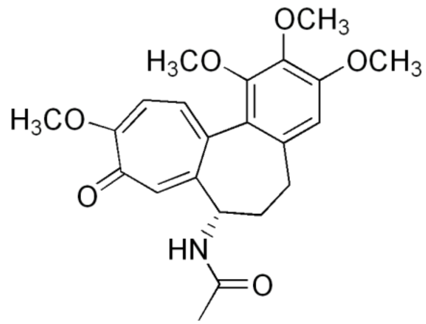
Polyploidy in Domesticated Plants





Polyploidy: the making of a "seedless" watermelon

First make a tetraploid watermelon…



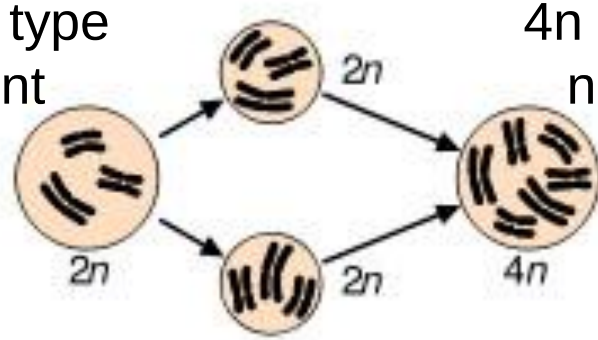
Colchicine

Inhibits chromosome segregation during meiosis

2n pollen

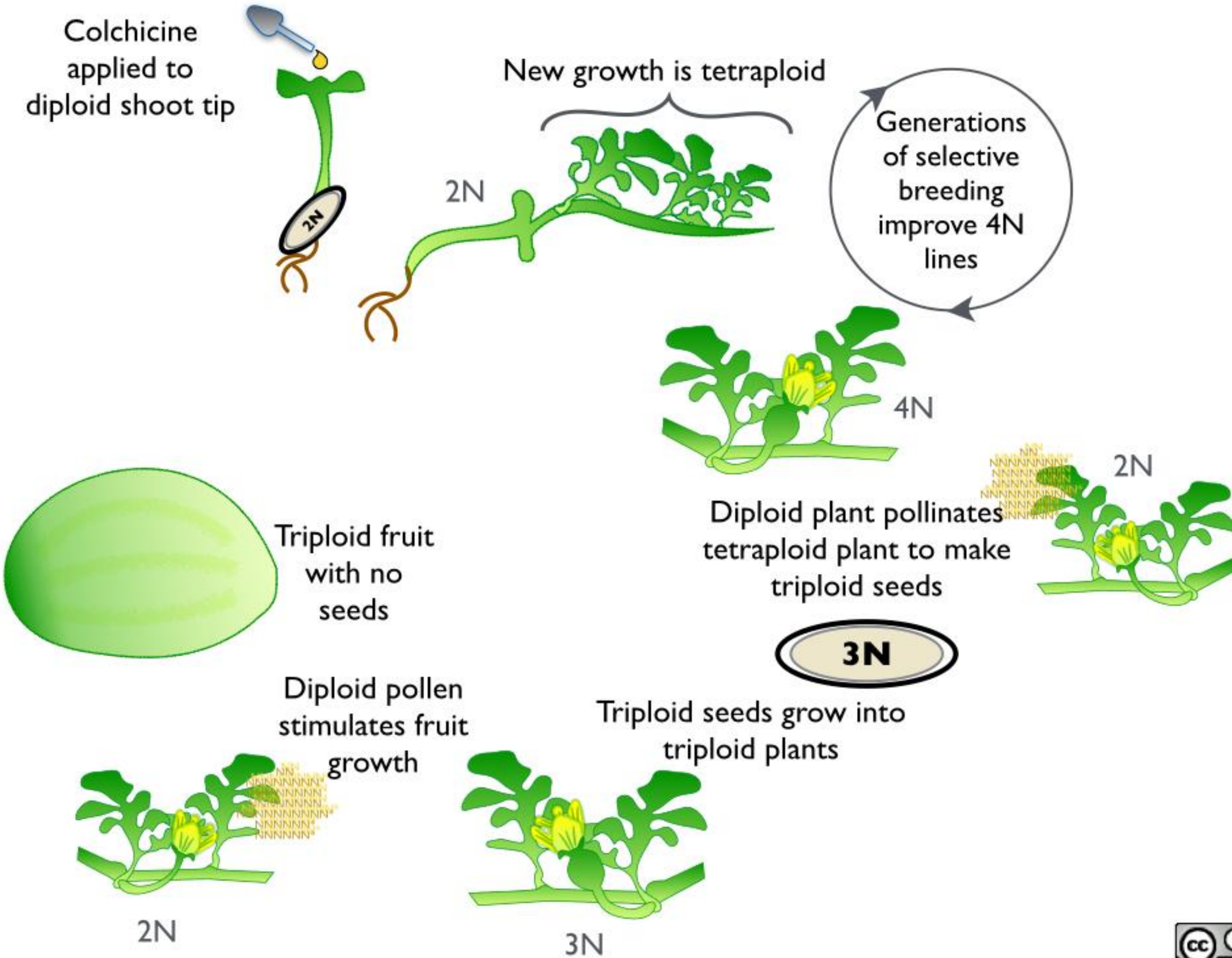
2n wild type parent

4n parent for next step



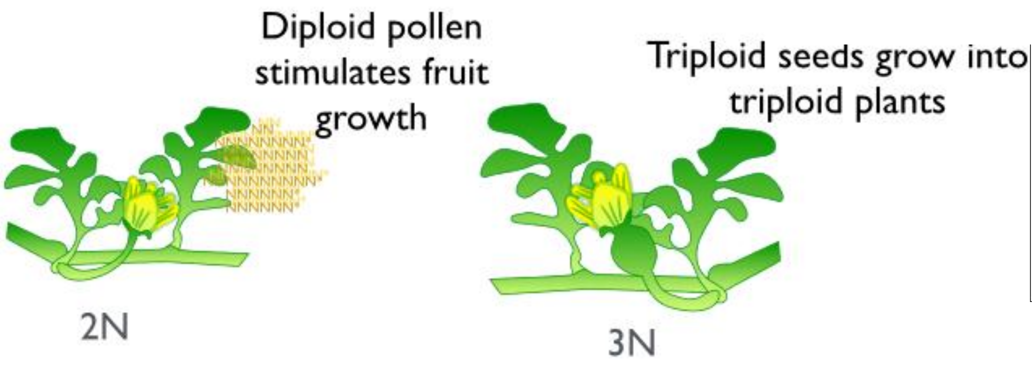
2n seed

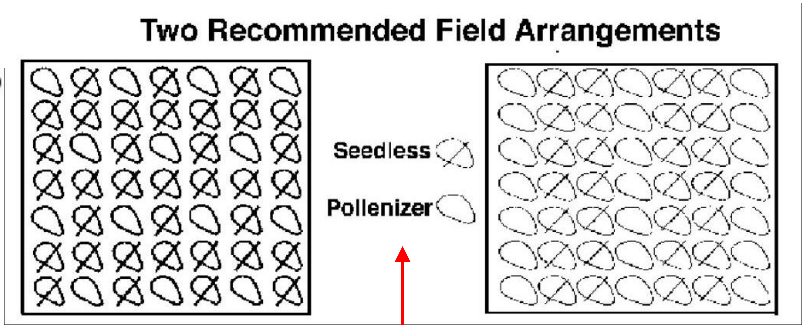
Polyploidy: the making of a "seedless" watermelon



Polyploidy: the making of a “seedless” watermelon

Pollen from diploids is needed to induce fruit formation





Seedless – 3N triploid;
Pollenizer – 2N diploid

Plant Triploid and Diploid seeds together and reap the benefits!

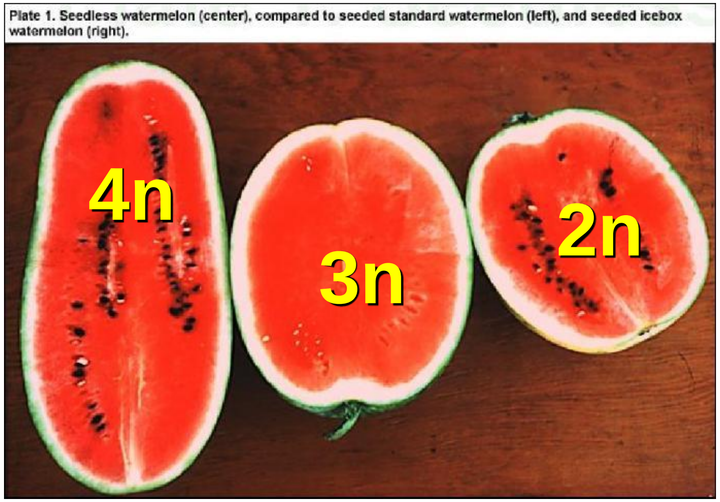


Plate 1. Seedless watermelon (center), compared to seeded standard watermelon (left), and seeded icebox watermelon (right).

Asexual Reproduction and Evolution

Many plants can reproduce both **sexually** and **asexually**

Asexual Reproduction

a plant can produce many identical plants quickly and efficiently

Garlic Bulbs

Redwoods

Creosote bushes

In each case genetically identical individuals are produced

Polyploidy: Why are bananas seedless?

- Lots of hard seeds and little, sweet "flesh"

Musa x paradisiaca (Musaceae),

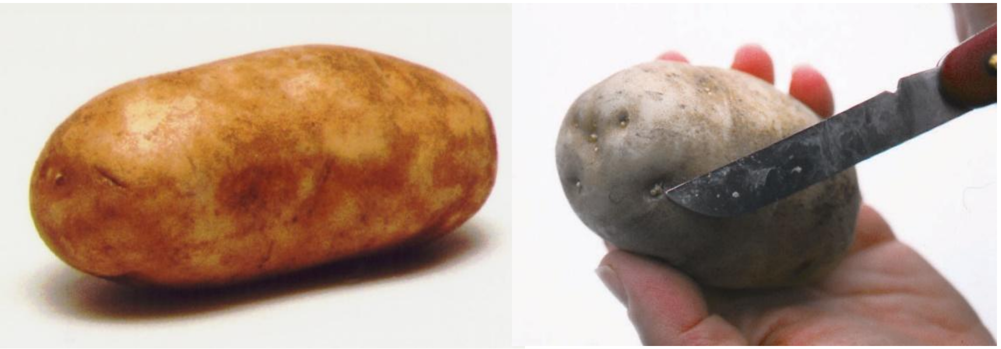
- **Why no seeds?**

Triploid (3n) = three sets of chromosomes

Commercial bananas reproduce entirely by vegetative reproduction – i.e., asexually

The Trouble with Clones!

- Potatoes: introduced in the 16th century, potatoes have been cultivated widely across Europe



Cloned potatoes

  - Potatoes can be cloned very easily, allowing extensive cultivation
  - Clones more susceptible to environmental changes due to their lack of genetic diversity

Ireland, 19th century…An Gorta Mór

In the 1840s, *Phytophthora infestans* (oomycete) infests Irish potatoes

Phytophthora infestans
"Potato Blight"

- The entire crop fails in 1845, 1846 and in 1848
- ca. 1,000,000 die
- ca. 1,000,000 leave Ireland

1847 at Grosse-Île :

- 5,000 die before arrival
- 5,424 die in quarantine
- and thousands of others in cities across Canada

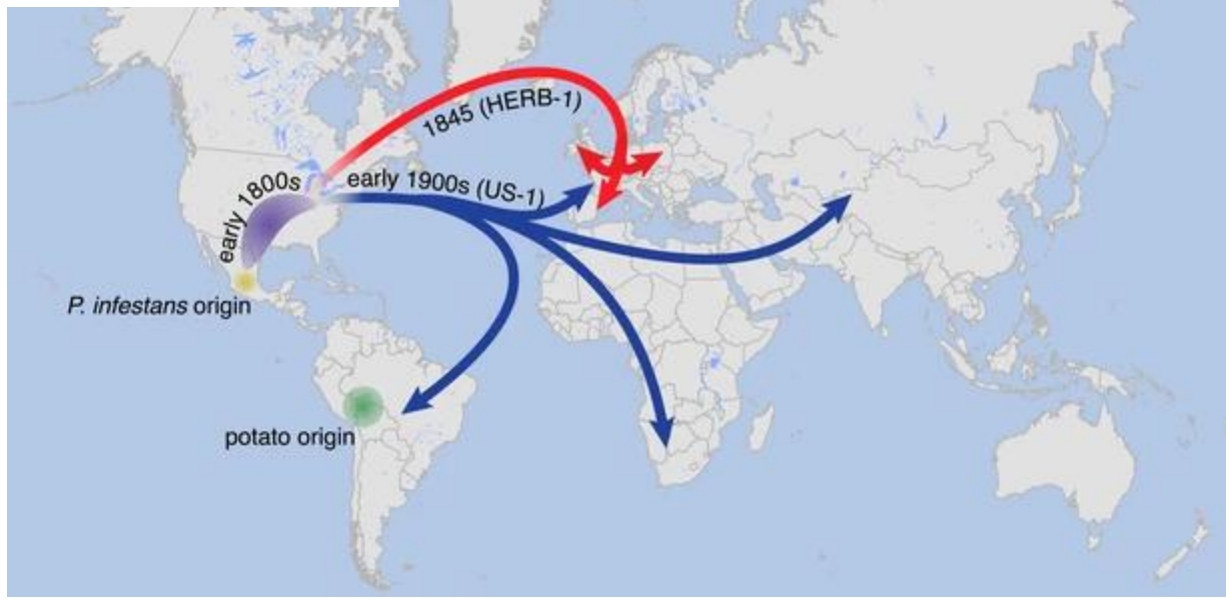
An Gorta Mór – The Great Hunger Revealed

eLIFE elife.elifesciences.org RESEARCH ARTICLE

The rise and fall of the *Phytophthora infestans* lineage that triggered the Irish potato famine

Kentaro Yoshida[1†], Verena J Schuenemann[2†], Liliana M Cano[1], Marina Pais[1], Bagdevi Mishra[3,4,5], Rahul Sharma[3,4,5], Chirsta Lanz[6], Frank N Martin[7], Sophien Kamoun[1‡], Johannes Krause[2‡], Marco Thines[3,4,5,8‡], Detlef Weigel[9‡], Hernán A Burbano[9*]

A potato specimen from Kew Gardens collected in 1847



The historical strains were extracted from the leaves of potato and tomato plants that were collected in North America and Europe, including Ireland and Great Britain, from 1845 onwards and stored in herbaria for future research.

We conclude that the 19th century epidemic was caused by a unique genotype, HERB-1, that persisted for over 50 years.