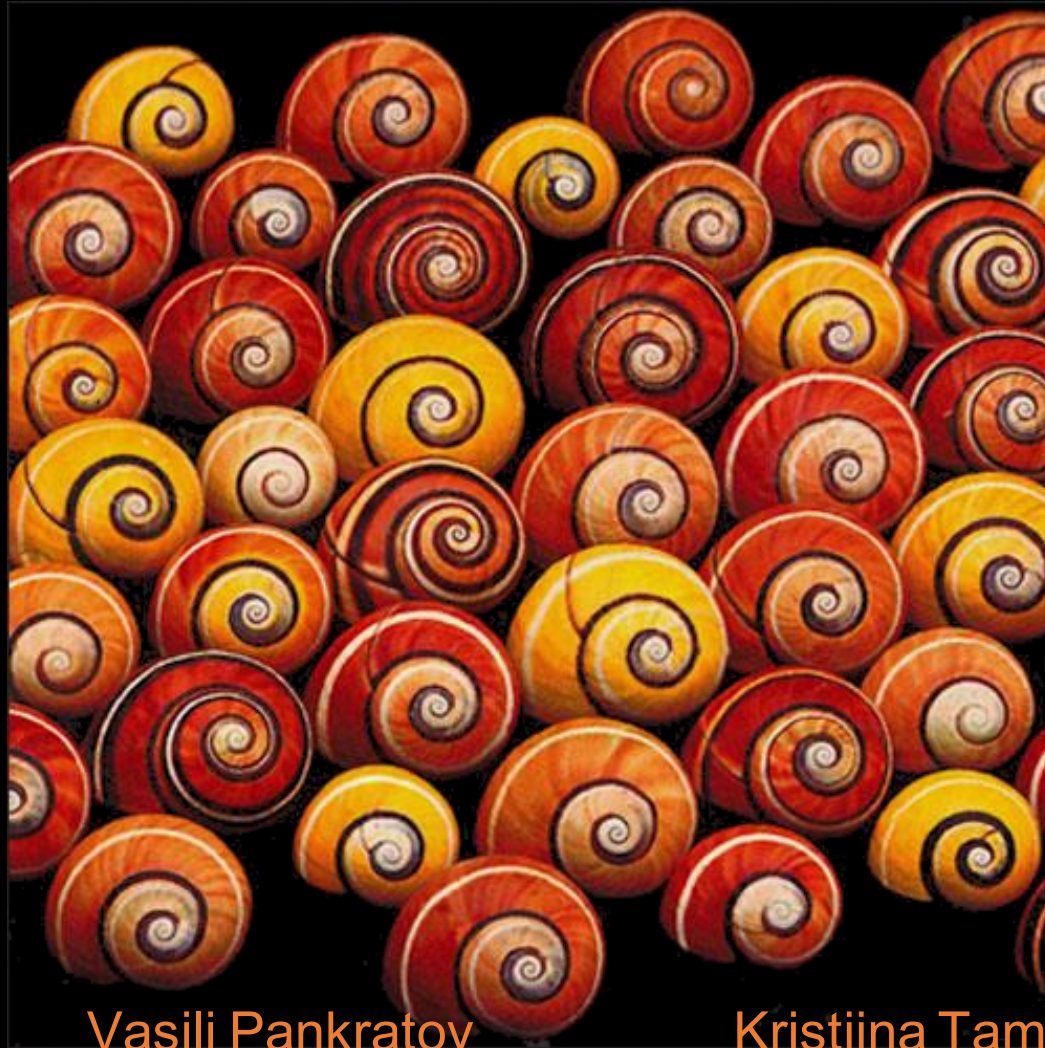


Evolution and the Natural World 2021



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Kristiina Tambets

Tina Saupe

Stefania Sasso

Mathilde Andre

Evolution and the Natural World 2021

Evolutionary biology; overview and history

The history and organisation of life

Many topics!

Species concept, speciation and classification

Evolutionary processes (follow-up course 2022):

Random drift, selection (natural and sexual)

Population genetics

Quantitative genetics

Evolution of sexual reproduction

Phylogenetic reconstruction

Genome evolution

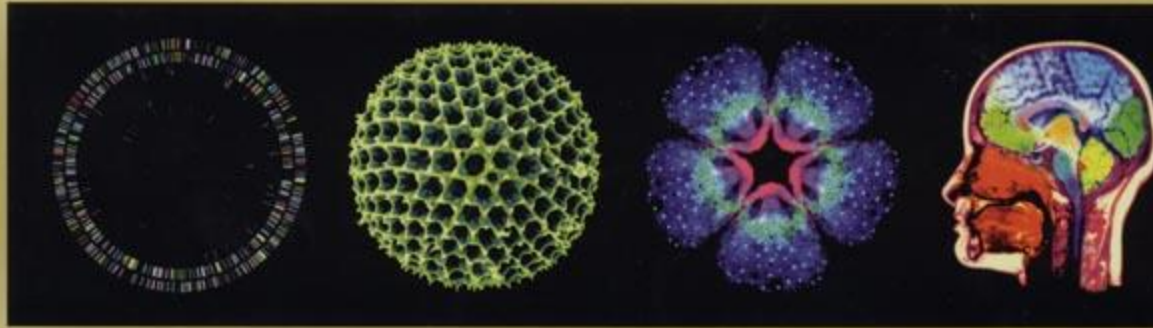
- General plan: each week consists of two lectures and one seminar/discussion/practical. These tasks will mostly be group tasks.
- Final mark is a composite of an exam and active participation in the seminar/discussion/practical

Week	Date	week day	time	Lecture/seminar	venue	Lecturer	Topic(s)
3	15.09.2021	Wed	12.15	Lecture 1	Nooruse 1 - 121	Mait	Course introduction & overview; organisational questions; Evidence for evolution; objections to evolutionary theory; evolutionary theory and the society
	16.09.2021	Thu	12.15	Lecture 2	Nooruse 1 - 121	Vasili	Revision: Genetics
4	21.09.2021	Tue	10.15	Lecture 3	Ravila 14A - 2075	Vasili	Revision: Biochemistry and Molecular Biology
	22.09.2021	Wed	12.15	Lecture 4	Nooruse 1 - 121	Vasili	Revision: Basics of Evolution and PopGen
	23.09.2021	Thu	12.15	Seminar 1	Nooruse 1 - 121	Mait	Student discussion "Perception of evolution in my country"
5	28.10.2021	Tue	10.15	Lecture 5	Ravila 14A - 2075	Mait	History of evolutionary biology: PreDarwin; Darwin; Synthesis
	29.09.2021	Wed	12.15	Lecture 6	Nooruse 1 - 121	Mait	History of evolutionary biology: Synthesis; Neutral theory
	30.09.2021	Thu	12.15	Lecture 7	Nooruse 1 - 121	Mait	Species concept, speciation and classification
6	5.10.2021	Tue	10.15	Lecture 8	Ravila 14A - 2075	Vasili	Biodiversity and the Tree of Life, evolutionary taxonomy and phylogenetics
	6.10.2021	Wed	12.15	Lecture 9	Nooruse 1 - 121	Vasili	Bacteria and Archea (in less details than before but with emphasize on their phylogeny and evolution)
	7.10.2021	Thu	12.15	Lecture 10	Nooruse 1 - 121	Vasili	Origin of Eukaryotes (key differences from Prokaryotes, endosymbiosis)
7	12.10.2021	Tue	10.15	Lecture 11	Ravila 14A - 2075	Vasili	Evolution of Eukaryotes (multicellularity, diversification)
	13.10.2021	Wed	12.15	Lecture 12	Nooruse 1 - 121	Vasili	Anterior-posterior patterning; Hox genes; universality of developmental systems
	14.10.2021	Thu	12.15	Lecture 13	Nooruse 1 - 121	Vasili	Origin of life; LUCA and the tree of life
8	19.10.2021	Tue	10.15	Seminar 3	Ravila 14A - 2075	Vasili	Major events in the Evolution of life on Earth
	20.10.2021	Wed	12.15	Lecture 14	Nooruse 1 - 121	Vasili	Quiz (socrative.com) on the course so far; putting together groups and selecting topics for the presentations on evolution
	21.10.2021	Thu	12.15	Lecture 15	Nooruse 1 - 121	Vasili	Going through the quiz questions and recaping everything covered so far
9	26.10.2021	Tue	10.15	Lecture 16	Ravila 14A - 2075	Kristiina	Evolution of primates and hominins
	27.10.2021	Wed	12.15	Lecture 17	Nooruse 1 - 121	Kristiina	Biogeography
	28.10.2021	Thu	12.15	Lecture 18	Nooruse 1 - 121	Vasili	Genetic (genomic) studies of human evolution / population genetics; admixture with Neanderthals & Denisova; Evolution of human traits; genetic basis of disease; more population genetics stuff?
10	2.11.2021	Tue	10.15	Seminar 4	Ravila 14A - 2075	Stefania, Mathilde	Group presentations on evolution I: prokaryotes, protists, fungi and plants (group has chosen an example to present based on at least 1 scientific paper & information from elsewhere)
	3.11.2021	Wed	12.15	Seminar 5	Nooruse 1 - 121	Stefania, Mathilde	Group presentations on evolution II: animals, incl hominins, but not humans (group has chosen an example to present based on at least 1 scientific paper & information from elsewhere)
	4.11.2021	Thu	12.15	Seminar 6	Nooruse 1 - 121	everyone	Course summary, revision for exam, student feedback

	Lecturer	Topic(s)
	Mait	Course introduction & overview; organisational questions; Evidence for evolution; objections to the society
	Vasili	Revision: Genetics
	Vasili	Revision: Biochemistry and Molecular Biology
	Vasili	Revision: Basics of Evolution and PopGen
	Mait	Student discussion "Perception of evolution in my country"
	Mait	History of evolutionary biology: PreDarwin; Darwin; Synthesis
	Mait	History of evolutionary biology: Synthesis; Neutral theory
	Mait	Species concept, speciation and classification
	Vasili	Biodiversity and the Tree of Life, evolutionary taxonomy and phylogenetics
	Vasili	Bacteria and Archea (in less details than before but with emphasize on their phylogeny and e
	Vasili	Origin of Eukaryotes (key differences from Prokaryotes, endosymbiosis)
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	Vasili	Anterior-posterior patterning; Hox genes; universality of developmental systems
	Vasili	Origin of life; LUCA and the tree of life
	Vasili	Major events in the Evolution of life on Earth
	Vasili	Quiz (socrative.com) on the course so far; putting together groups and selecting topics for the
	Vasili	Going through the quiz questions and recaping everything covered so far
	Kristiina	Evolution of primates and hominins
	Kristiina	Biogeography

75	Vasili	Origin of eukaryotes (key differences from prokaryotes; endosymbiosis)
L	Vasili	Anterior-posterior patterning; Hox genes; universality of developmental systems
L	Vasili	Origin of life; LUCA and the tree of life
75	Vasili	Major events in the Evolution of life on Earth
L	Vasili	Quiz (socrative.com) on the course so far; putting together groups and selecting topics for t
L	Vasili	Going through the quiz questions and recapping everything covered so far
75	Kristiina	Evolution of primates and hominins
L	Kristiina	Biogeography
		Genetic (genomic) studies of human evolution / population genetics; admixture with Neand
L	Vasili	genetic basis of disease; more population genetics stuff?
75	Stefania, Mathilde	Group presentations on evolution I: prokaryotes, protists, fungi and plants (group has chose
	Stefania, Mathilde	scientific paper & information from elsewhere)
L	Stefania, Mathilde	Group presentations on evolution II: animals, incl hominins, but not humans (group has cho
	Stefania, Mathilde	scientific paper & information from elsewhere)
L	everyone	Course summary, revision for exam, student feedback

EVOLUTION



Nicholas H. Barton
Derek E.G. Briggs
Jonathan A. Eisen
David B. Goldstein
Nipam H. Patel



Cold Spring Harbor
Laboratory Press

<http://www.evolution-textbook.org/>

"Nothing in Biology Makes Sense
Except in the Light of Evolution",



Theodosius Dobzhansky
(1900-1975)

Evolutionary biology is a meta-science for all life-sciences

- molecular biology
- (population)genetics
- morphology, systematics
- developmental biology
- cell biology
- palaeontology
- ...



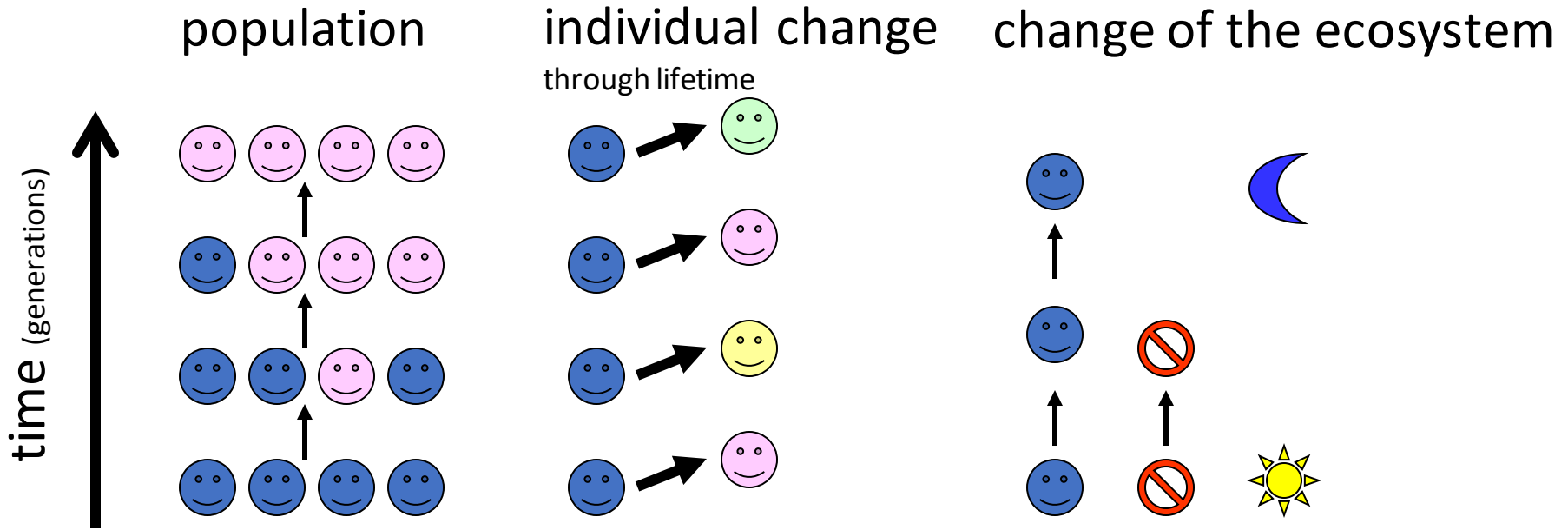
DNA, morphology, behaviour..



... studies the **change** in the heritable characters of populations through successive generations

These **changes** can be due to random (genetic drift, mutation) or non-random (selection) evolutionary forces/processes

Not all change is evolutionary

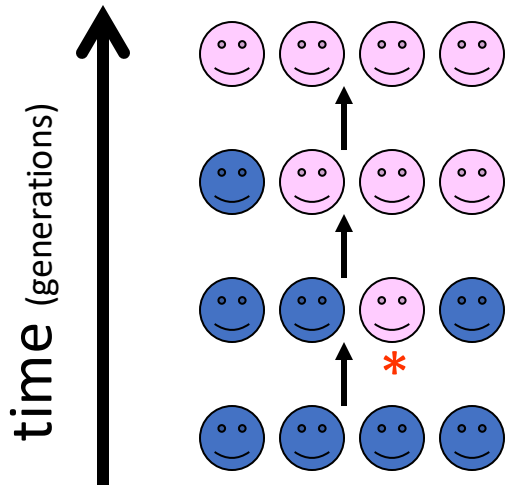


mutation →
selection →
change in frequency

acquired traits are
(largely) not
heritable

A change in the
environment can
trigger local
change in species
composition

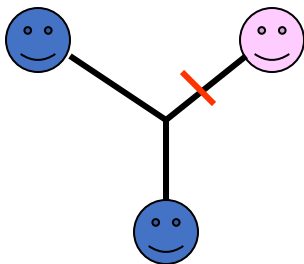
Change and divergence



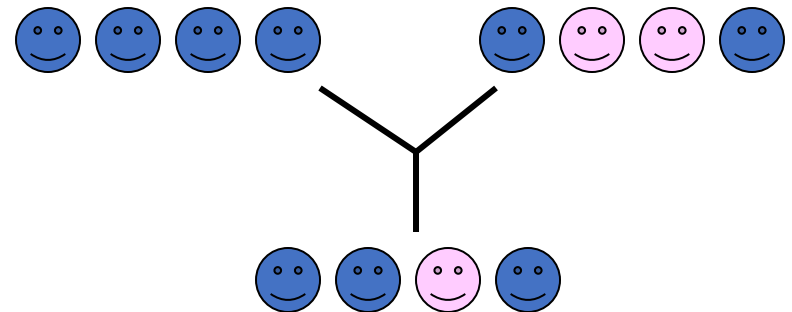
Evolutionary change:

- mutation *
- change in frequency

Mutational divergence

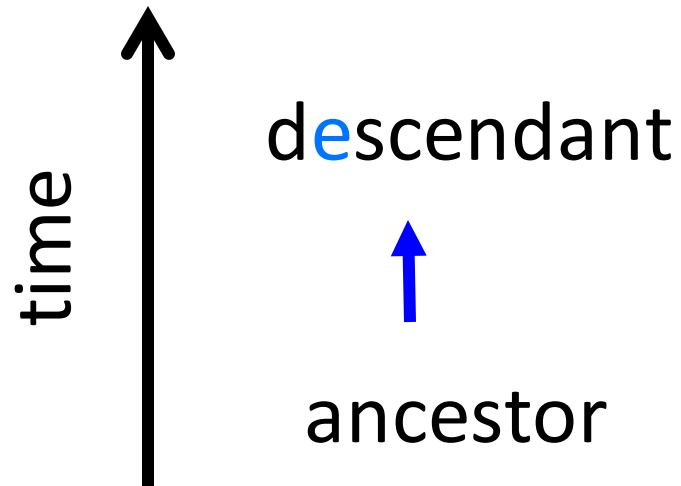


Divergence and change



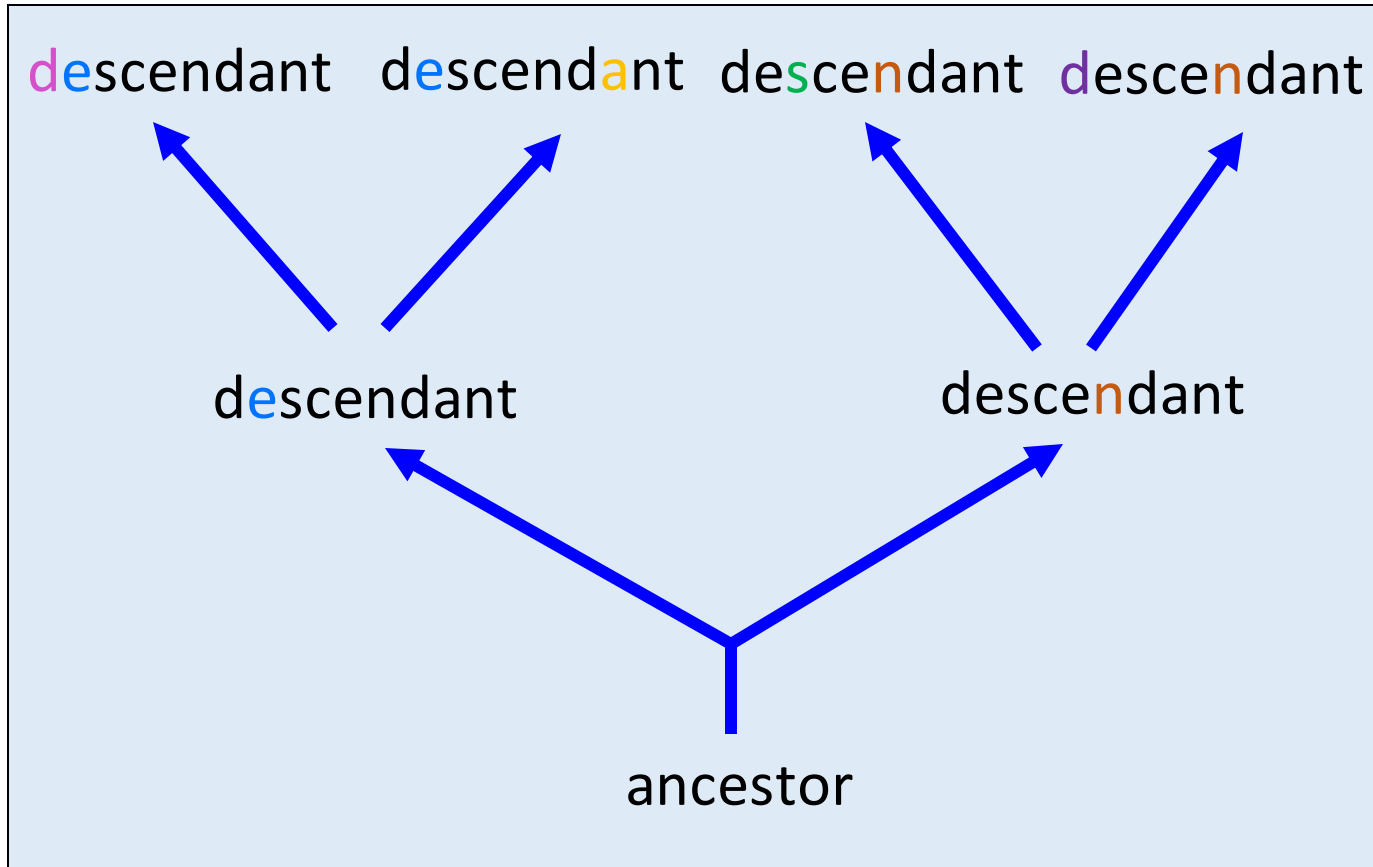
Evolution is:

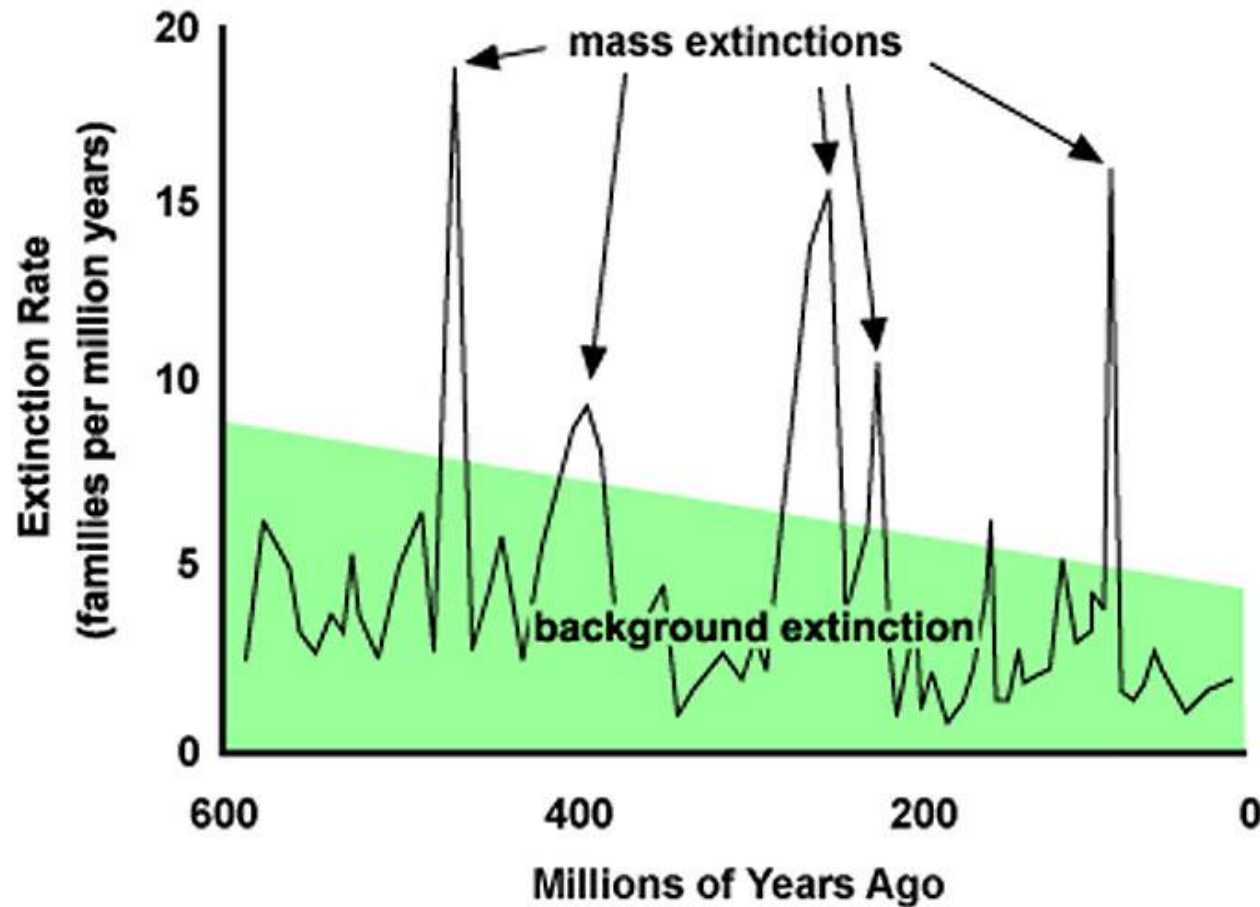
1. Descent with **modification**



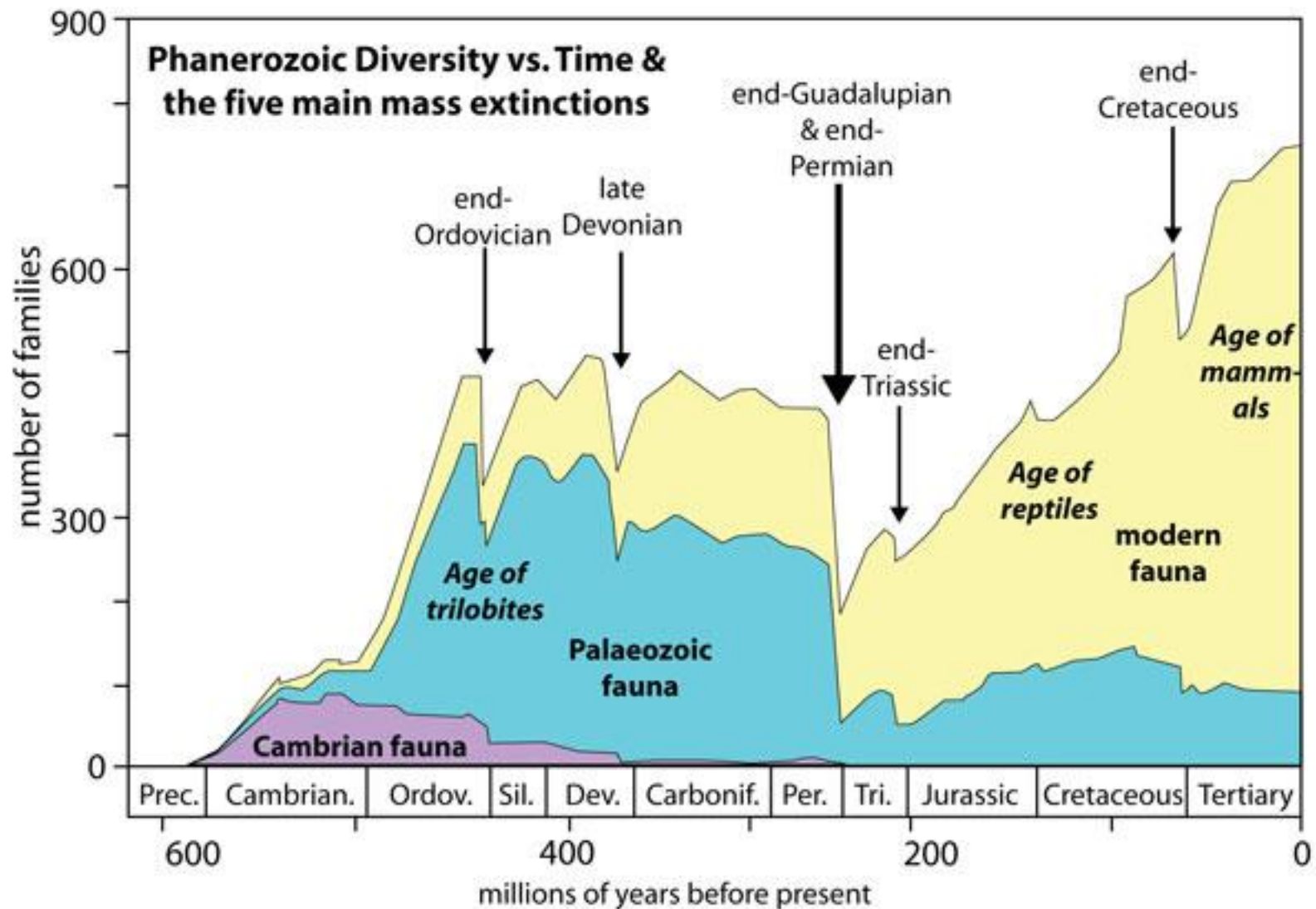
Evolution is:

2. Repeated divergence of lineages starting from common ancestor



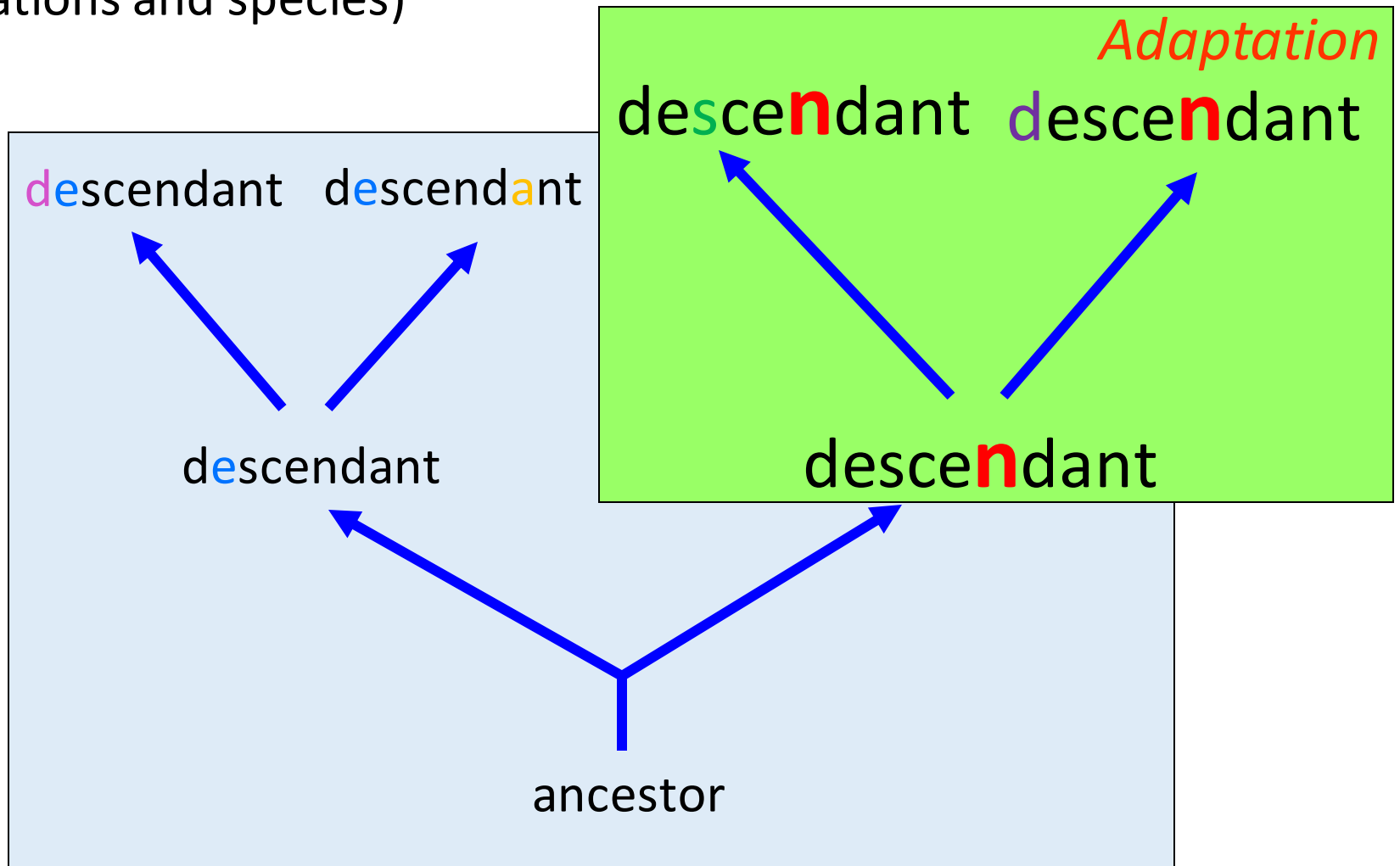


Permanent diversification of life through formation of new species (and change of the species) is coupled by permanent loss of species. More than 99% of species that have existed on our Planet are extinct.



Evolution is:

3. Differential survival of the diverged lineages (within and also between populations and species)



One of the key tasks in evolutionary biology is to explain adaptation

Natural selection is the differential survival and reproduction of individuals due to differences in phenotype.



Natural Selection

It Still Works



Which is different from
random differential survival
and reproduction

..and artificial differential survival and reproduction



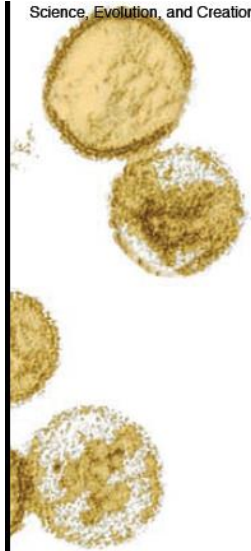
Evidence for Evolution

- Constant branching of the “tree of life”. Is nature organised as a nested structure of species and groups of species? Do different species share common ancestors?
- Decent with modification. Do species change over time?

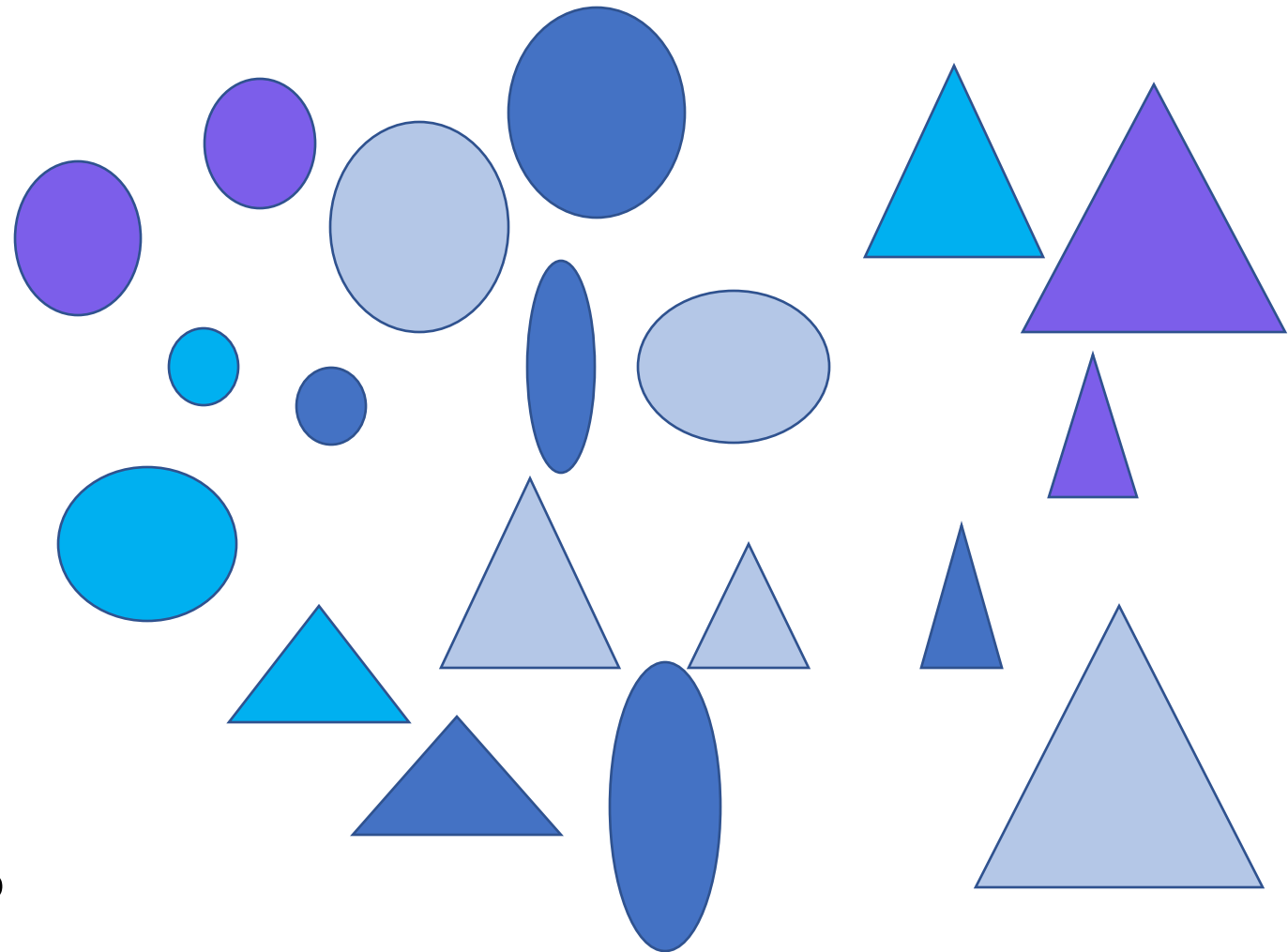
Science, Evolution, and Creationism

SCIENCE,
EVOLUTION,
AND
CREATIONISM

NATIONAL ACADEMY OF SCIENCES
INSTITUTE OF MEDICINE



One can classify a set of objects hierarchically based on similarity. This does not implicitly imply common origin. Depending on the characters chosen one can end up with different classifications.



- Colour
- Size
- Shape
- Height/width ratio

Do different species share common ancestors?

In life different characters (more precisely – homologies) are correlated and form a nested structure of similarity (tree). Common ancestry is the best/simplest explanation for this phenomenon

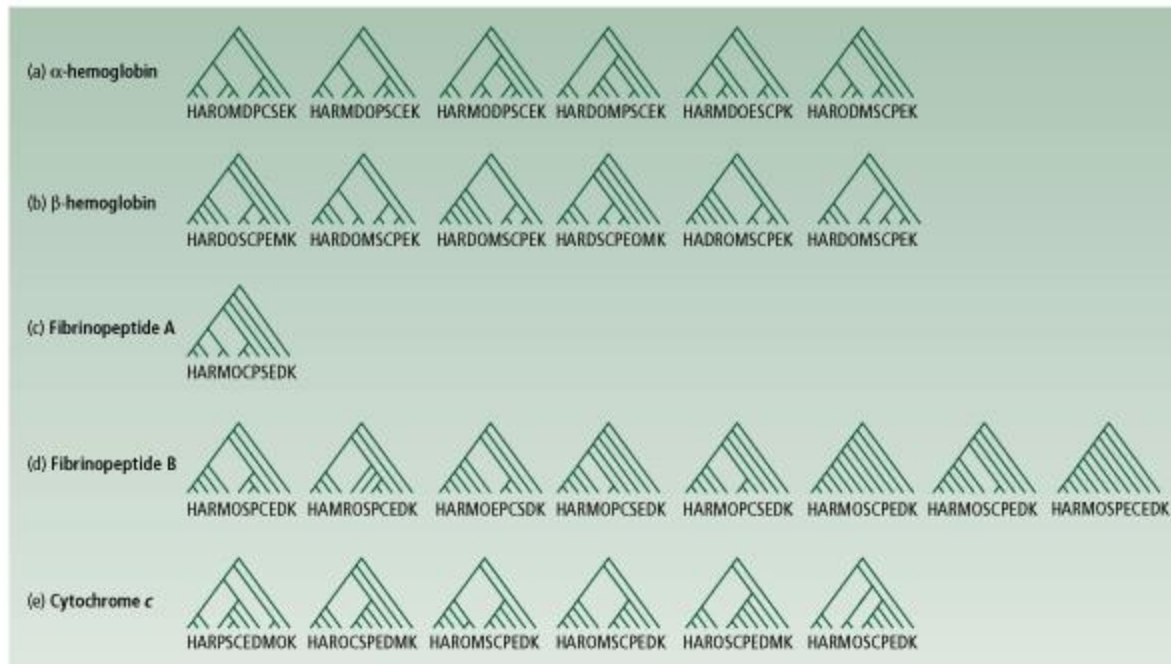


Figure 3.10

Penny *et al.* constructed the best estimate of the phylogenetic tree for 11 species using five different proteins. The “best estimate” of the phylogenetic tree is the tree that requires the smallest number of evolutionary changes in the protein. For (a) α -hemoglobin, and (b) β -hemoglobin there were six equally good estimates of the tree for the 11 species. All six trees in each case require the same number of changes. (c) For fibrinopeptide A there was one best tree; (d) for fibrinopeptide B there were eight equally good trees; and (e) for cytochrome c there were six equally good trees. The important point is how

similar these trees are for all five proteins, given the large number of possible trees for 11 species. A, ape (*Pan troglodytes* or *Gorilla gorilla*); C, cow (*Bos primigenios*); D, dog (*Canis familiaris*); E, horse (*Equus caballus*); H, human (*Homo sapiens*); K, kangaroo (*Macropus konguru*); M, mouse (*Mus musculus*) or rat (*Rattus norvegicus*); O, rabbit (*Oryctolagus auniculus*); P, pig (*Sus scrofa*); R, rhesus monkey (*Macaca mulatta*); S, sheep (*Ovis amnion*). Redrawn, by permission of the publisher, from Penny *et al.* (1982). © 1982 Macmillan Magazines Ltd.

Similarity (phylogenetic) trees of 5 proteins among 11 species. The branching order of the trees is similar although they are not identical. With 11 species there are 34 million (unrooted) tree possibilities.

Homology vs Analogy

Analogy: functional explanation – convergent evolution (due to adaptation to a similar niche)



bat



insect

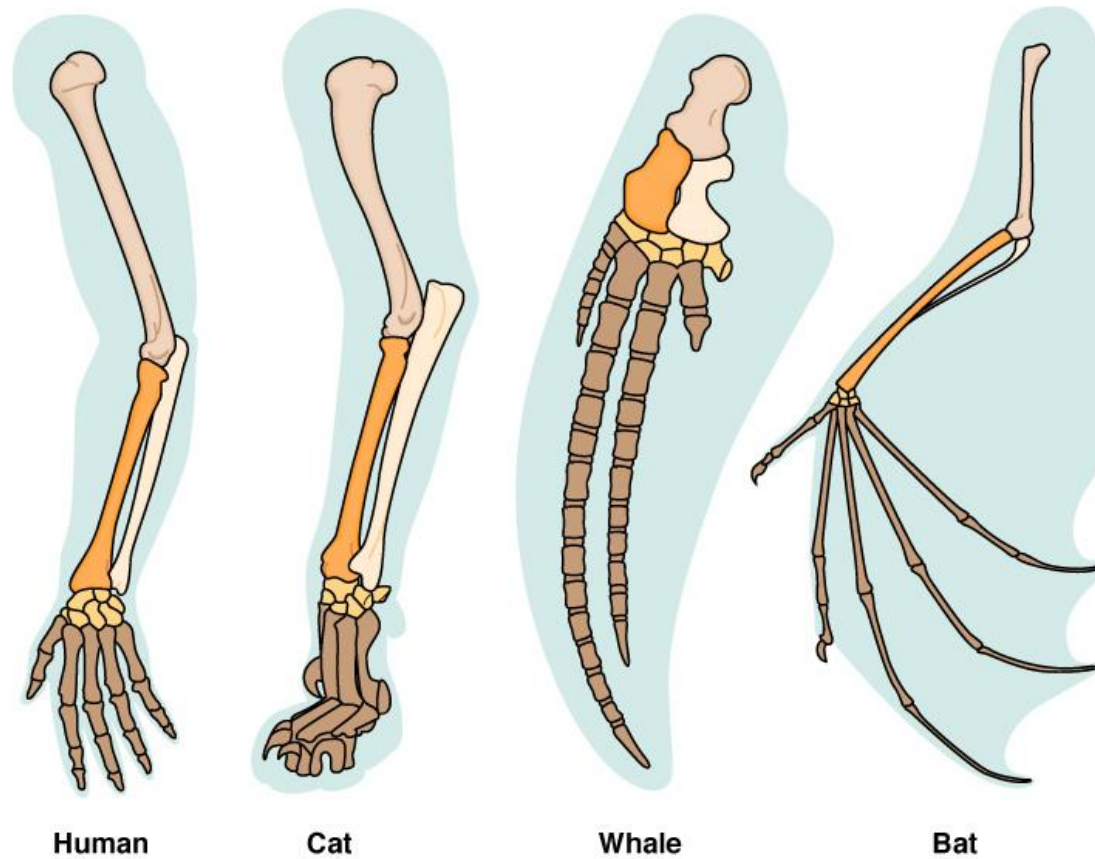


bird



petrodactyl

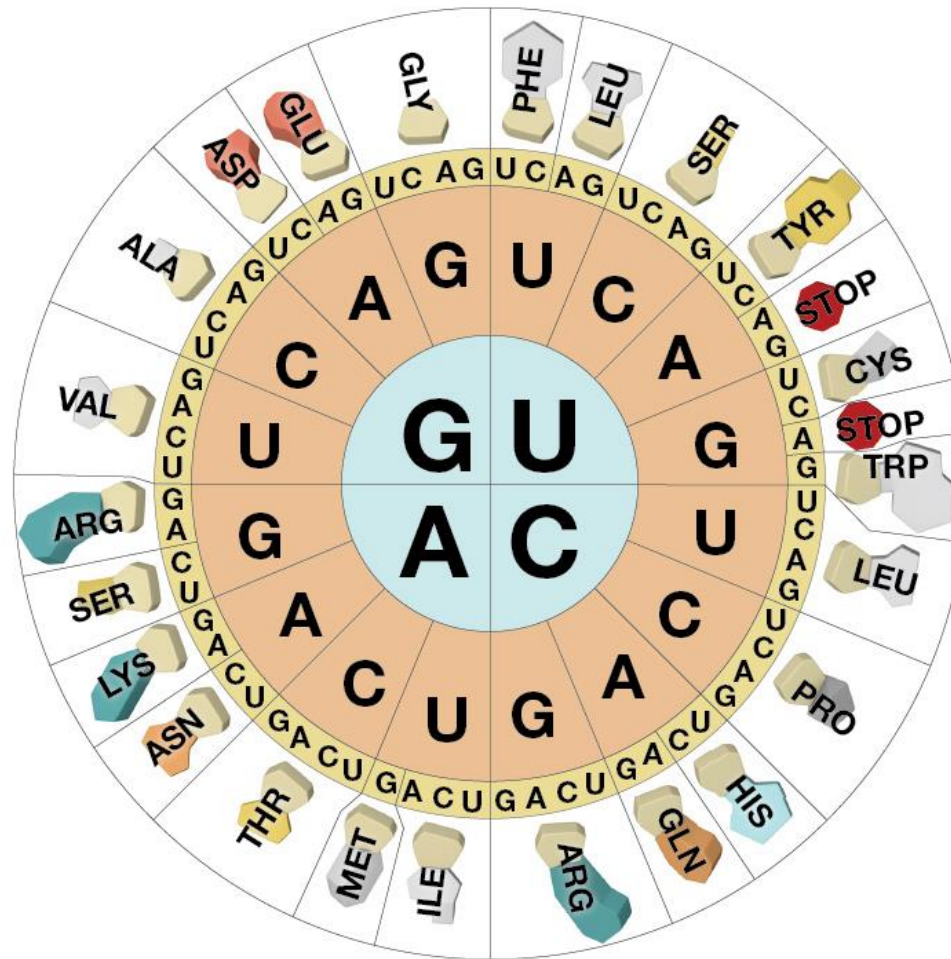
Homology: (functionally unnecessary similarity):
For example five toe limbs of tetrapods



©1999 Addison Wesley Longman, Inc.

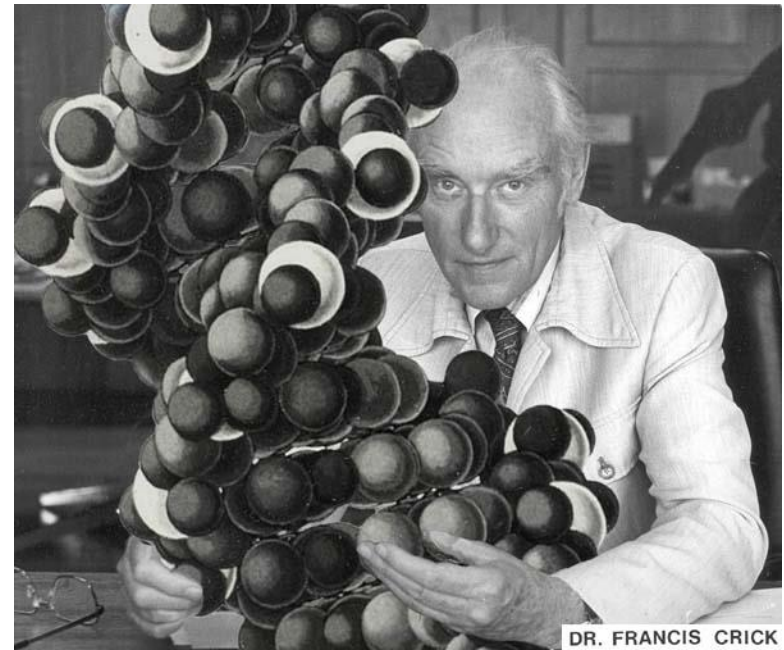
Common ancestry is the best/simplest explanation for this phenomenon

The most universal homology is the universal genetic code



Francis Crick: “frozen accident”

Any code would do. The fact that GCx codes for alanine is an accident. But after the code was established it has been very difficult to change it. Hence we see only (very) minor differences in the code across Life.

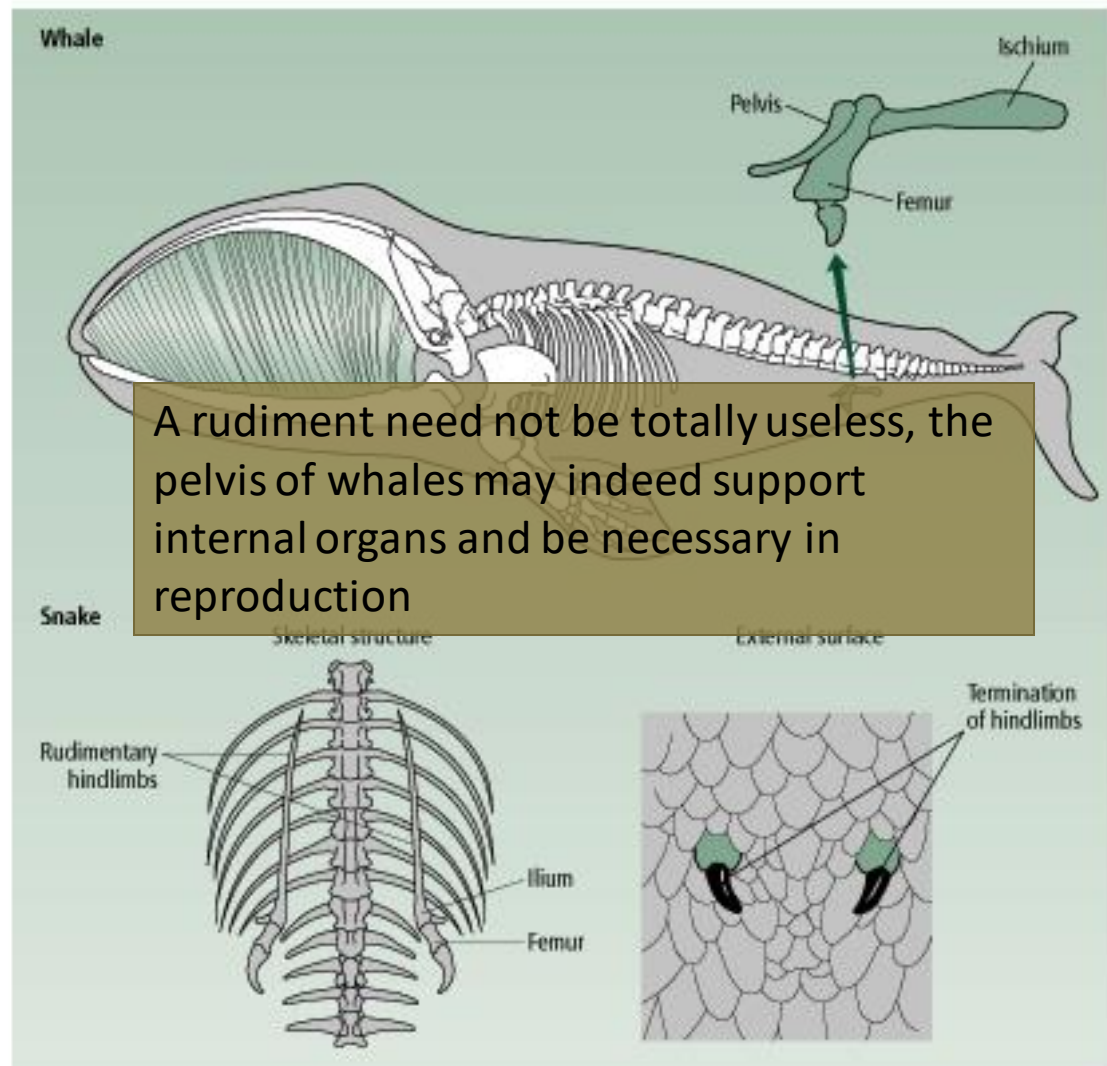


While Darwin suggested that all life had one or a few universal ancestors (because palaeontologists showed that animals have four basic body plans with no shared homologies) then the genetic code suggest one LUCA (last universal common ancestor)

Rudiments (a homology that is not needed any more)

Figure 3.9

Whales have a vestigial pelvic girdle, even though they do not have bony hindlimbs. The pelvic bones are homologous with those of other tetrapods. Snakes have vestigial hindlimb bones, homologous with those of other tetrapods — but snakes do not use them for locomotion.



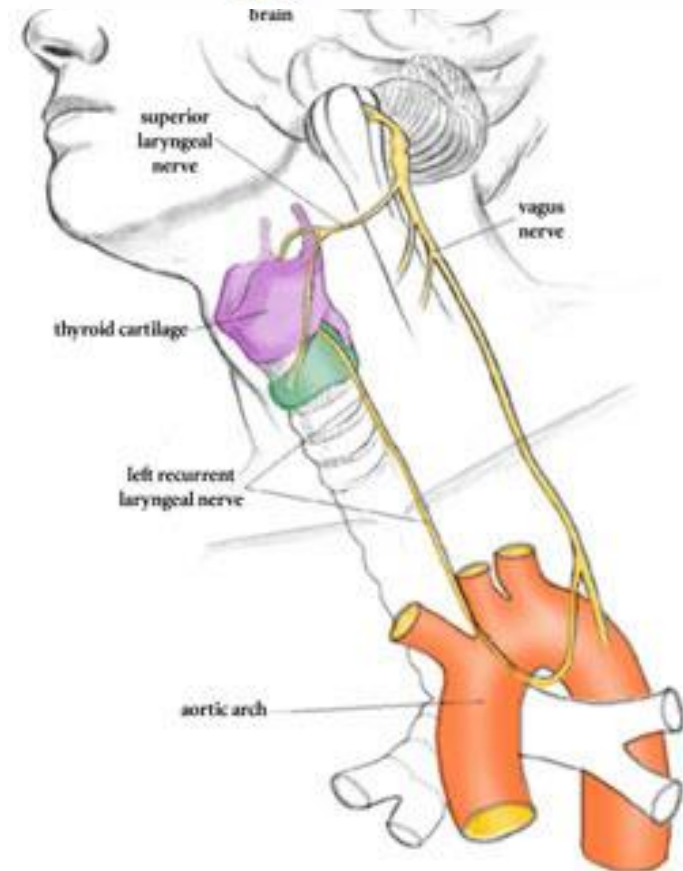
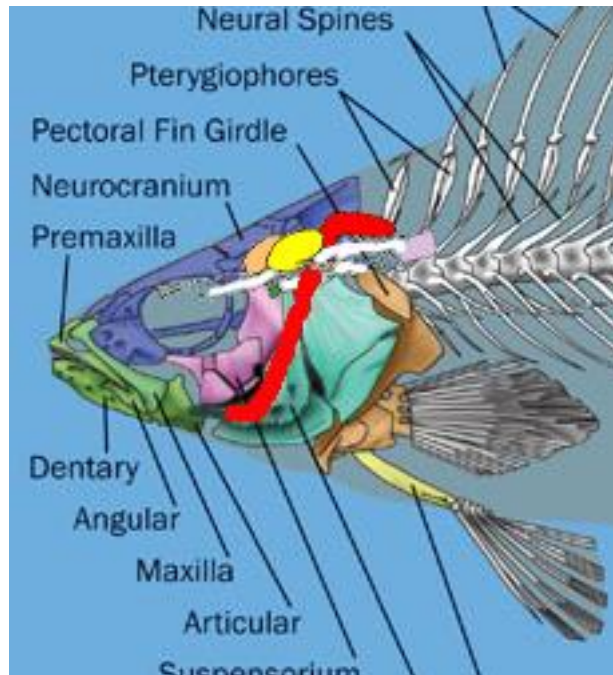
Do different species share common ancestors?

Some rudiments are bad!

The recurrent laryngeal nerve.

laryngeus recurrens

In fish it runs from the brain directly to the throat. In mammals it therefore runs around the aortic arch which can be a distance....



- Constant branching of the “tree of life”. Is nature organised as a nested structure of species and groups of species. Do different species share common ancestors? - YES
- Decent with modification. Do species change over time?
 - Different time-scales. Fossils, drug resistance, ...

What about fossils? There is both evidence for change over time and radiation of species

Silica algae - diatoms

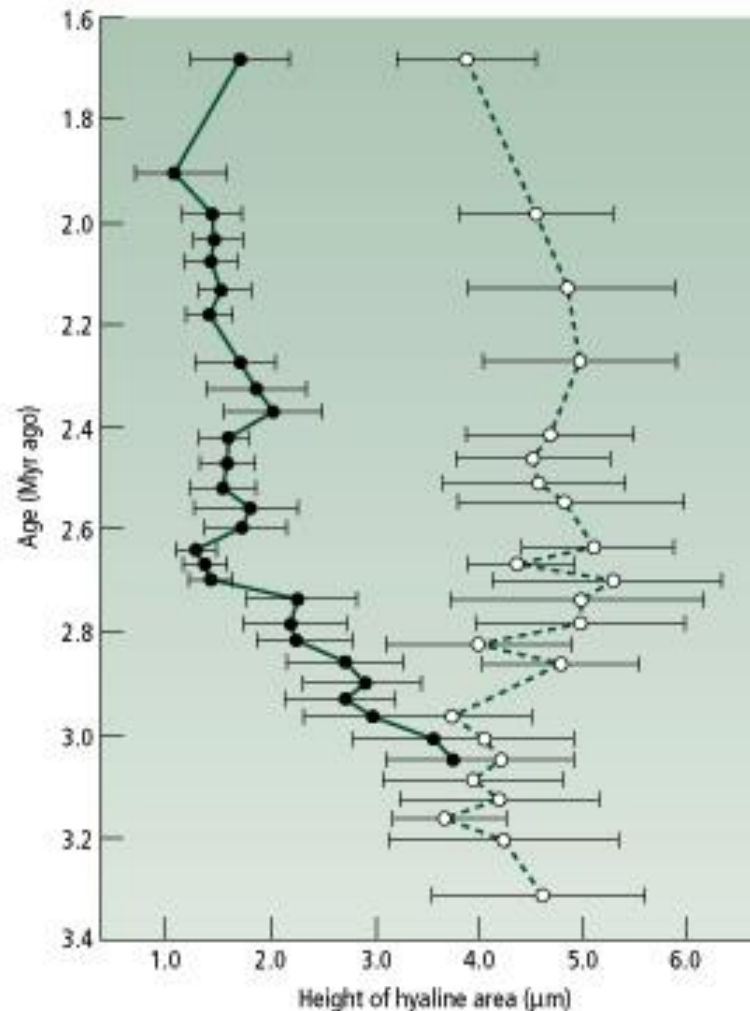


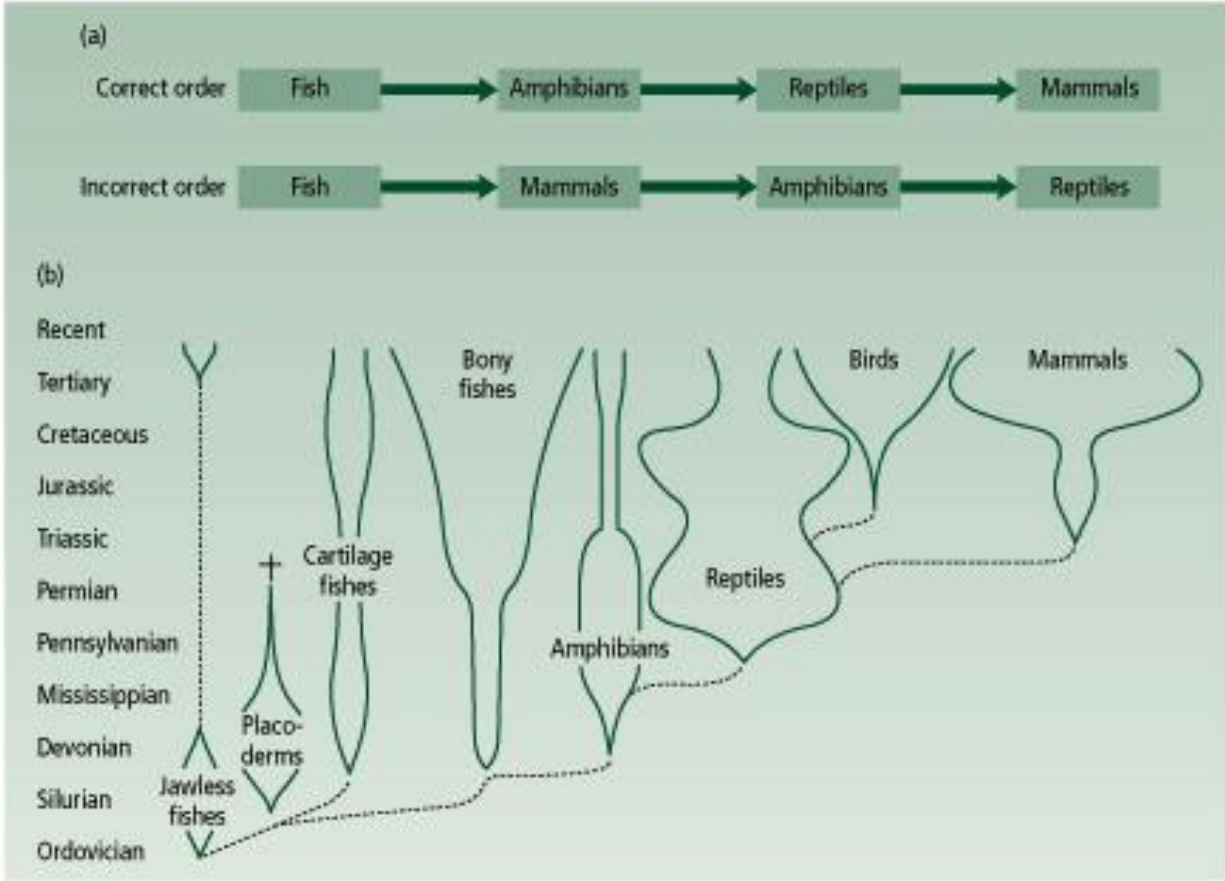
Figure 3.11

Evolution of the diatom *Rhizosolenia*. The form of the diatom is measured by the height of the hyaline (glass-like) area of the cell wall. Open circles indicate forms classified as *R. praebergonii*, closed circles indicate *R. bergonii*. Bars indicate the range of forms at each time. Redrawn, by permission of the publisher, from Cronin & Schneider (1990).

Do species change over time?

Figure 3.12

(a) Anatomic analysis of modern forms indicates that amphibians and reptiles are evolutionarily intermediate between fish and mammals. This order fits with (b) the geological succession of the major vertebrate groups. The width of each group indicates the diversity of the group at that time. Redrawn, by permission of the publisher, from Simpson (1949).

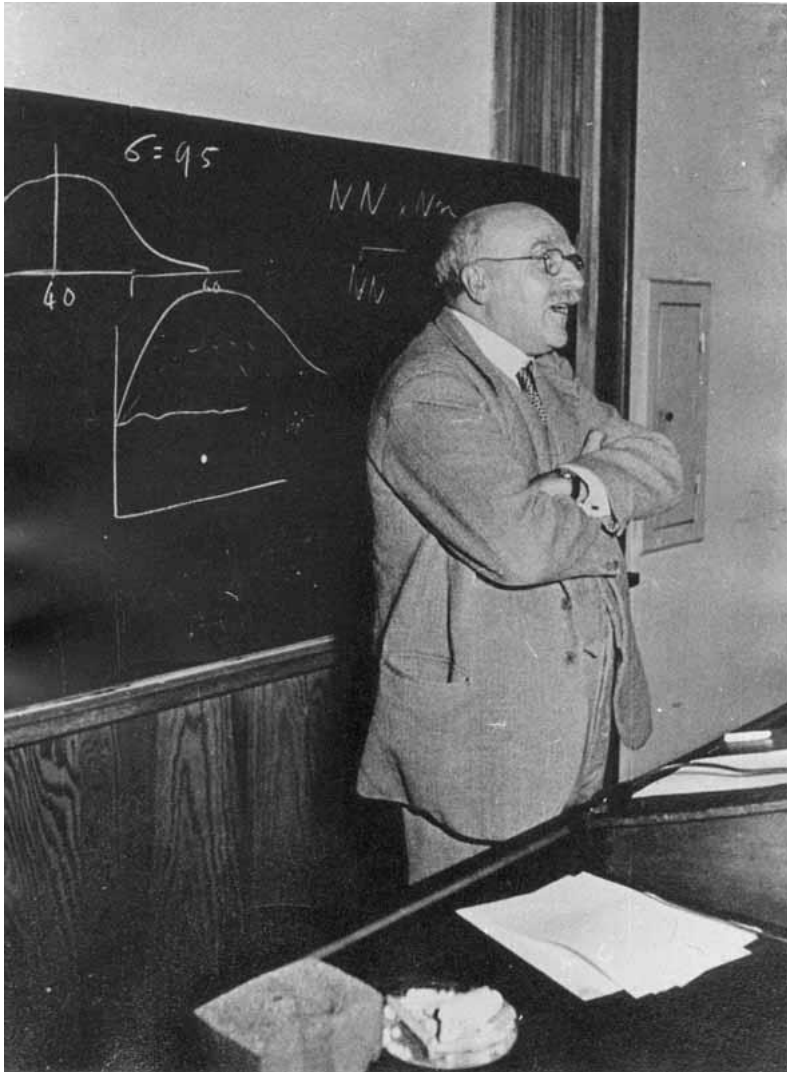


gills -> lungs
(lobe)fins -> limbs

The timeline of appearance of fossils: fish -> amphibians -> reptiles -> mammals
And not something like: fish -> mammals -> reptiles -> amphibians

Do species change over time?

J.B.S. Haldane (1892–1964) said that the discovery of a fossil rabbit in Precambrian rocks would be enough to destroy his belief in evolution.



Fossil record is in many senses the best evidence for evolution. But it has its limitations. It will never be perfect.

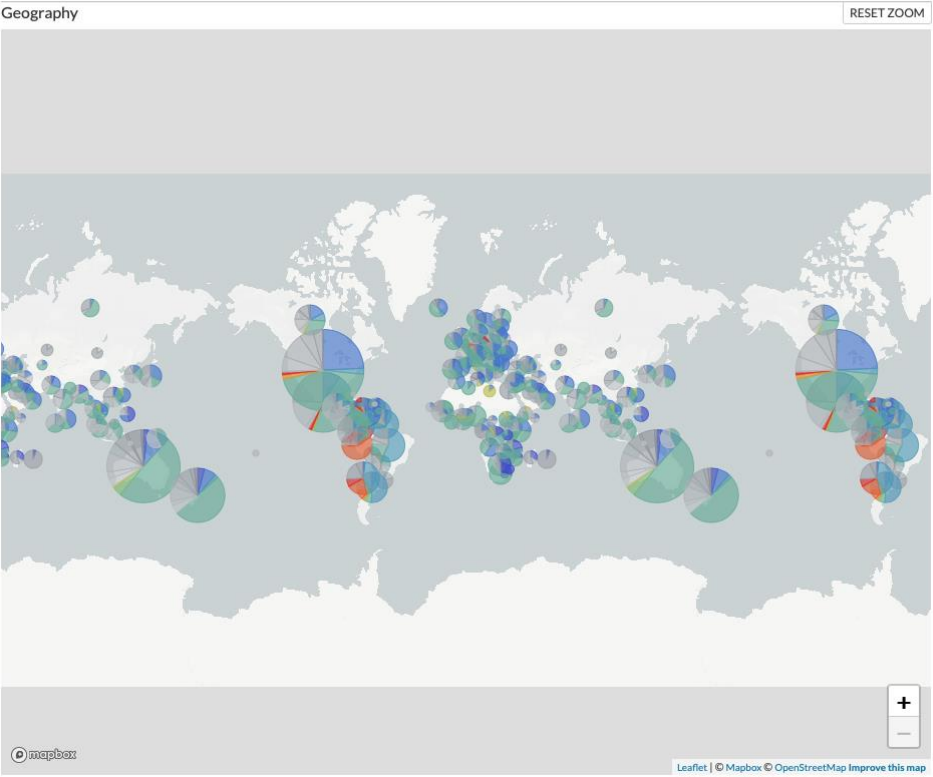
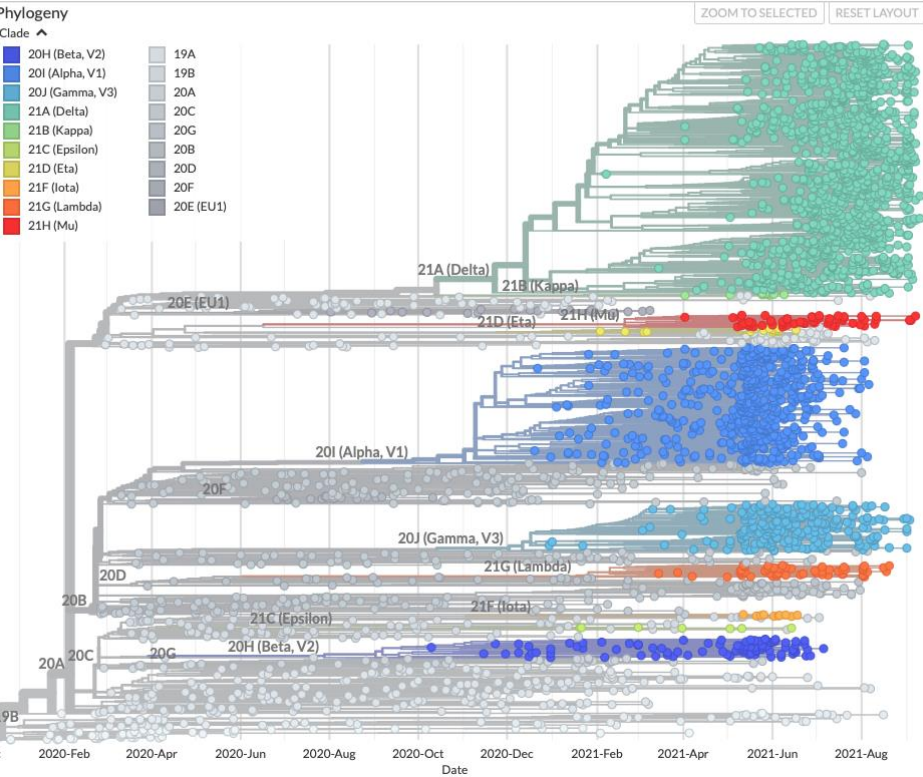
Can we observe and document change of species over humanly comprehensible timescale?

Do species change over time?

Genomic epidemiology of novel coronavirus - Global subsampling

Built with [nextstrain/ncov](#). Maintained by the [Nextstrain team](#). Enabled by data from [GISAID](#).

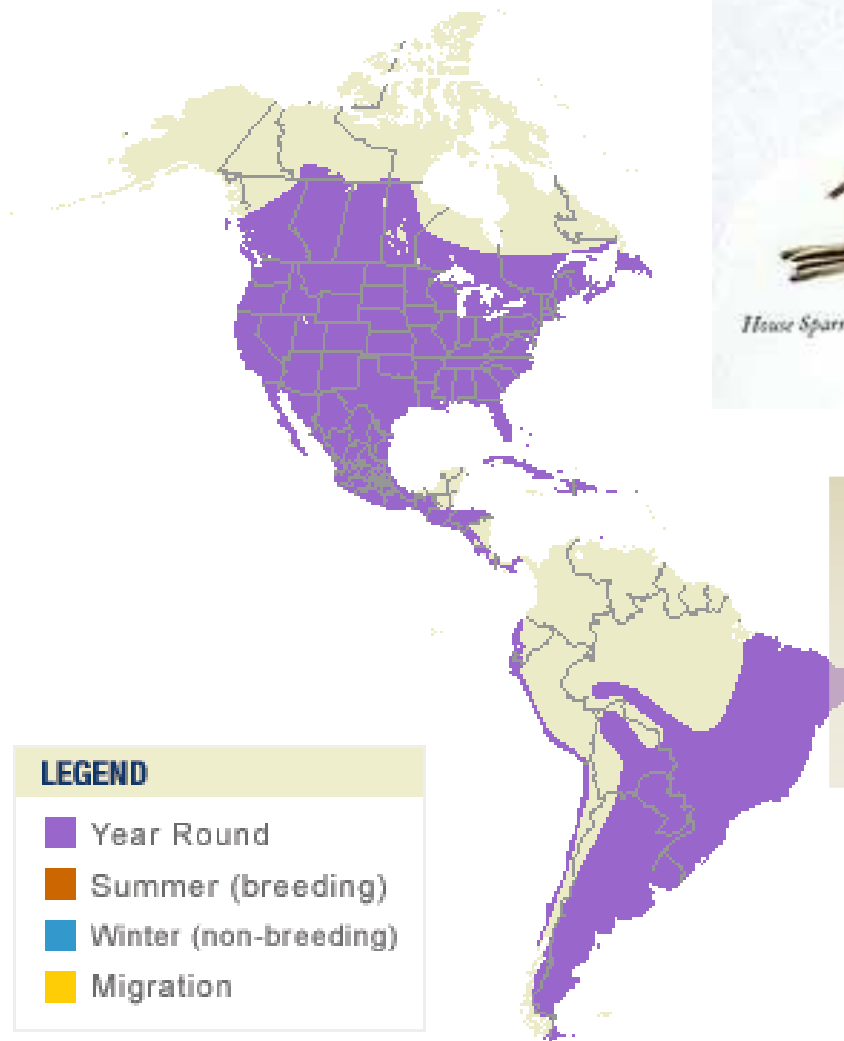
Showing 3414 of 3414 genomes sampled between Dec 2019 and Sep 2021.



Do species change over time?

We can observe the change of species in historic time (hundreds or thousands of years)

House Sparrow *Passer domesticus*



LEGEND

- Year Round
- Summer (breeding)
- Winter (non-breeding)
- Migration

Map by Cornell Lab of Ornithology
Range data by NatureServe



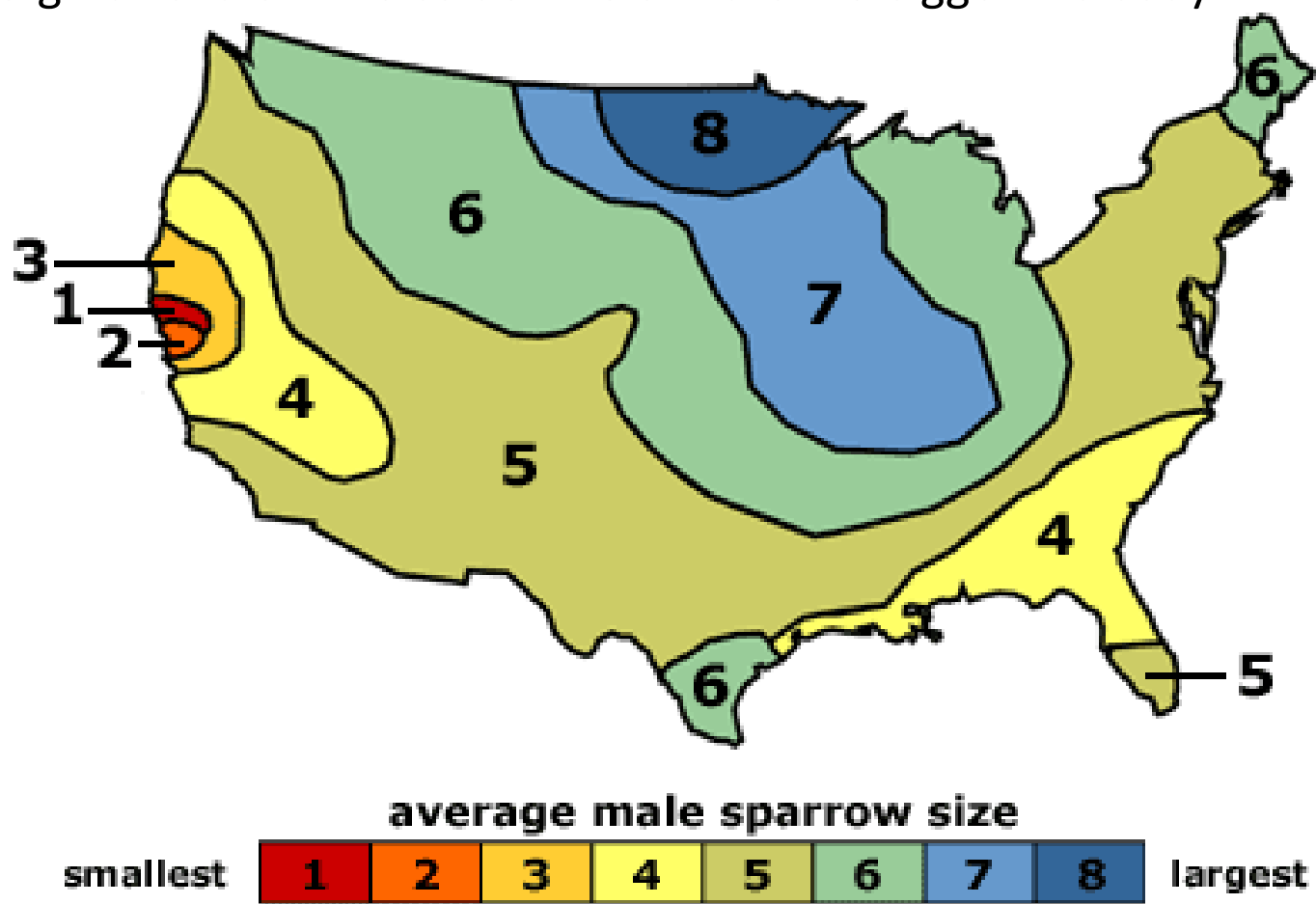
Also known as “flying rat”

Was introduced from England to Brooklyn in 1851-2

Today, 150 years later, the sparrows in southern and northern US differ considerably and genetically (from looks) would not be considered as one species

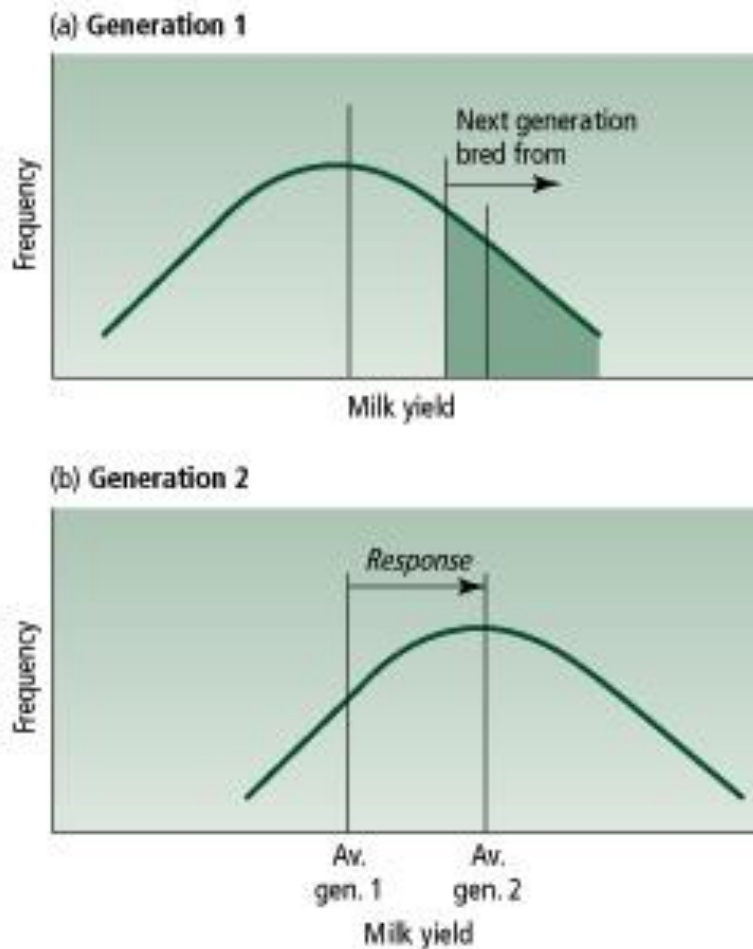
Do species change over time?

Bergman's rule – the colder the climate the bigger the body



Bergmann's rule is an ecogeographical rule that states that within a broadly distributed taxonomic clade, populations and species of larger size are found in colder environments, and species of smaller size are found in warmer regions. Although originally formulated in terms of species within a genus, it has often been recast in terms of populations within a species. It is also often cast in terms of latitude.

Breeding – experimental evolution – Artificial selection



If, for breeding, one chooses a subset of cows whose milk yield is above the average then in the next generation the average milk yield of the population increases.

Figure 3.3

An artificial selection experiment. Generation 2 is formed by breeding from a selected minority (shaded area) of the members of generation 1. Here, for example, we imagine a population of cows and selectively breed for high milk yield. In nearly all cases, the average in the second generation changes from the first in the selected direction.

Species do change: modification by decent = true

But considering the case of the sparrows the question remains – does such change in the end yield new species?

What is a species? This depends on what you think a species is.

There is no single species concept that applies well to the immense diversity of life (or data about life).

We shall return to this but for now let's consider two types species concepts – based on:

1. Phenotypic similarity
2. Reproduction (ability to) – Biological species concept

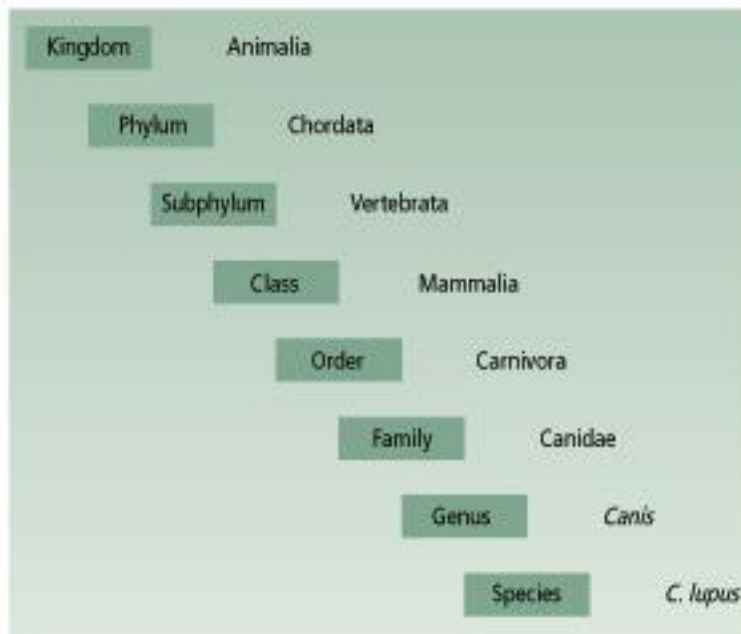


Figure 3.5

Each species in a biological classification is a member of a group at each of a succession of more inclusive hierarchical levels. The figure gives a fairly complete classification of the gray wolf *Canis lupus*. This way of classifying living things was invented by the eighteenth-century Swedish biologist who wrote under the latinized name Carolus Linnaeus.

Darwin's pigeons

Darwin did breeding experiments with pigeons.


According to phenotypic classification there were 15 “English” species of pigeons from three different genera. They all could interbreed – hence were one species according to biological species concept.




Do species change over time?

The phenotypic variance of domestic animals even between breeds of the same biological species can be much larger than that of different species or even genera of wild animals. Why would that be?

Canis lupus



Canis aureus



Different species

African wild dog *Lycaon pictus*

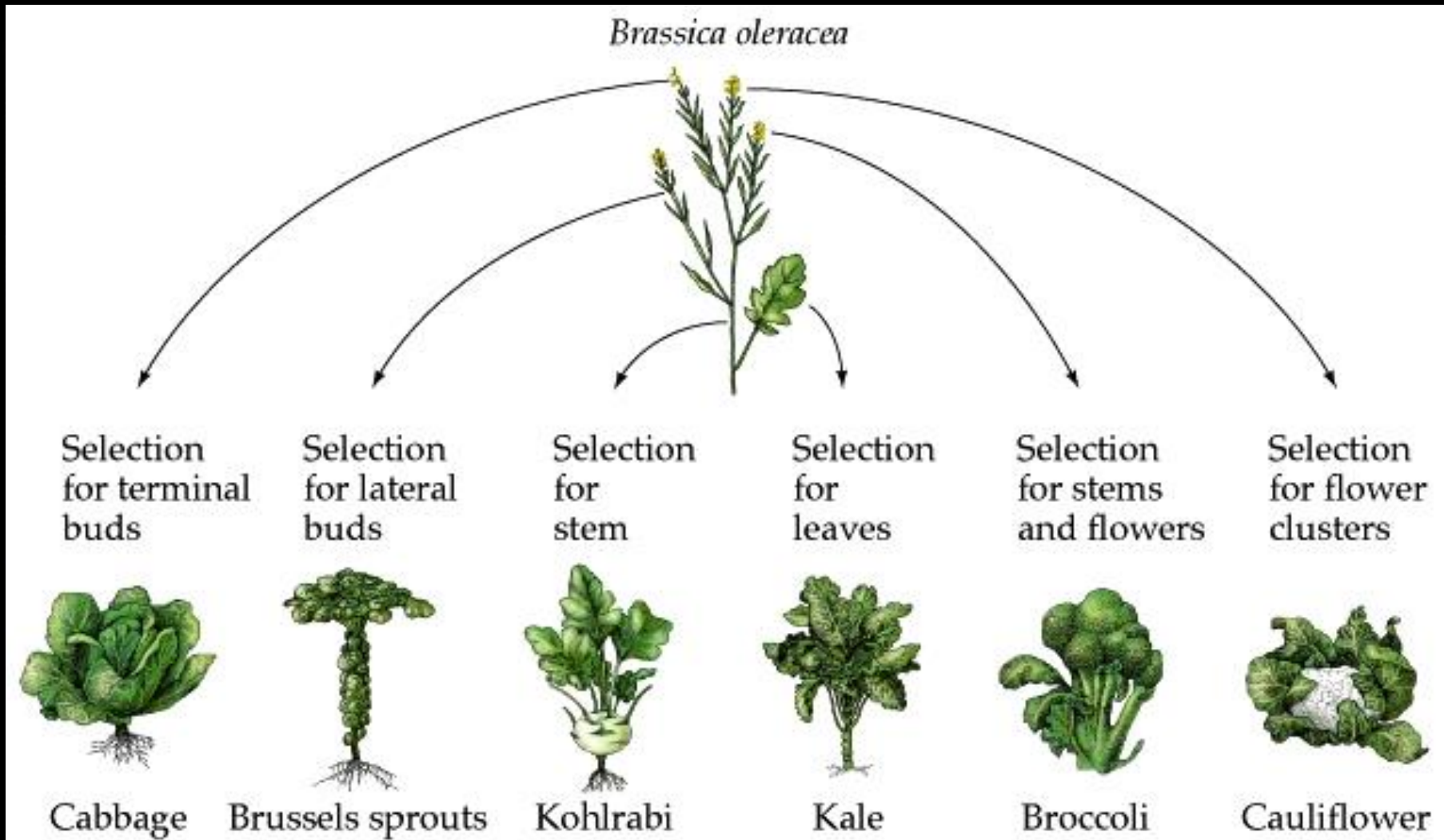


Different genera



Same species

Do species change over time?



© 2001 Sinauer Associates, Inc.

Brassica oleracea

<http://lsyl.la.asu.edu/plb598/kpigg/Brassica.htm>
http://www.fishing-in-wales.com/_pics/plantpic/seaspics/wildcabb.jpg

Cabbage

Kale

Artificial selection can lead to new phenetic species and do so fast.

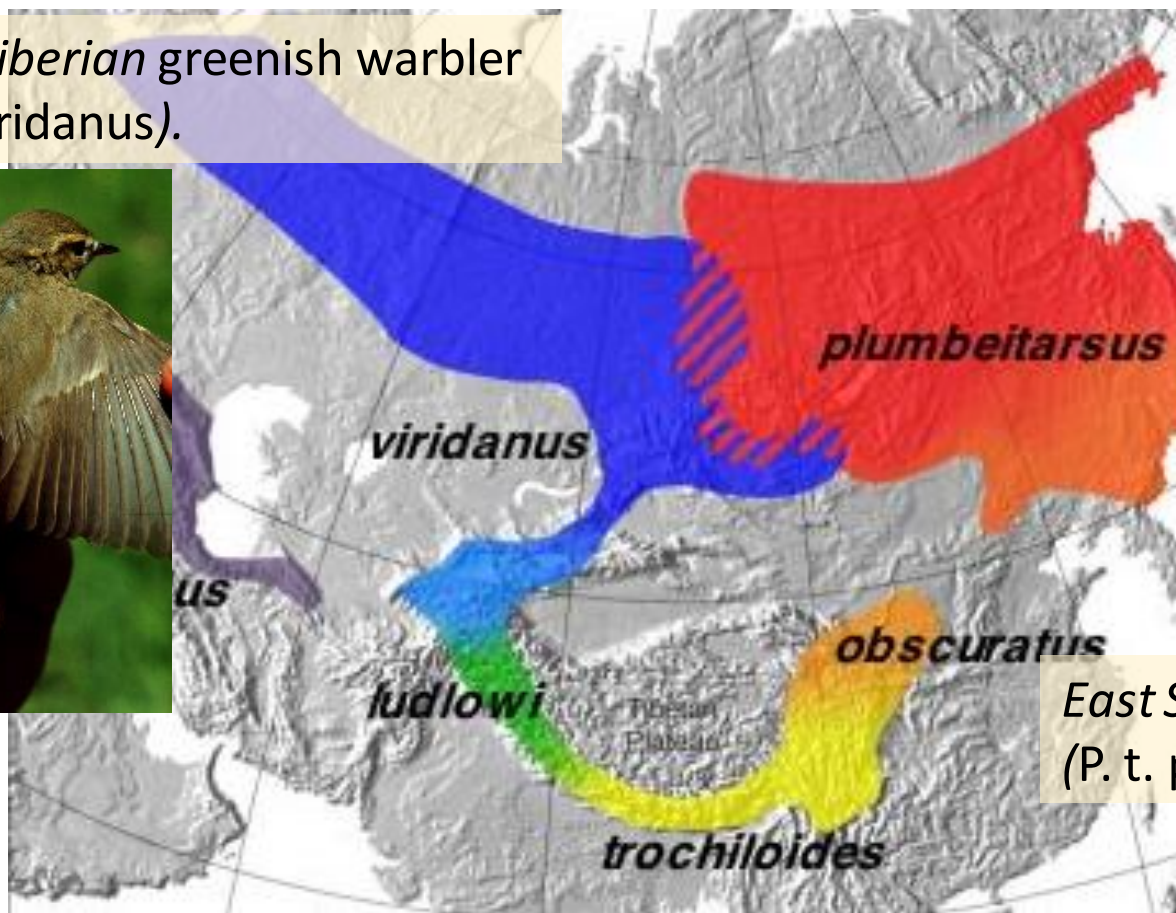
The problem of phenetic vs biological species is deeper than what species is. For most species that have lived on earth we only have fossil data – hence we cannot apply the biological species concept.

Phenetic SP is also valuable for classification of living species.

But can (spatial) phenotypic variation within a species lead to biological species. Is it possible to observe and document the appearance of reproductive isolation in historic/comprehensible time?

Do species change over time?

West Siberian greenish warbler
(*P. t. viridanus*).



East Siberian greenish warbler
(*P. t. plumbeitarsus*).

Map of Asia showing the six subspecies of the greenish warbler described by Ticehurst in 1938. The crosshatched blue and red area in central Siberia shows the contact zone between *viridanus* and *plumbeitarsus*, which do not interbreed. Colors grade together where Ticehurst described gradual morphological change. The gap in northern China is most likely the result of habitat destruction.

Speciation in a ring

Darren E. Irwin*, Staffan Bensch* & Trevor D. Price

Department of Biology 0116, University of California, San Diego,
9500 Gilman Drive, La Jolla, California 92093, USA

NATURE | VOL 409 | 18 JANUARY 2001 | www.nature.com

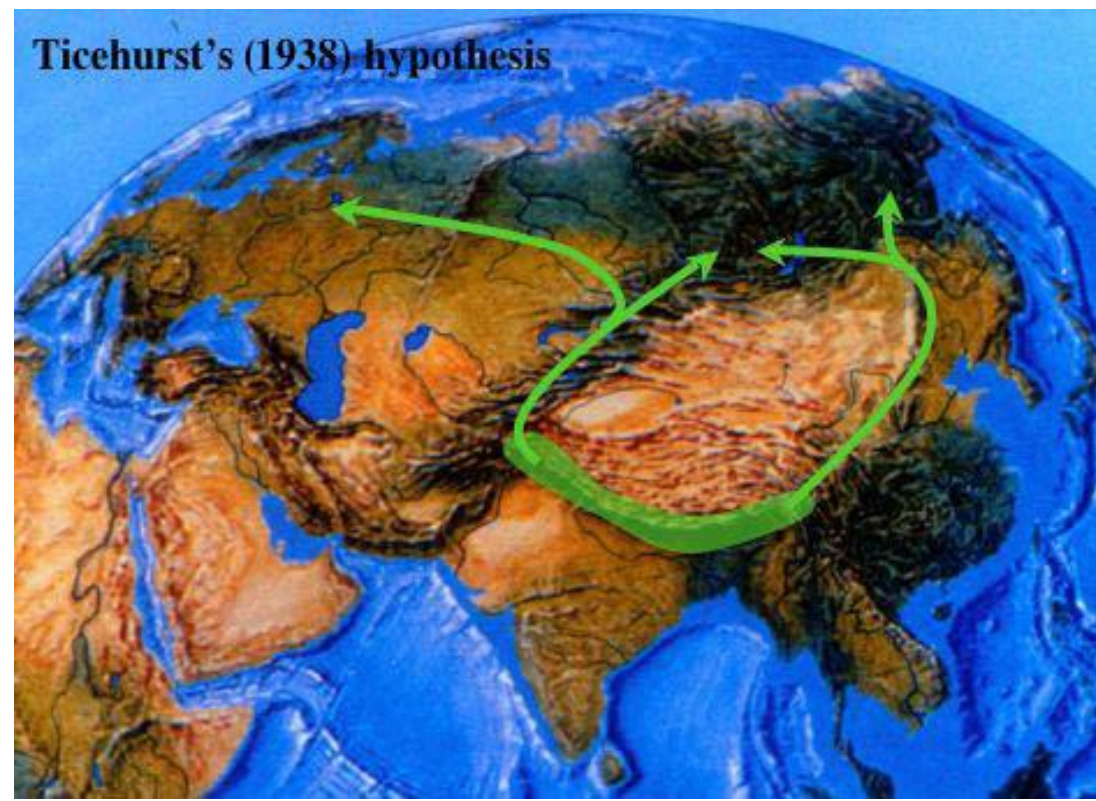
Speciation by Distance in a Ring Species

Darren E. Irwin,^{1*} Staffan Bensch,² Jessica H. Irwin,¹
Trevor D. Price³

21 JANUARY 2005 VOL 307 SCIENCE

Genetics and history

Genetic data show a pattern very similar to the pattern of variation in plumage and songs. The two northern forms *viridanus* and *plumbeitarsus* are highly distinct genetically, but there is a gradient in genetic characteristics through the southern ring of populations. All of these patterns are consistent with the hypothesis, first proposed by Ticehurst (1938), that greenish warblers were once confined to the southern portion of their range and then expanded northward along two pathways, evolving differences as they moved north. When the two expanding fronts met in central Siberia, they were different enough that they do not interbreed.

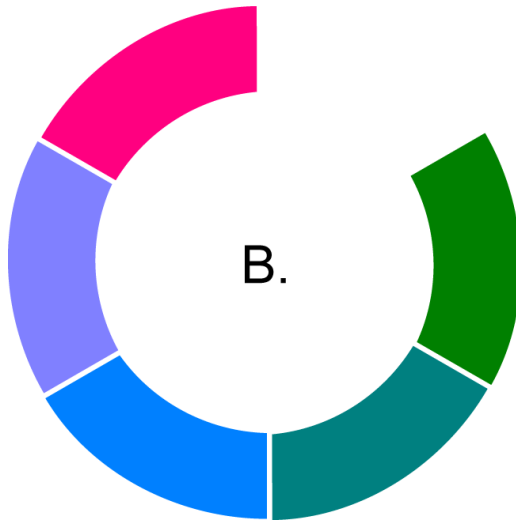


Ringspecies

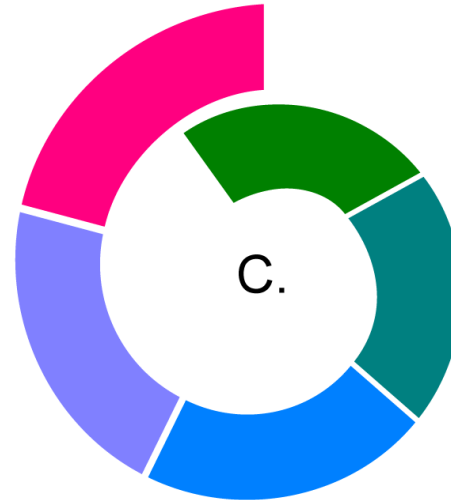
A.



B.



C.



The take home message is that variation within species is of the "same type" as variation between species and can and will lead to speciation also in the biological sense i.e. reproductive isolation.

Occurrence of reproductively isolated new plant species in Nature through polyploidy
Polyploid hybrid plants:



Primula verticillata (18 chromosomes)
x
Primula floribunda (18 chromosomes)



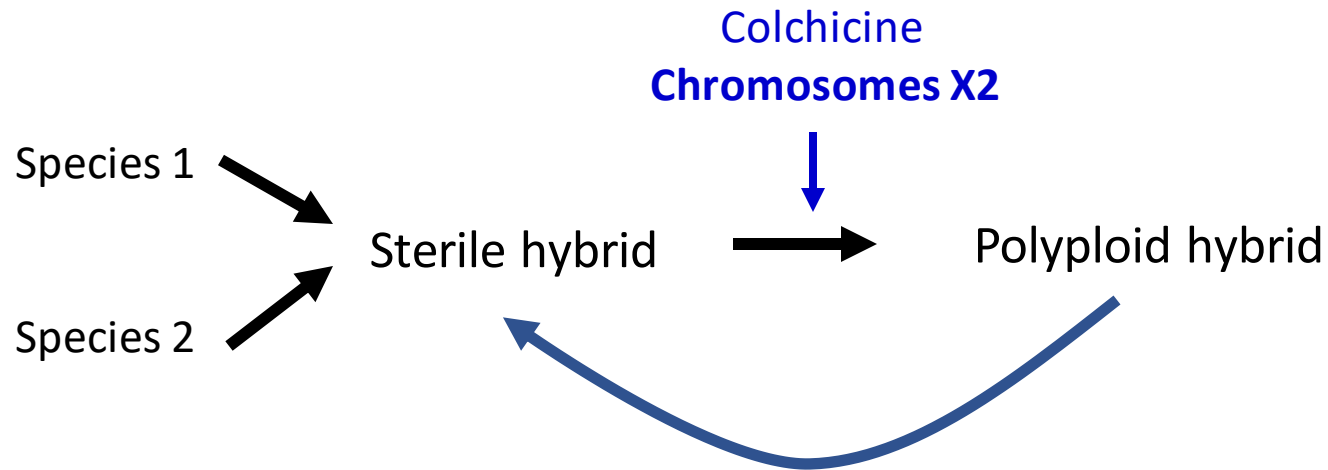
Viable new species

Primula kewensis (36 chromosomes)



This is very widespread among plants

Creating reproductively isolated plants experimentally



Interbreeds with the original hybrid but not with the parent species



Galeopsis pubescens
(pehme karvane kõrvik)



Galeopsis speciosa (kirju kõrvik)

Müntzing recreated a naturally occurring species which occurred through hybridization in 1930

x



Galeopsis tetrahit
(kare kõrvik)

Over 50% of flowering plants have their origin as polyploid hybrids

They use this method to create some 30 new orchid species every month

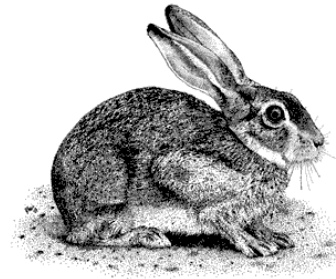
Evolution is modification with decent where populations diverge to form new species.

The main forces/processes of evolution are:

Random: genetic drift and mutation

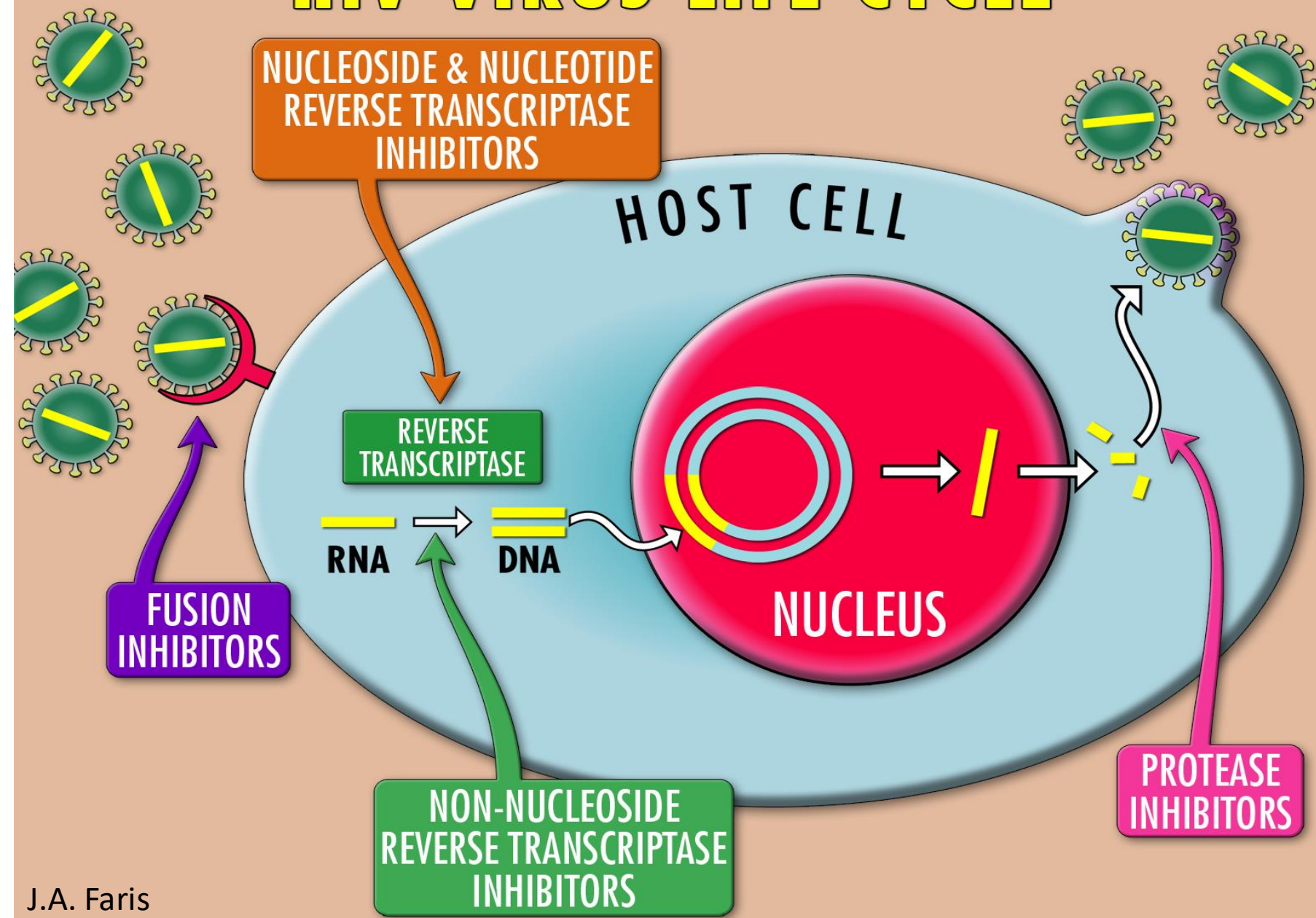
Non-random: natural selection

Evidence for evolution is plenty and while the theory of evolution continues to evolve, it is safe to assume, that evolution is a fact.



- Which of the following are homologies and analogies?
 - Fins of fish and dolphins
 - Five toes of dolphin fin and a frogs leg,
 - Long ears of (marsupial) Bilby and rabbit
 - Seven cervical vertebrae of a camel, giraffe, rat and rabbit.
- What do we mean by "frozen accident" in describing the genetic code?
- Why would Haldane question evolutions if a pre-Cambrian fossil of a rabbit would be unearthed?

HIV VIRUS LIFE CYCLE



We can observe the change of species in real time (days, weeks, ..)

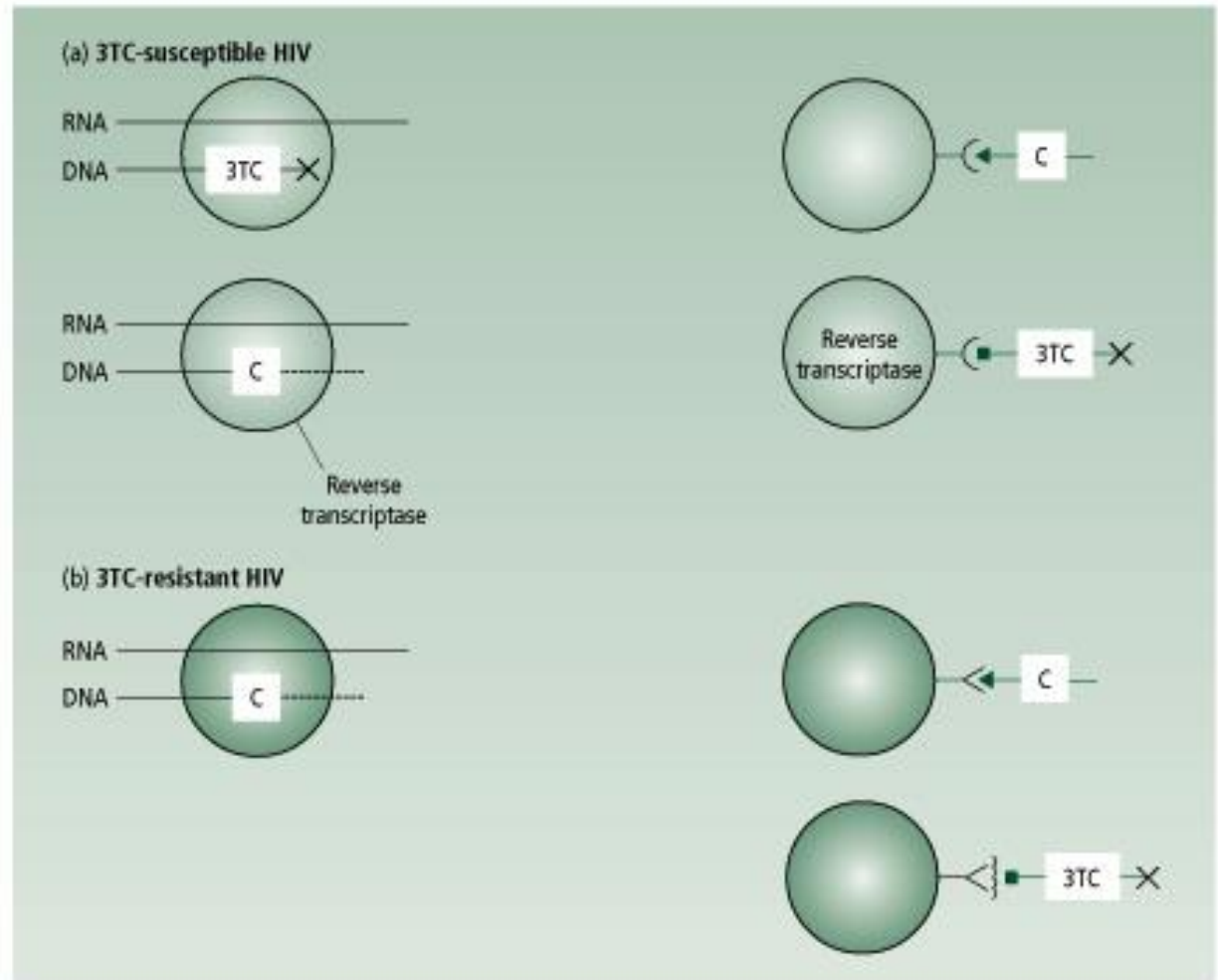
Figure 3.2

Evolution of drug resistance in HIV. 3TC is a nucleoside inhibitor and it resembles C. (a) Drug-susceptible reverse transcriptase binds both 3TC and C. When 3TC is incorporated into a growing DNA chain, it inhibits further replication. (b) Drug resistance is achieved by the evolution of reverse transcriptase that binds only C, and not 3TC.

At the onset of treatment the virus abundance decreases drastically but in 80% of cases it is fully restored with the resistant form

HIV resistance to drugs

3TC - lamivudin



Only one amino acid (methionine) in the viral reverse transcriptase has to be changed in order for resistance to 3CT to appear.