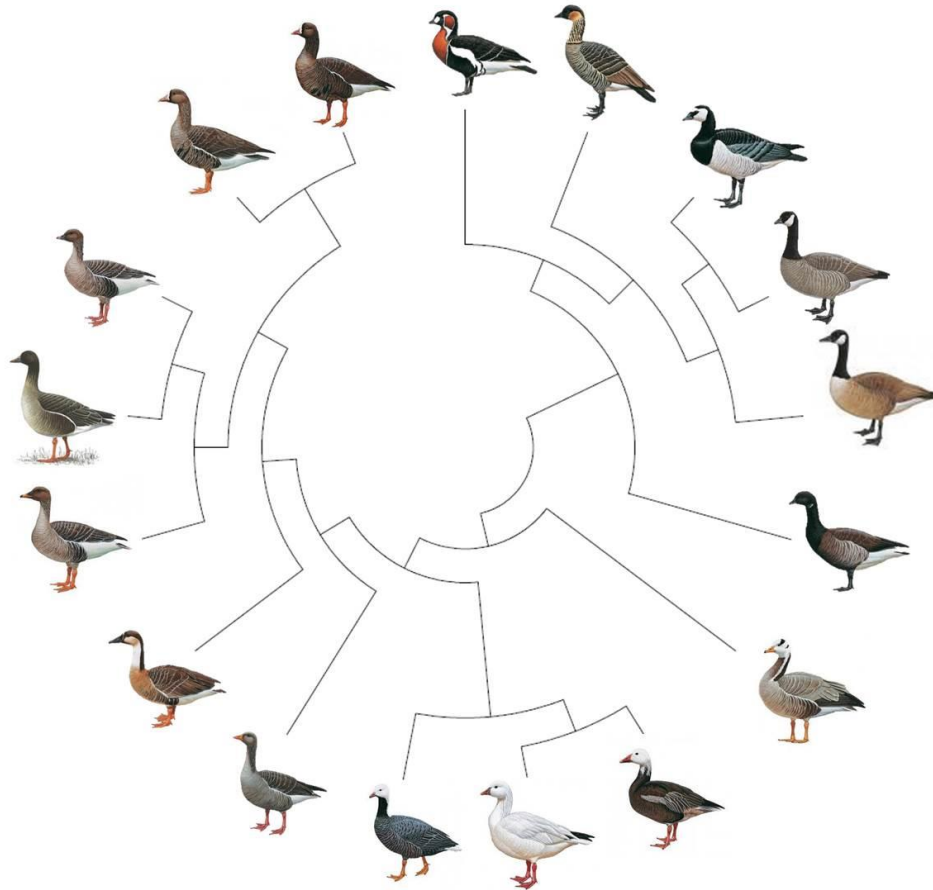


The Genetics of Waterfowl Hybridization



Greylag (*Anser anser*) x Canada Goose (*Branta canadensis*)

Jente Ottenburghs
Wageningen University

Hasselt University (Belgium) – Bachelor Biology

Antwerp University (Belgium) – Master Biology: Evolution and Behavioral Biology

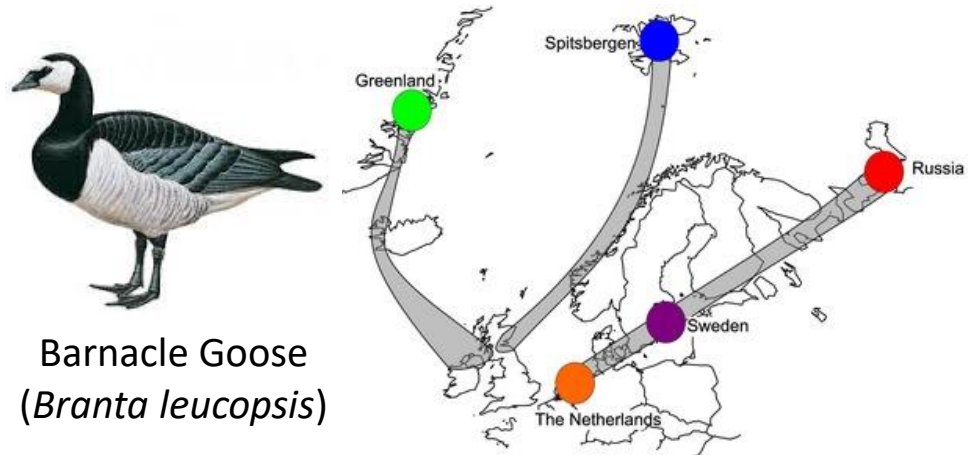
KHLim (Belgium) – Lector Chemistry

Wageningen University (the Netherlands) – PhD

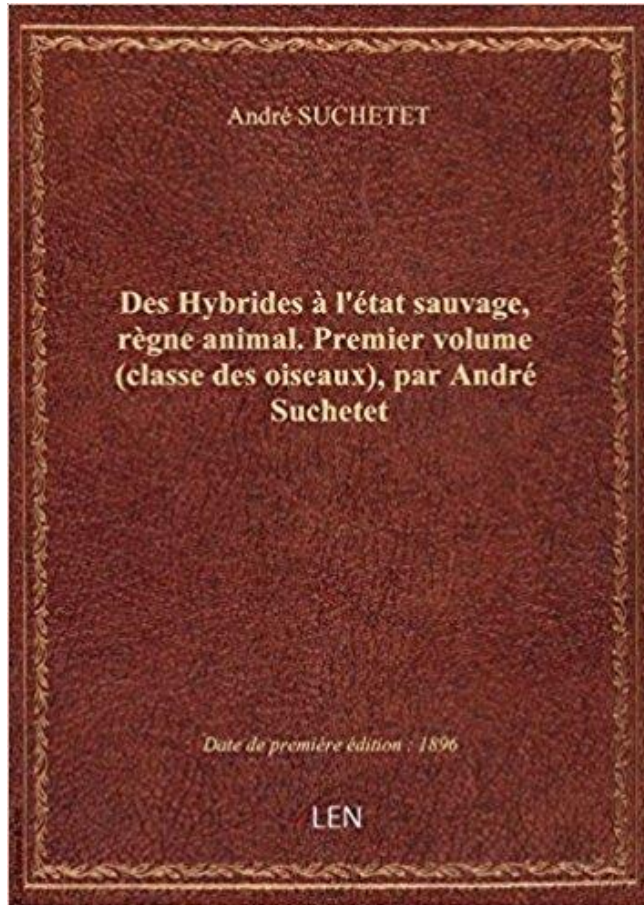
De Volkskrant (the Netherlands) – Science Journalist

Karolinska Institutet (Sweden) – Postdoc

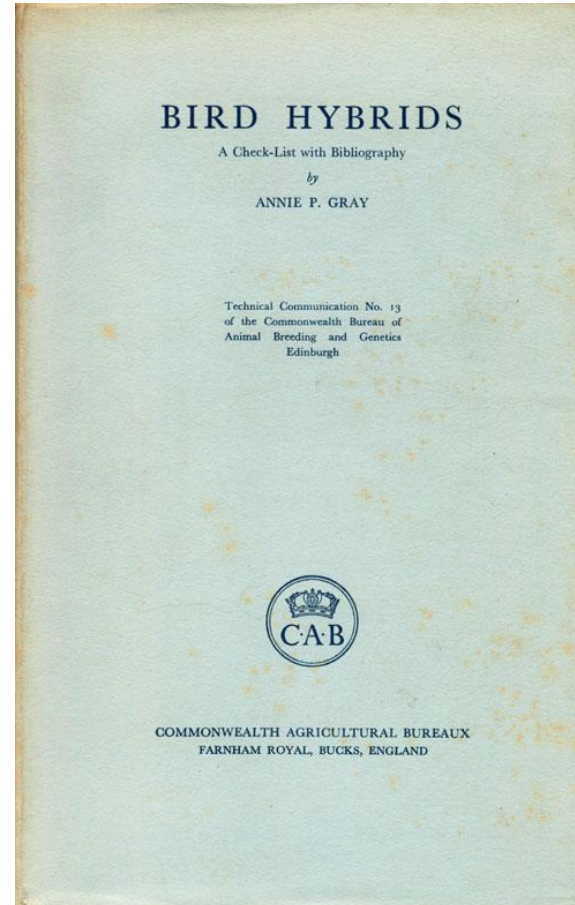
Uppsala University (Sweden) – Postdoc



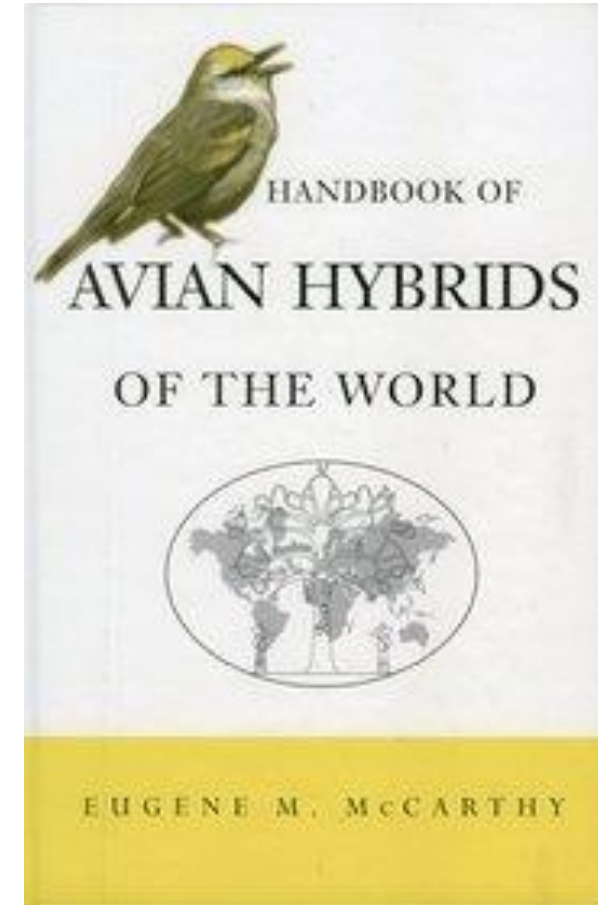
How common is hybridization in birds?



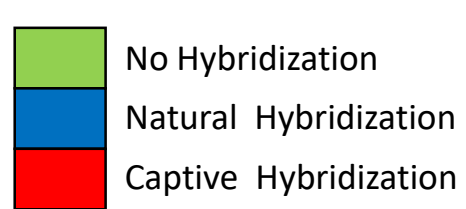
Suchetet (1896)



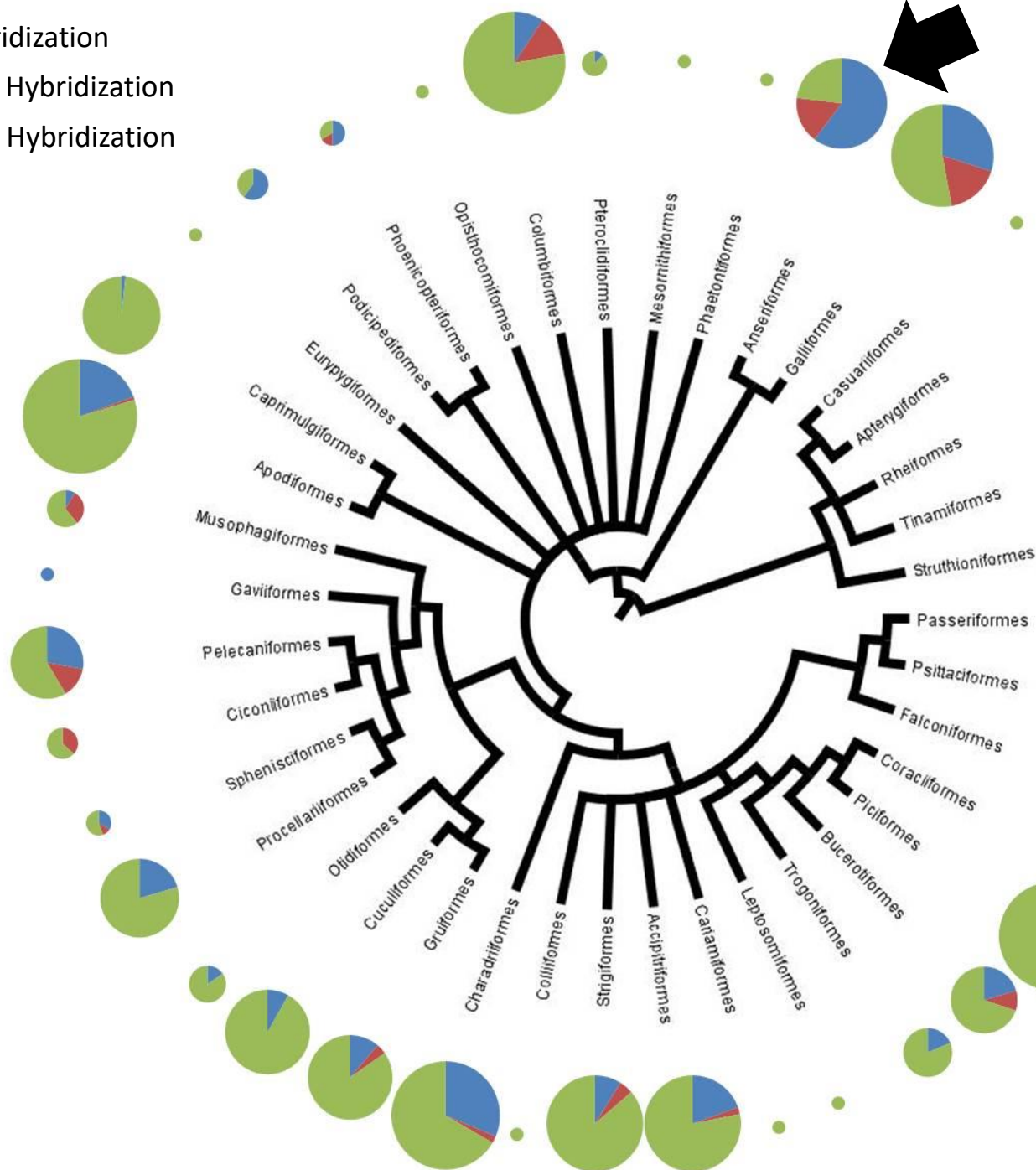
Gray (1958)



McCarthy (2006)



16% of bird species hybridize in the wild
22% when including captive hybrids



The Avian Hybrids Project

<http://avianhybrids.wordpress.com/>

Ottenburghs *et al.* (2015) *Ibis*

Anseriformes = Hybrid Heaven



Mute Swan (*Cygnus olor*) x Greylag Goose (*Anser anser*)
"Swoose"

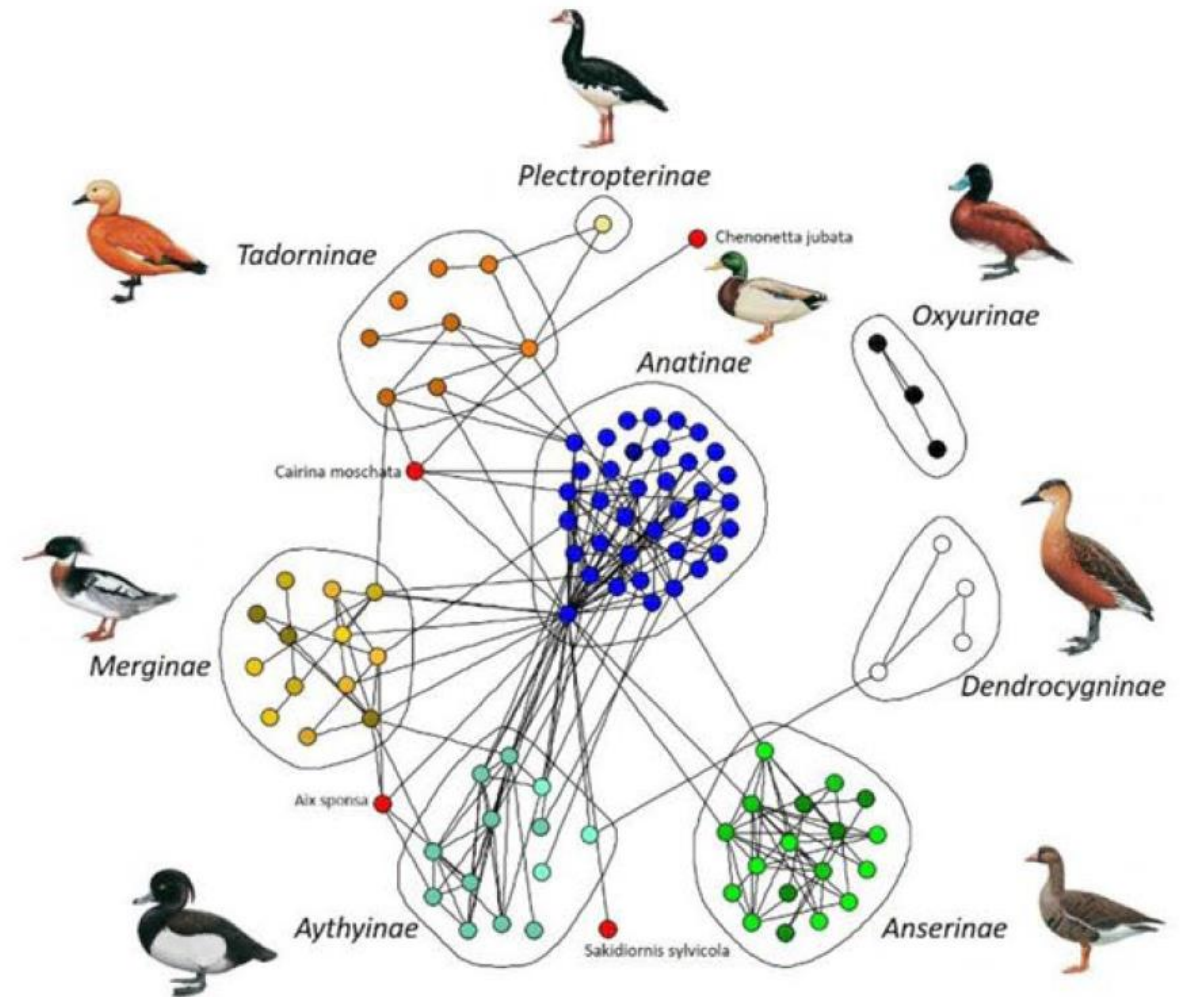
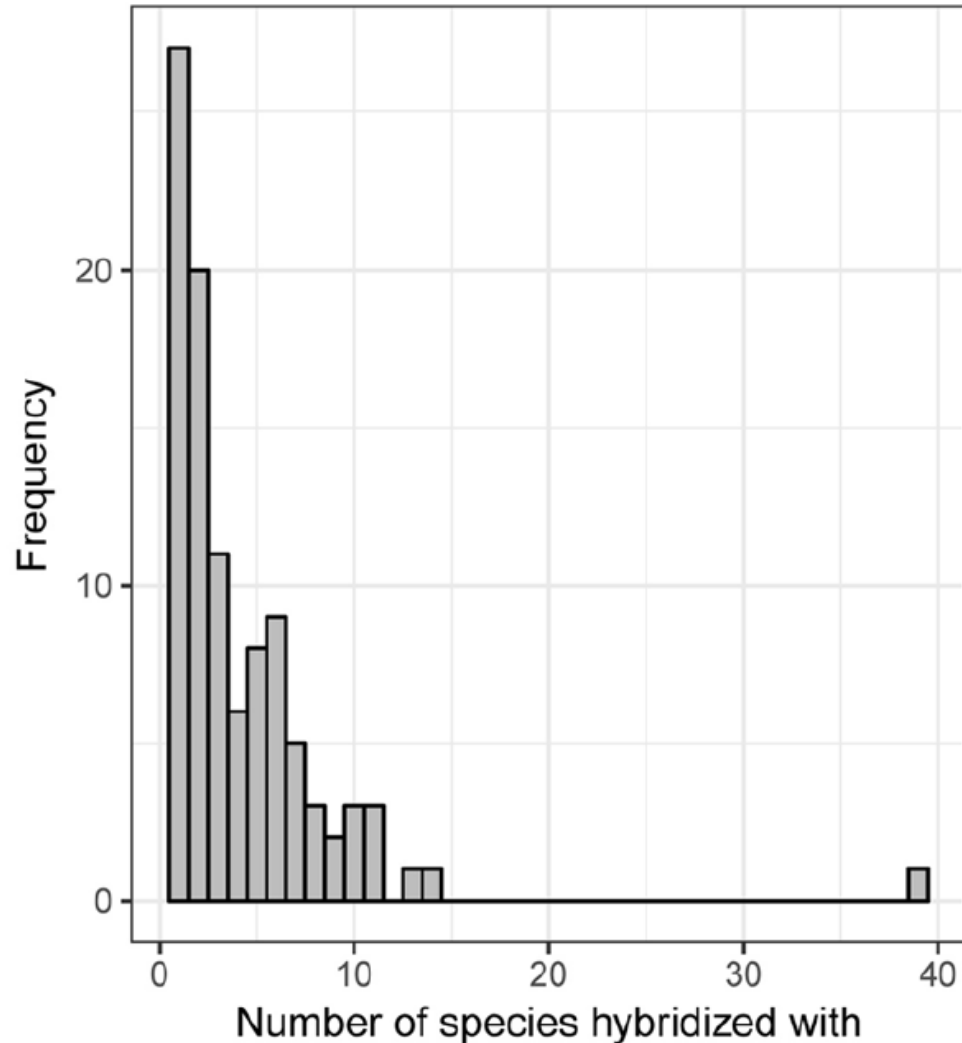


Mallard (*Anas platyrhynchos*) x Northern Pintail (*A. acuta*)



Wood Duck (*Aix sponsa*) x Chestnut Teal (*Anas castanea*)

Anseriformes = Hybrid Heaven



Why do birds choose a partner from another species?



Barnacle Goose



Greater White-fronted Goose



Lesser White-fronted Goose



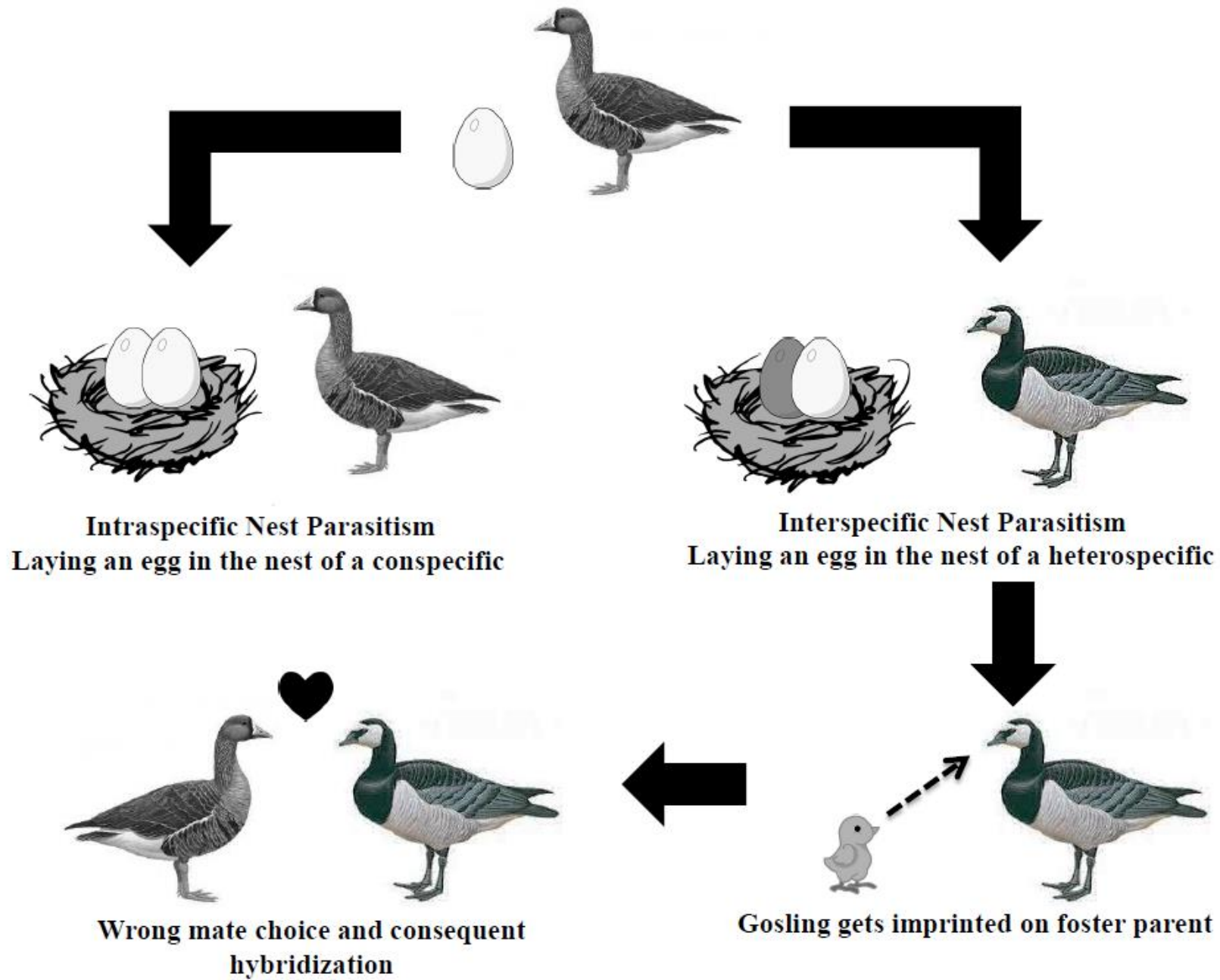
Ross' Goose

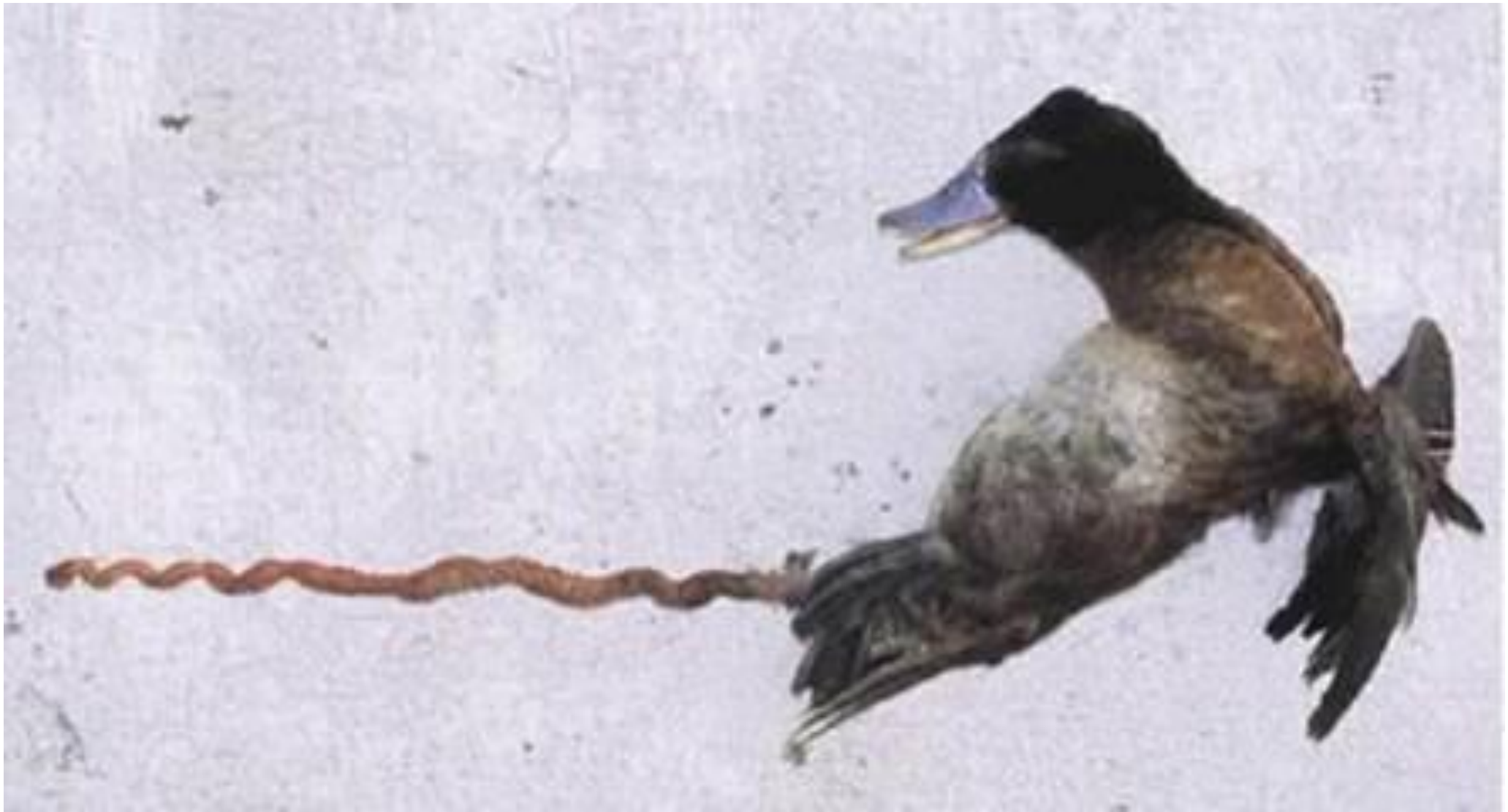


Hawaiian Goose



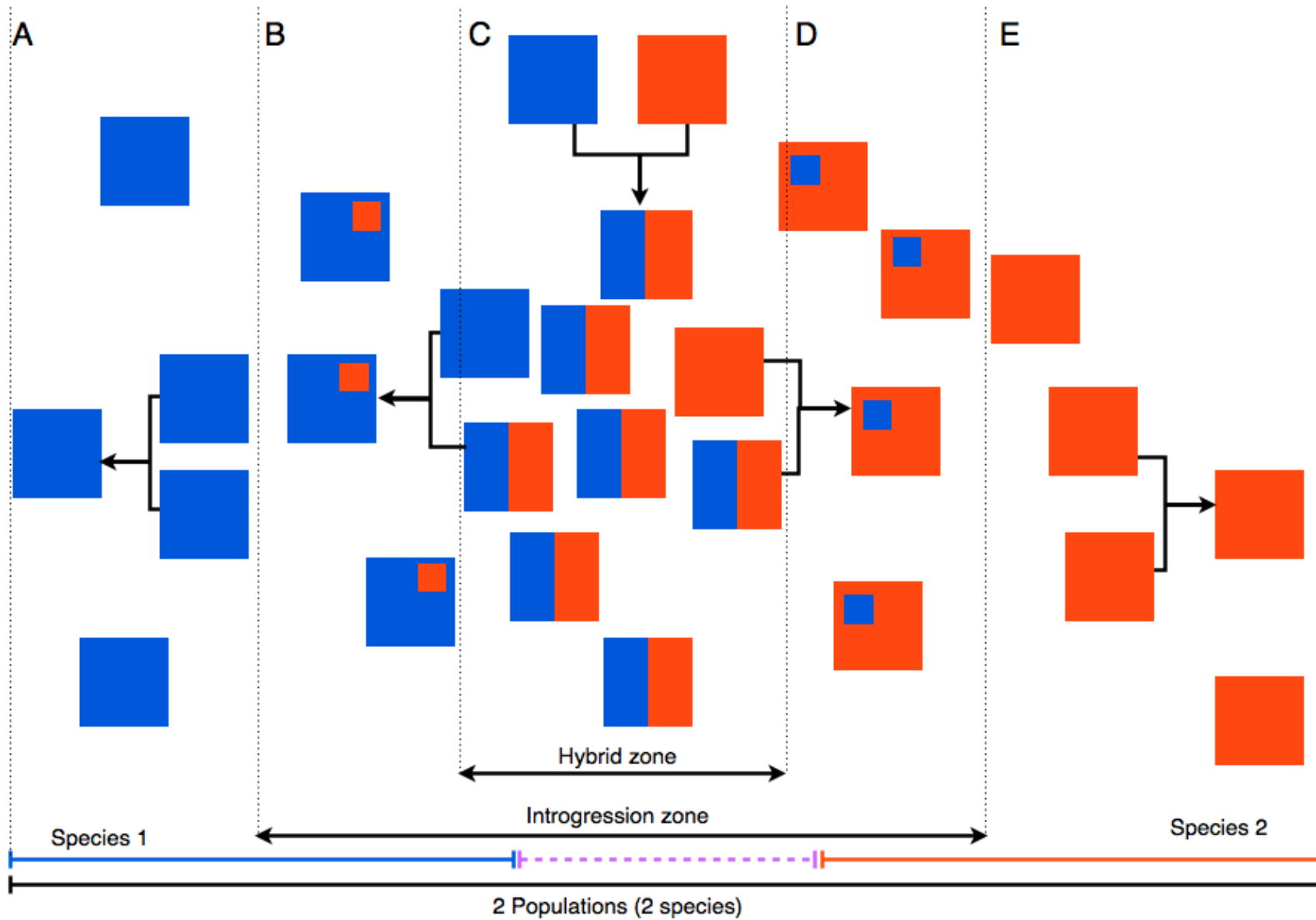
Emperor Goose





Argentine Ruddy Duck

The consequences of hybridization: Introgression



Introgression is the exchange of genetic material

For example: humans and Neanderthals

Got Neanderthal DNA?

An estimated 3.0% of your DNA is from Neanderthals.

Jente Ottenburghs (you)



3.0%

89th percentile

Average 23andMe user

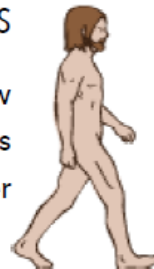


2.7%

For better comparison with your ethnic group, please complete your profile.

MODERN HUMANS

Higher brow
Narrower shoulders
Slightly taller

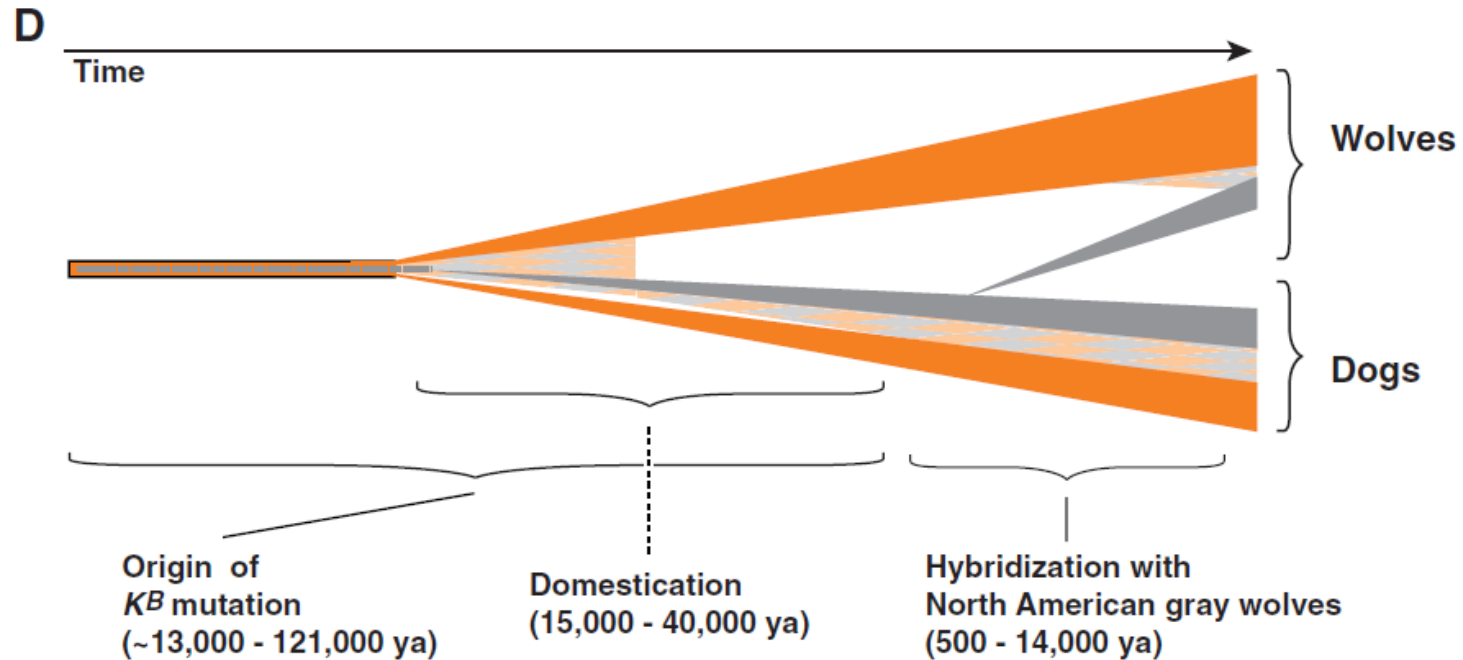
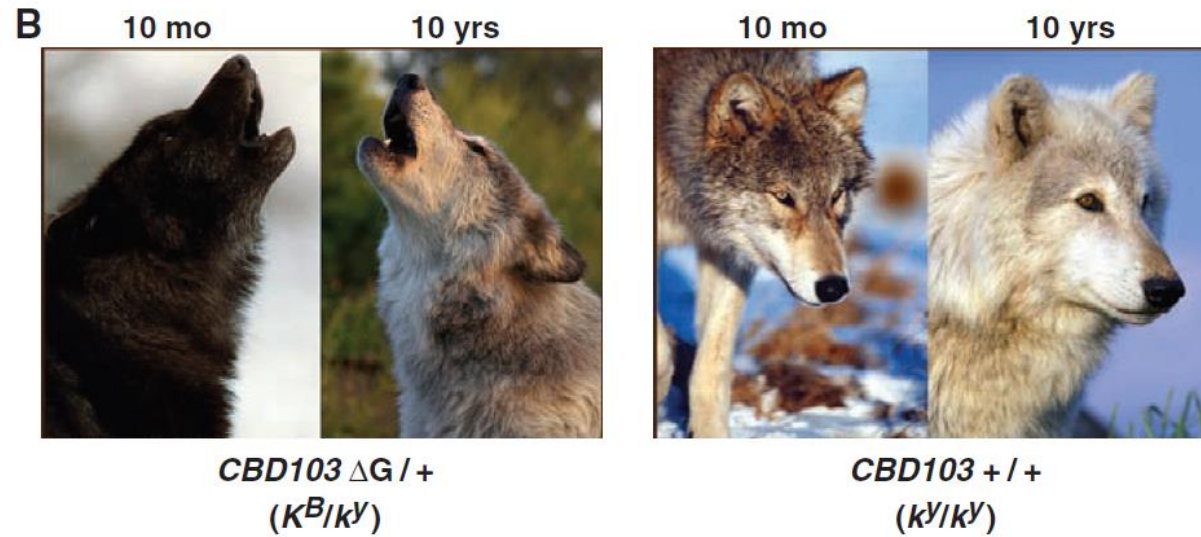


NEANDERTHALS

Heavy eyebrow ridge
Long, low, bigger skull
Prominent nose with developed nasal chambers for cold-air protection



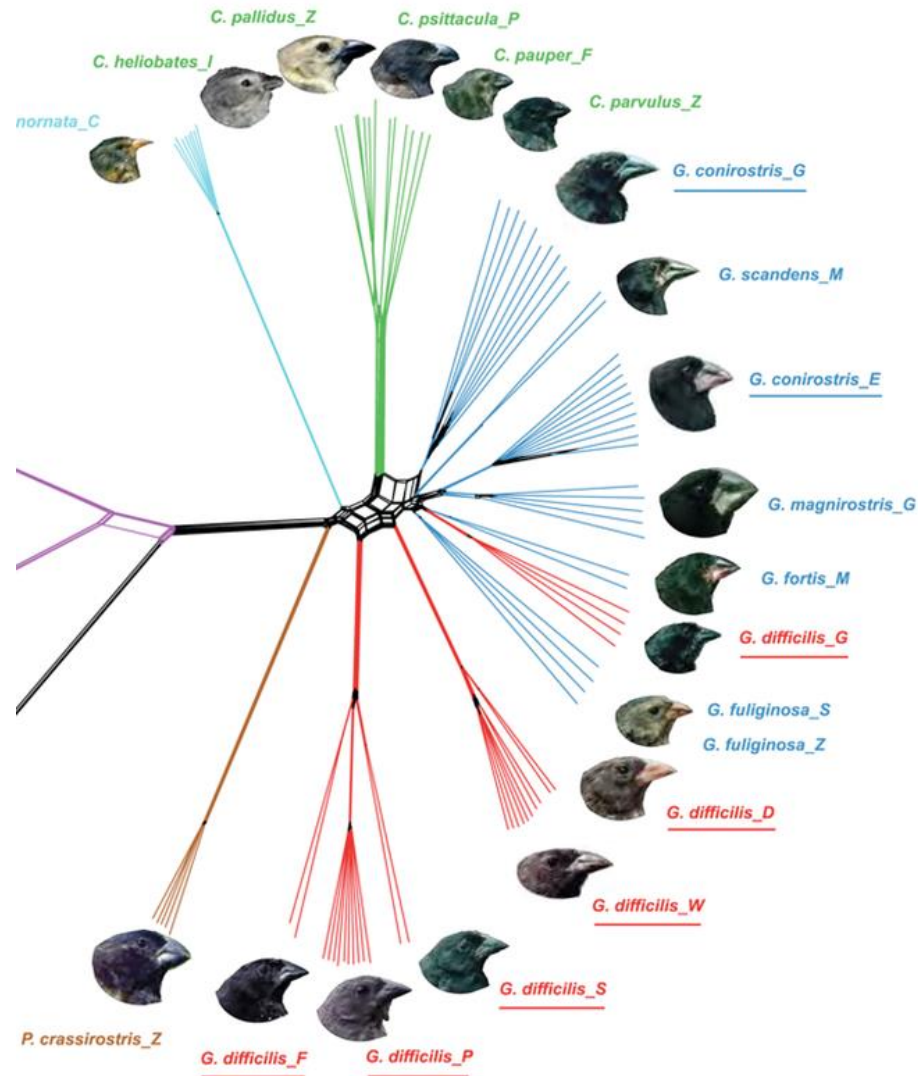
Adaptive Introgression: Exchanged DNA is beneficial



Adaptive Introgression: Exchanged DNA is beneficial

Darwin's Finches

Genes involved in beak morphology



American Buntings

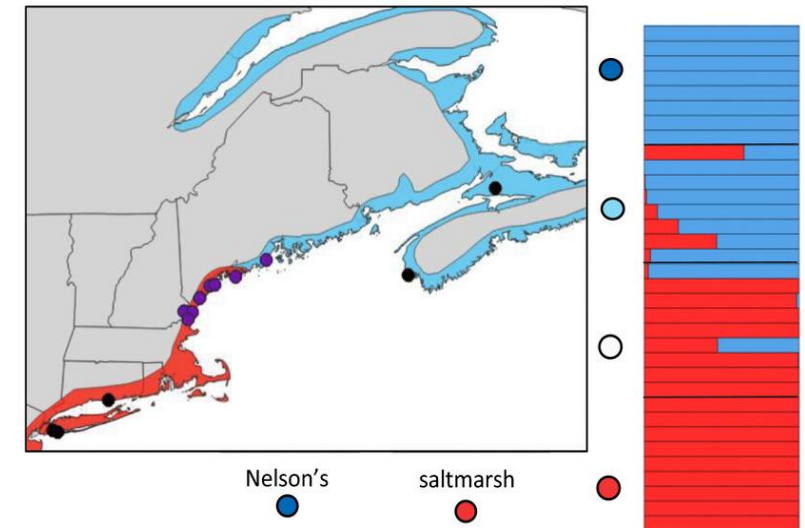
Genes for adaptation to salty environment



Saltmarsh sparrow



Nelson's sparrow

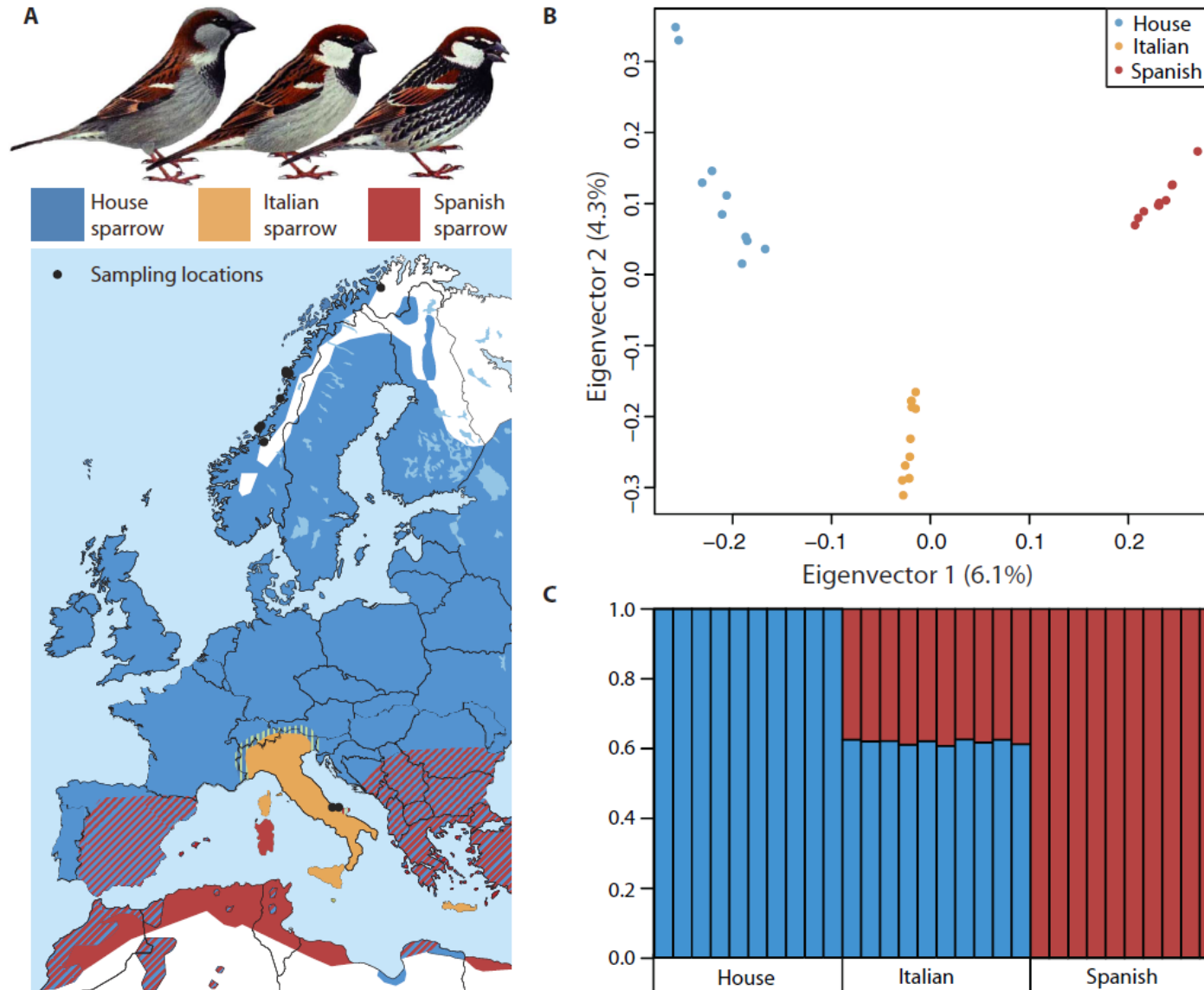


Walsh et al. (2018) *Evolution*

Lamichhaney et al. (2015) *Nature*

Hybrid Speciation: 1 + 1 = 3

House Sparrow x Spanish Sparrow = Italian Sparrow



Genetic admixture supports an ancient hybrid origin of the endangered Hawaiian duck

P. LAVRETSKY*, A. ENGILIS JR†‡, J. M. EADIE† & J. L. PETERS*

*Department of Biological Sciences, Wright State University, Dayton, OH, USA

†Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, Davis, CA, USA

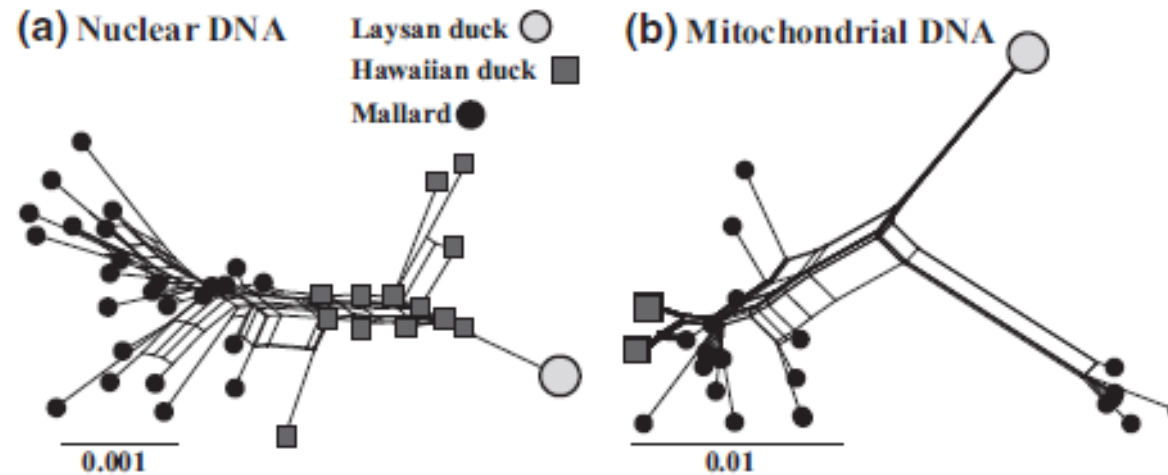
‡Museum of Wildlife and Fish Biology, Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, Davis, CA, USA



Hawaiian Duck

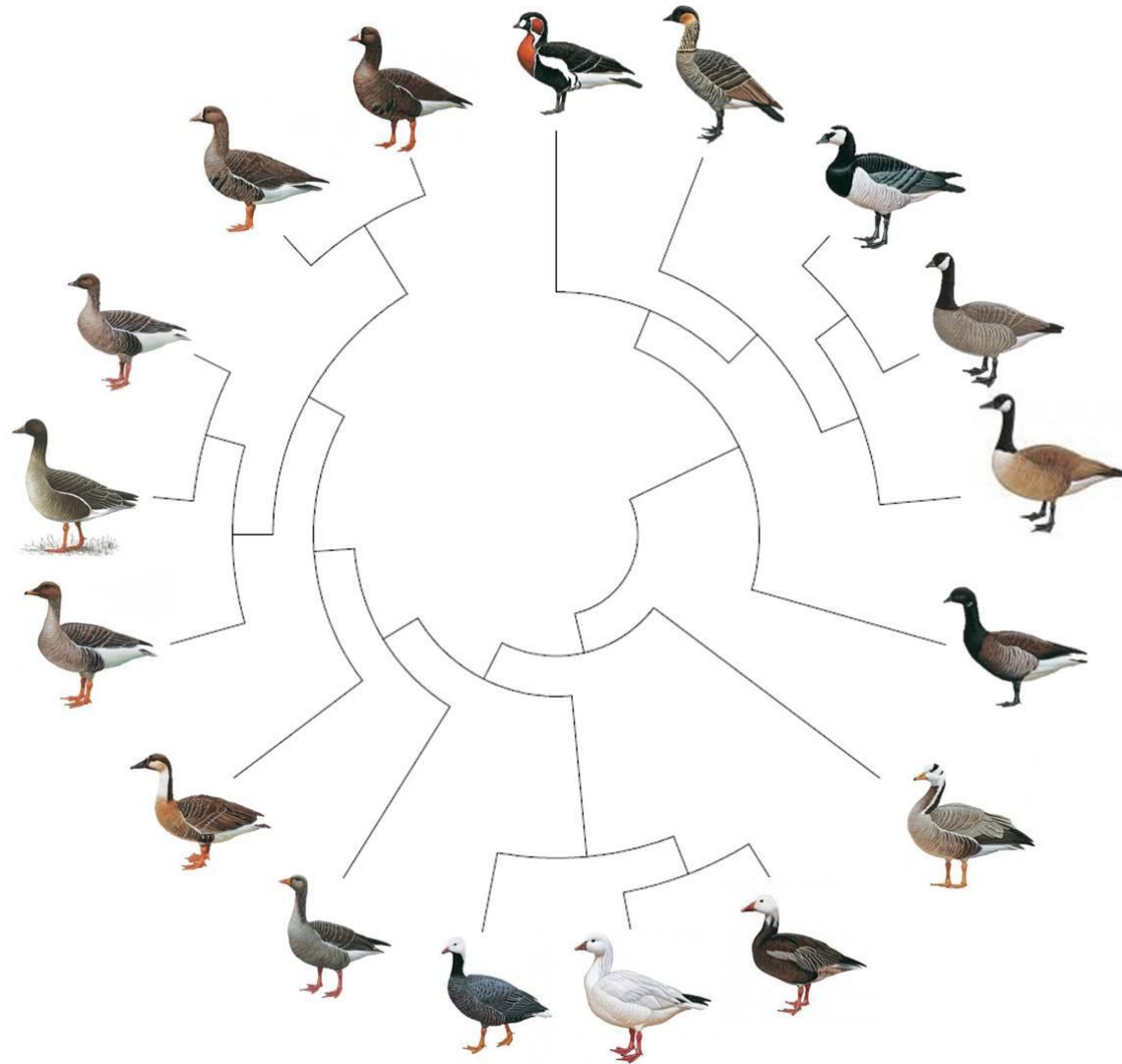


Mallard



Laysan Duck

Study System – The True Geese



Livezey (1996)

Donne-Gousse *et al.* (2002)

Gonzalez *et al.* (2009)

Greater White-fronted Goose
(*A. albifrons*)



Lesser White-fronted Goose
(*A. erythropus*)



Ruokonen *et al.* (2000)

Lee *et al.* (2008)

Pink-footed Goose
(*A. brachyrhynchus*)



Taiga Bean Goose
(*A. fabalis*)



Phylogeny of geese not resolved

Extensive Hybridization

What is the impact of hybridization on the evolutionary history of geese?



19 Goose Genomes

100bp PE
10-15X Coverage



Anser ("Grey Geese")

Greater White-fronted Goose (*A. albifrons*)

Lesser White-fronted Goose (*A. erythropus*)

Pink-footed Goose (*A. brachyrhynchus*)

Tundra Bean Goose (*A. serrirostris*)

Taiga Bean Goose (*A. fabalis*)

Bar-headed Goose (*A. indicus*)

Greylag Goose (*A. anser*)

Swan Goose (*A. cygnoides*)



Branta ("Black Geese")

Barnacle Goose (*B. leucopsis*)

Canada Goose (*B. canadensis*)

Cackling Goose (*B. hutchinsii*)

Hawaii Goose (*B. sandvicensis*)

Red-breasted Goose (*B. ruficollis*)

Brent Goose (*B. bernicla*) [3 subspecies]



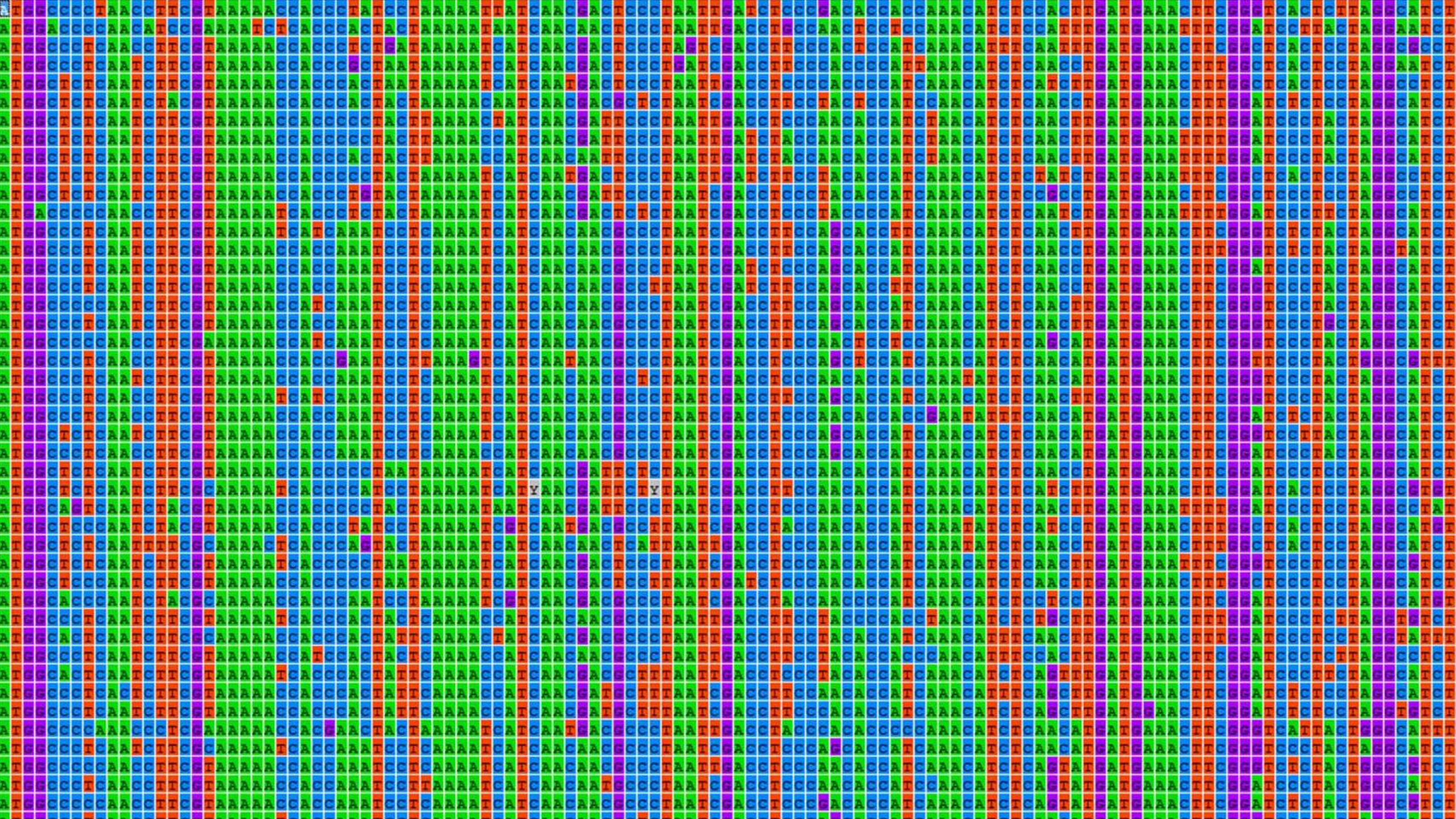
Anser ("White Geese")

Snow Goose (*A. caerulescens*)

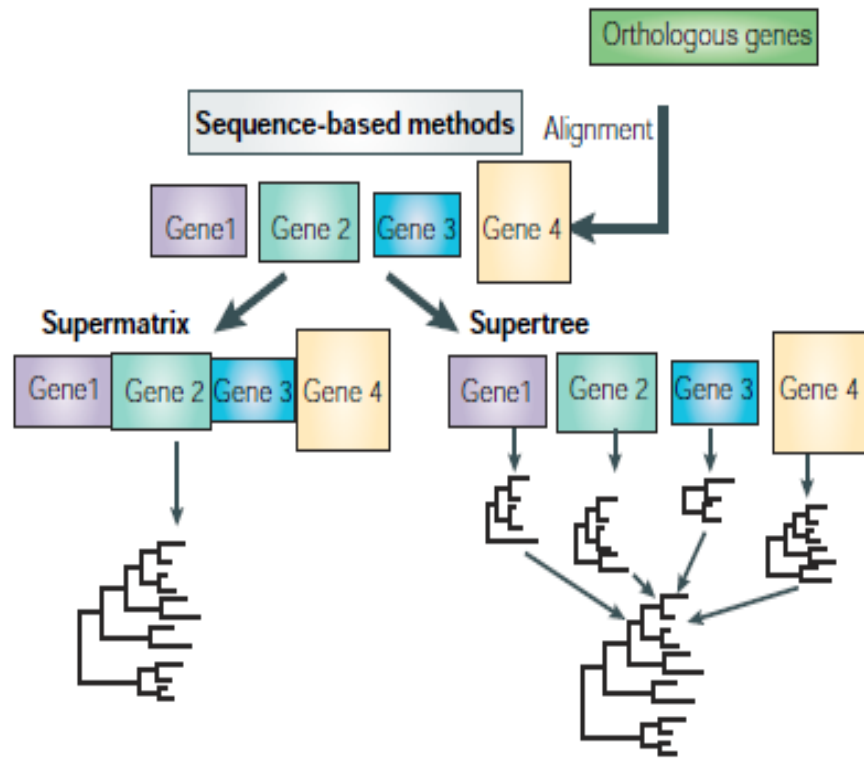
Ross' Goose (*A. rossii*)

Emperor Goose (*A. canagicus*)

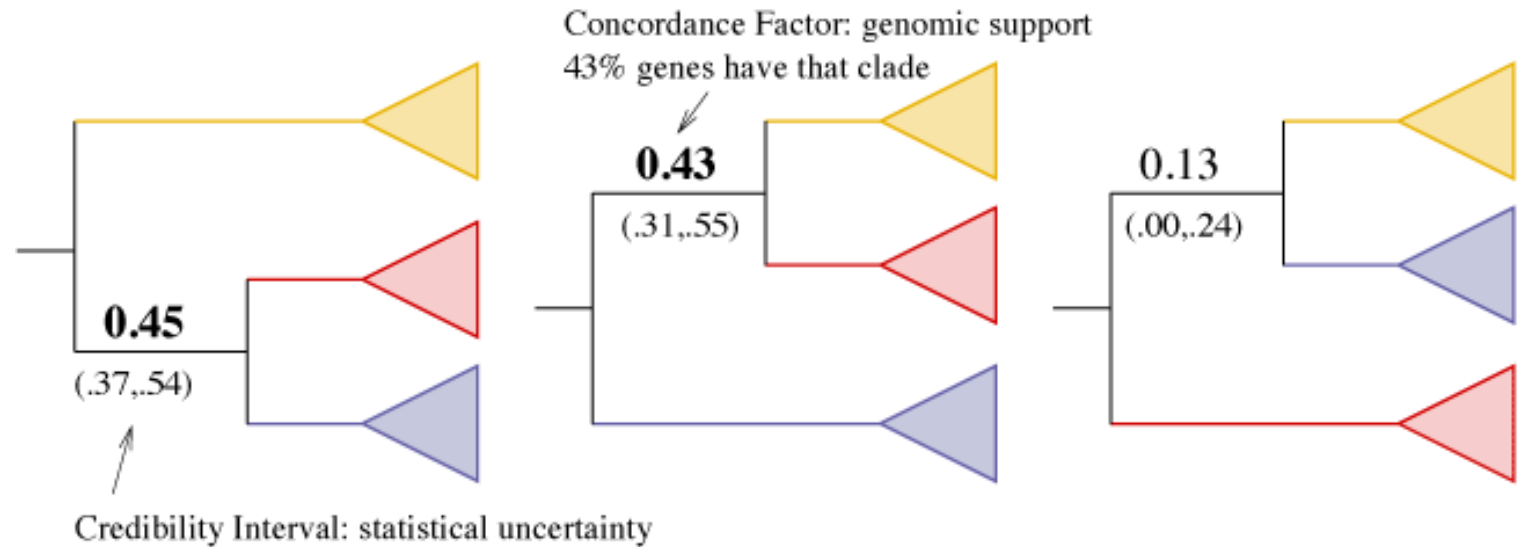
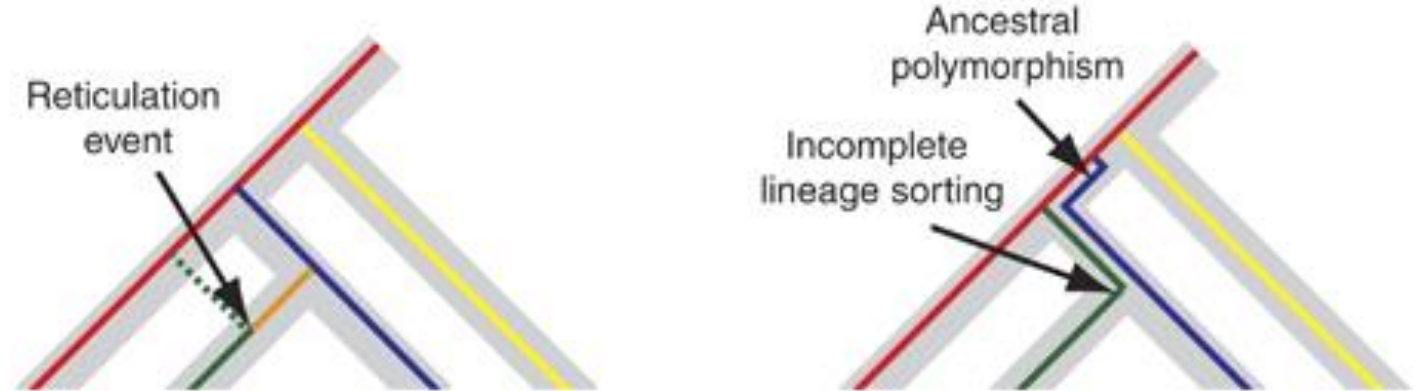




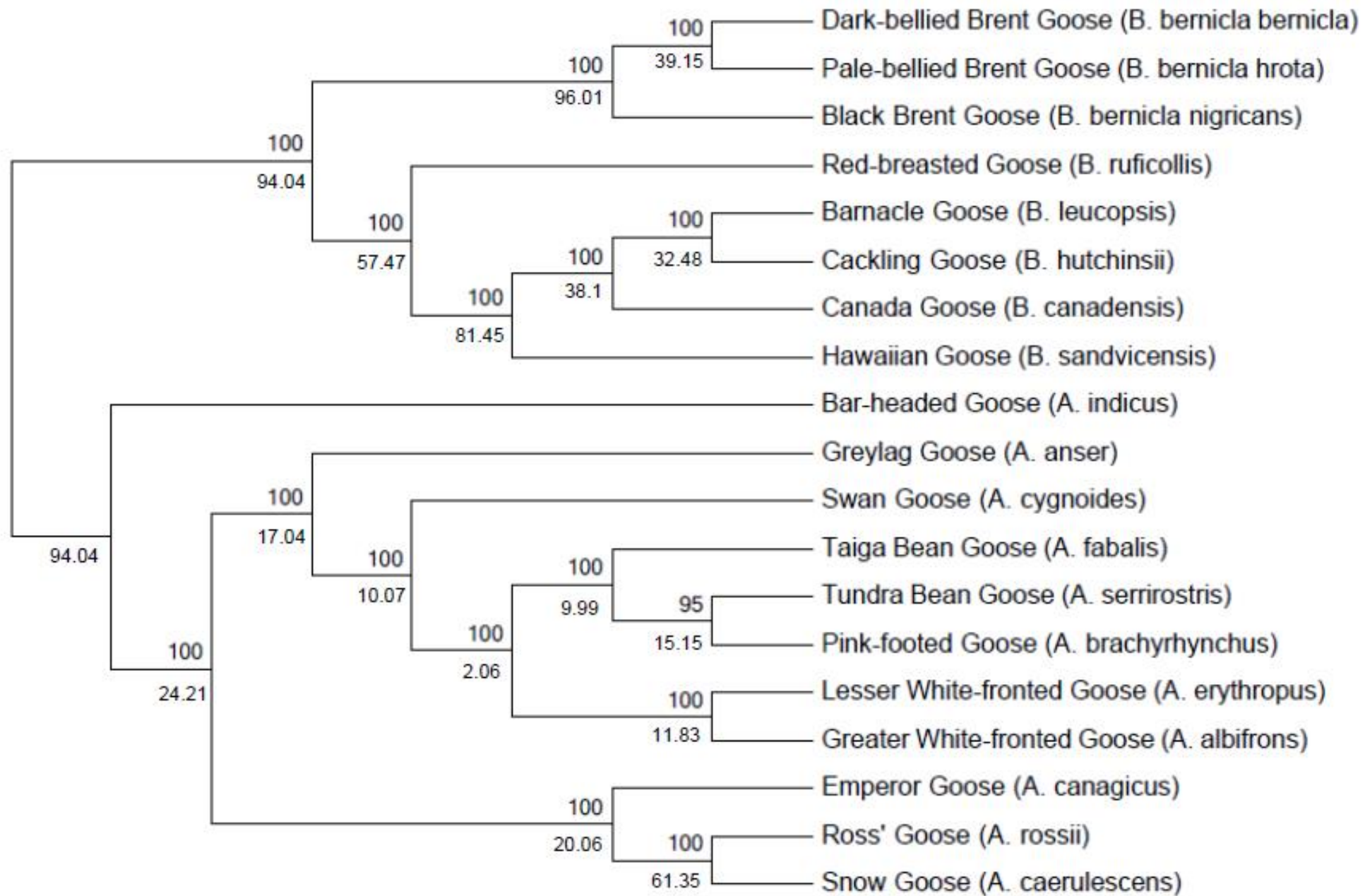
Estimating the Species Tree



Delsuc *et al.* 2005 *Nature Reviews Genetics*



Degnan & Rosenberg (2009) *Trends in Ecology & Evolution*



Legend

- Brent Goose
- Cackling Goose
- Barnacle Goose
- Canada Goose
- Hawaiian Goose
- Red-breasted Goose

Red-breasted Goose
Branta ruficollis

Brent Goose
Branta bernicla

Barnacle Goose
Branta leucopsis

Cackling Goose
Branta hutchinsii

Canada Goose
Branta canadensis

Hawaiian Goose
Branta sandvicensis

Year
present

1 M

2 M

3 M

4 M

5 M

6 M

7 M

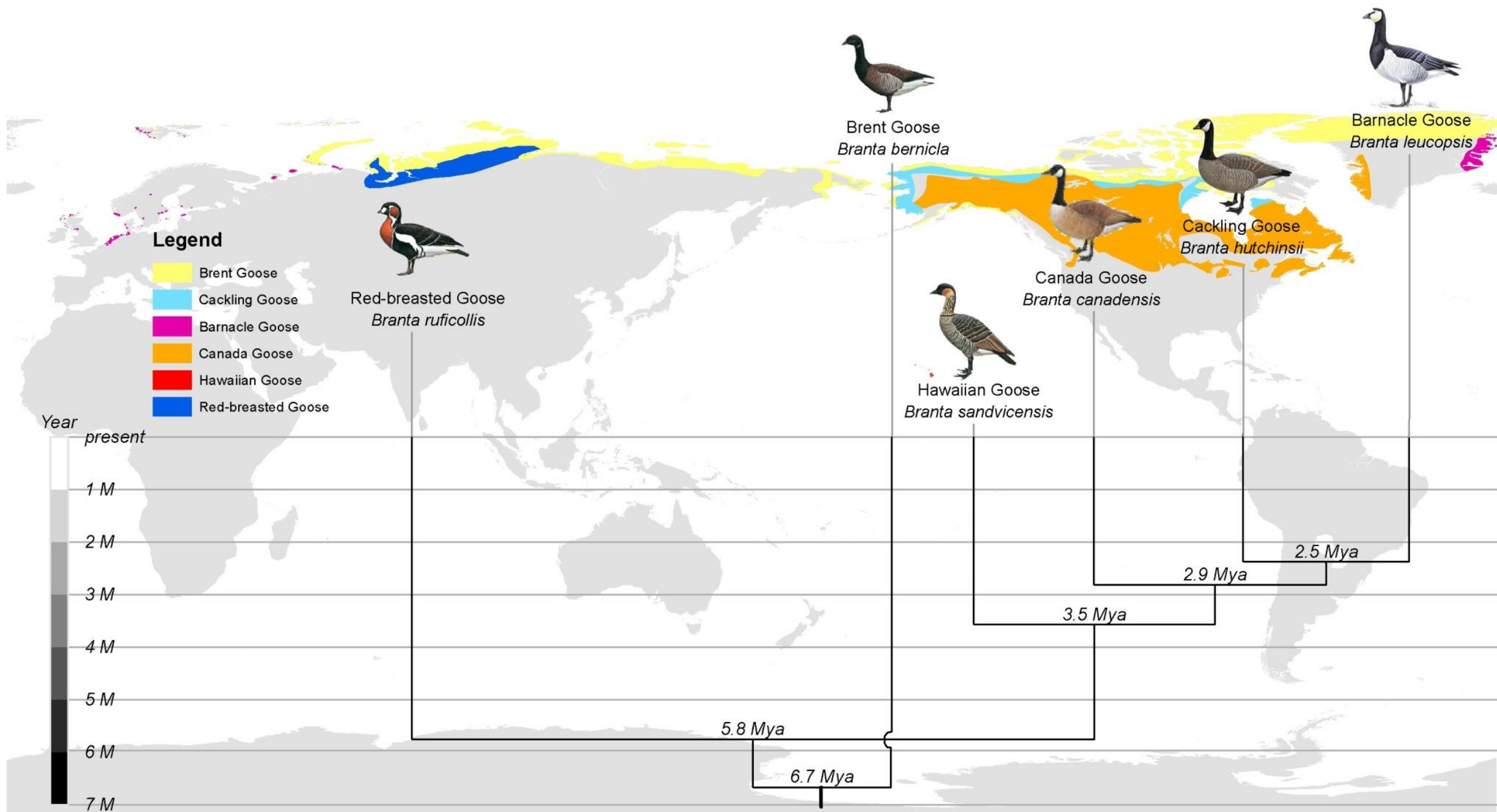
5.8 Mya

6.7 Mya

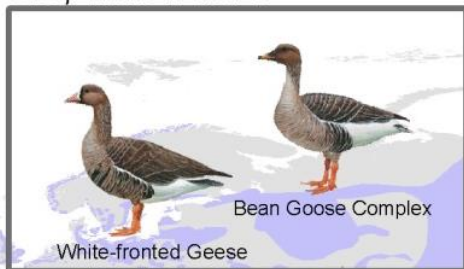
3.5 Mya

2.9 Mya

2.5 Mya



see panels C and D



Legend

- Greylag Goose
- Swan Goose
- Emperor Goose
- Ross Goose
- Snow Goose
- Bar-headed Goose

Year
present
1 M
2 M
3 M
4 M
5 M

2.8 Mya

3.1 Mya

3.4 Mya

3.9 Mya

4.5 Mya

3.5 Mya

2.1 Mya



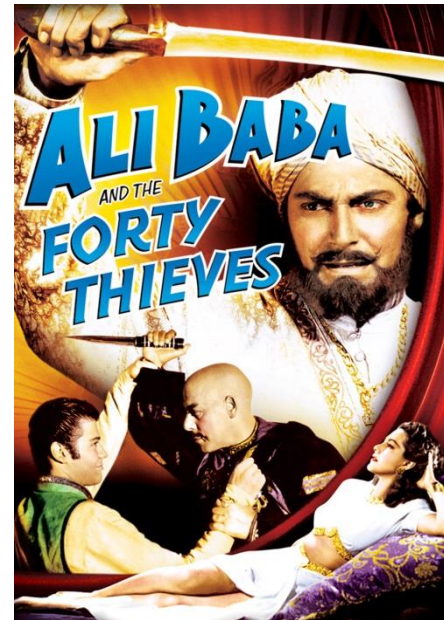
Finding Introgression

D-statistic

$$D(P_1, P_2, P_3, O) = \frac{\sum_{i=1}^n C_{ABBA}(i) - C_{BABA}(i)}{\sum_{i=1}^n C_{ABBA}(i) + C_{BABA}(i)}.$$



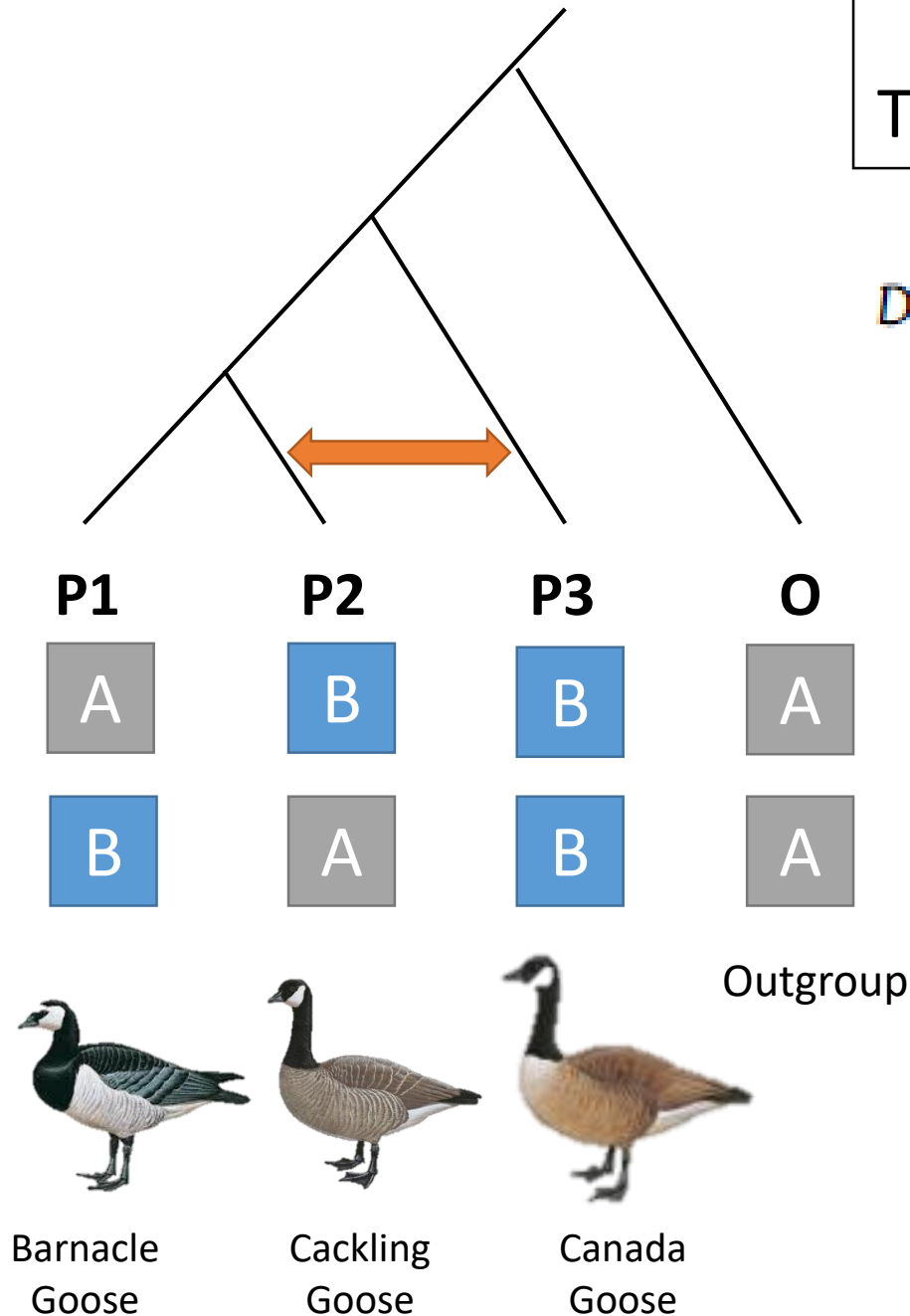
ABBA



BABA

If $D \neq 0$ and Z-score > 3
 T=then there has been introgression

$$D(P_1, P_2, P_3, O) = \frac{\sum_{i=1}^n C_{ABBA}(i) - C_{BABA}(i)}{\sum_{i=1}^n C_{ABBA}(i) + C_{BABA}(i)}$$

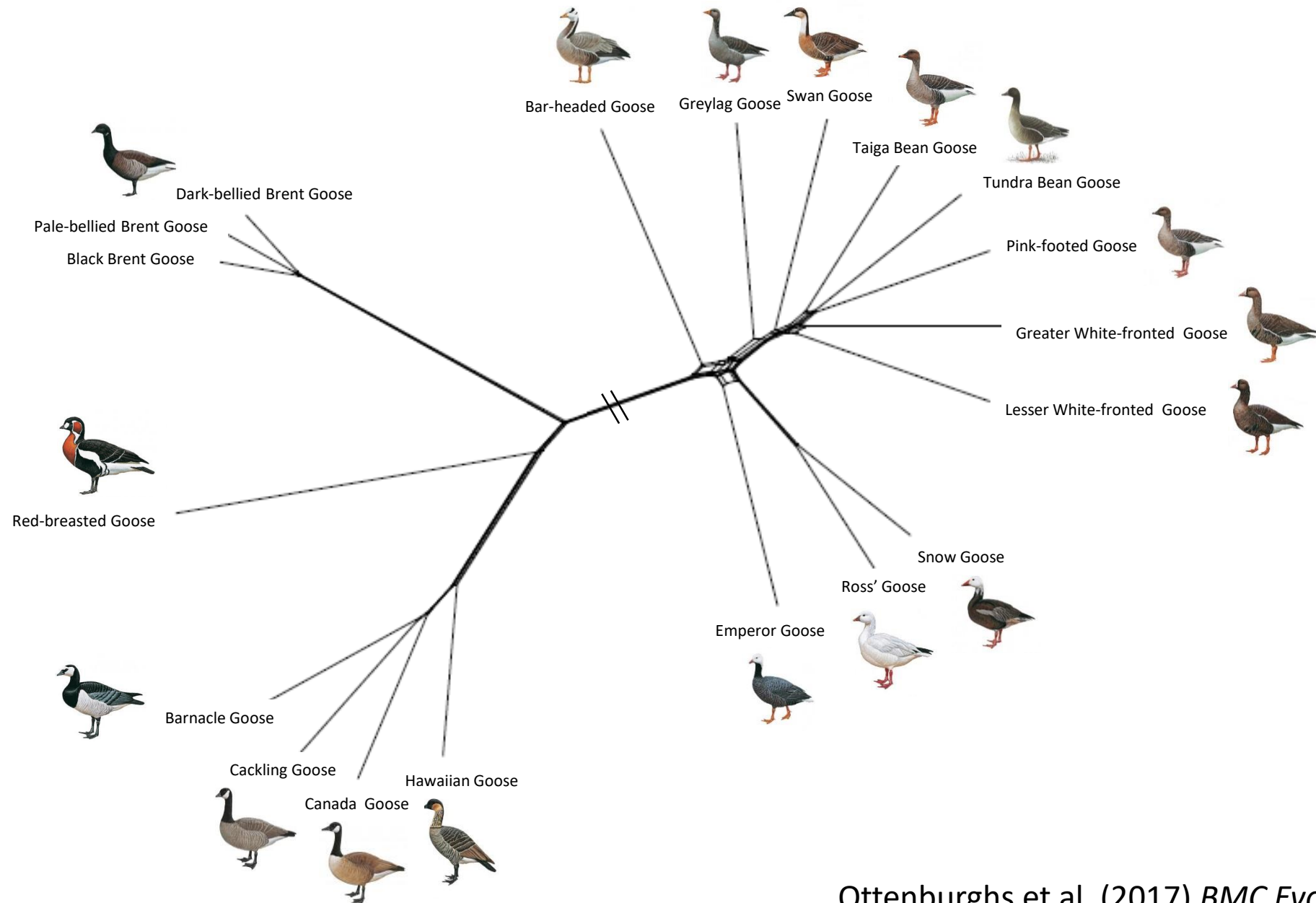


18,937

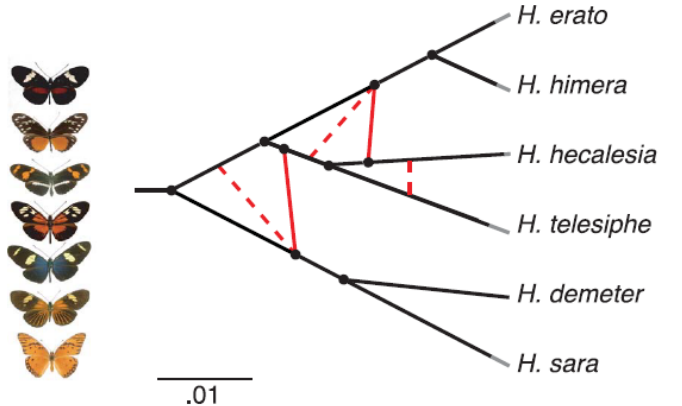
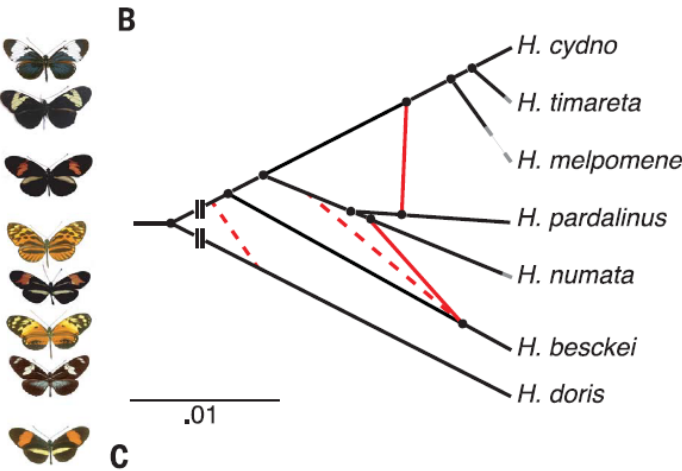
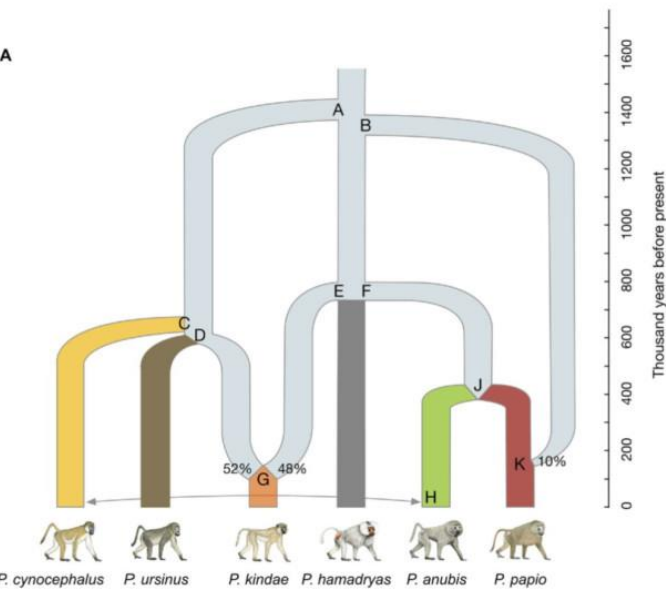
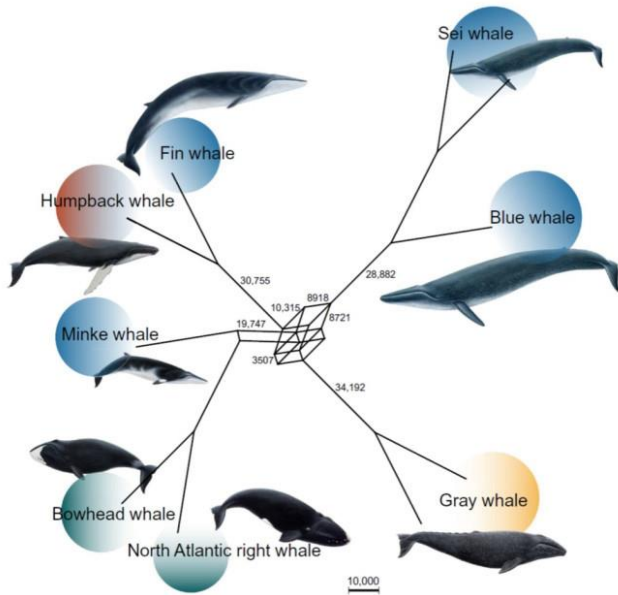
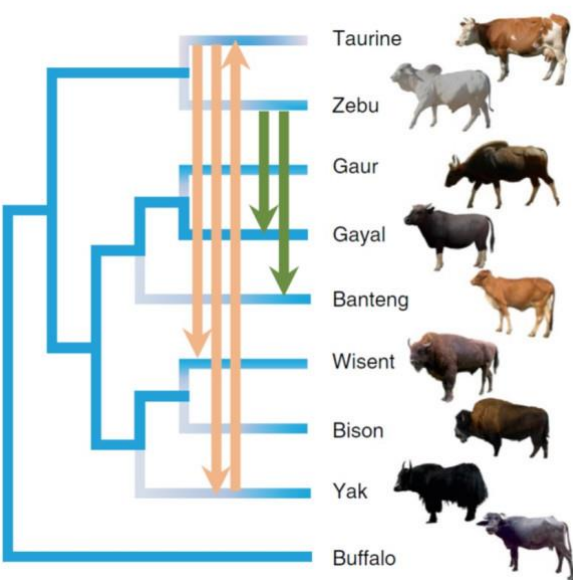
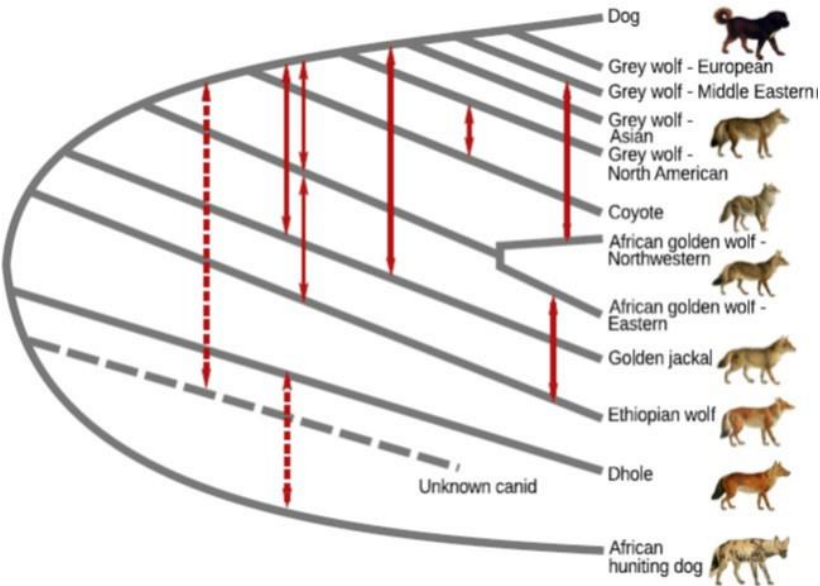
15,896

D = 0.087
Z-score = 4.32

It's not a tree but a network



Not only in birds...



Hybridization Networks



Is the Red-breasted Goose a hybrid species?



Ottenburghs *et al.* (2017) *BMC Evolutionary Biology*
Ottenburghs (2018) *Ecology and Evolution*

What is a species?

The **Biological Species Concept** defines a species as members of populations that actually or potentially interbreed in nature

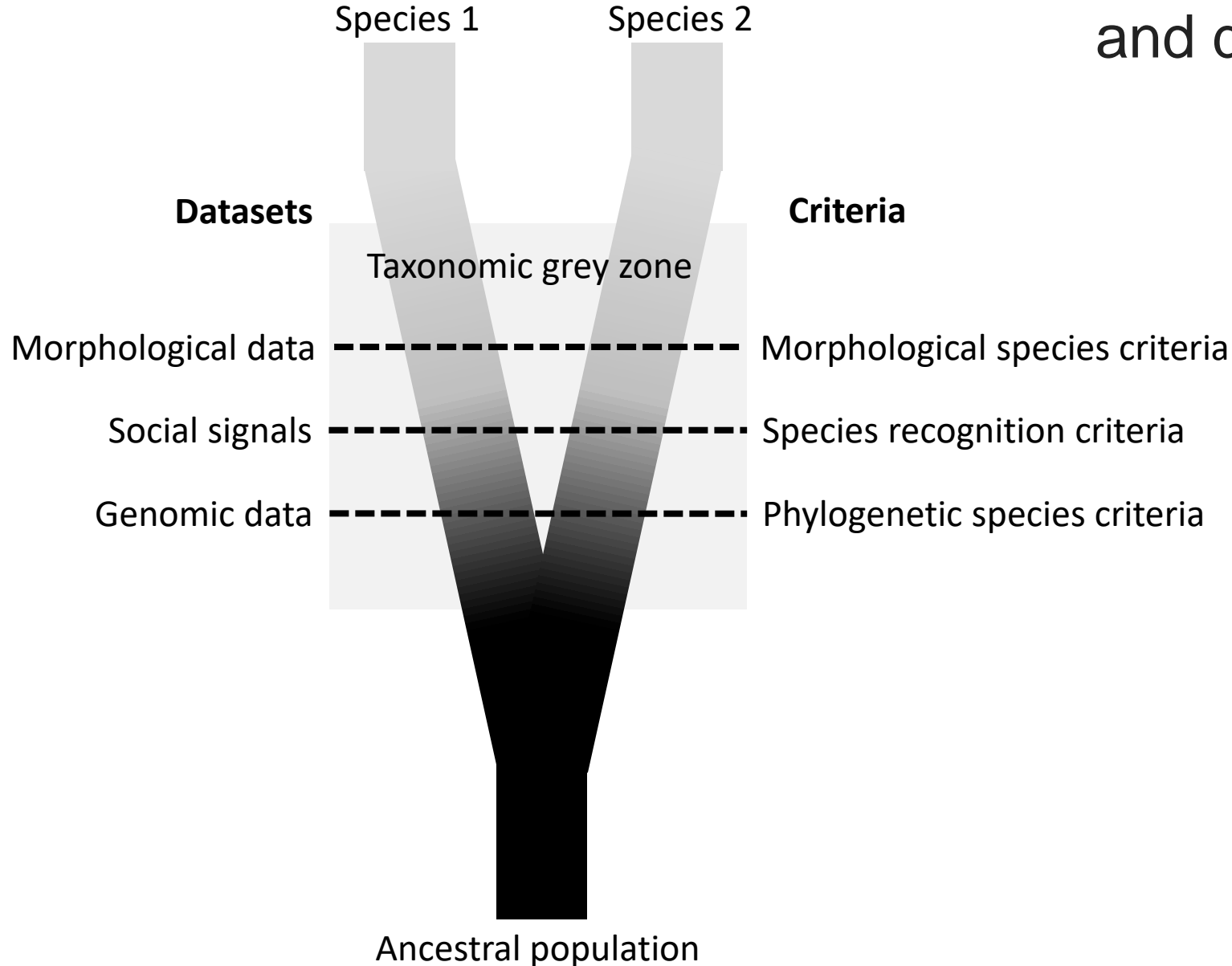


What is a species?

Mayden (1997): 24 species concepts

- Agamospecies Concept (ASC)
- Biological Species Concept (BSC)
- Cladistic Species Concept (ClSC)
- Cohesion Species Concept (CSC)
- Composite Species Concept (CpSC)
- Ecological Species Concept (EcSC)
- Evolutionary Species Concept (ESC)
- Evolutionary Significant Unit (ESU)
- Genealogical Concordance Concept (GCC)
- Genetic Species Concept (GSC)
- Hennigian Species Concept (HSC)
- Internodal Species Concept (ISC)
- Morphological Species Concept (MSC)
- Non-dimensional Species Concept (NDSC)
- Phenetic Species Concept (PhSC)
- Phylogenetic Species Concept (PSC)
 - Diagnosable Version
 - Monophyly Version
 - Diagnosable and Monophyly Version
- Polythetic Species Concept (PtSC)
- Recognition Species Concept (RSC)
- Reproductive Competition Concept (RCC)
- Successional Species Concept (SSC)
- Taxonomic Species Concept (TSC)

Speciation is a gradual process
and different criteria arise at
different times



What is a species?



Taiga Bean Goose



Tundra Bean Goose

Subtle differences in beak morphology

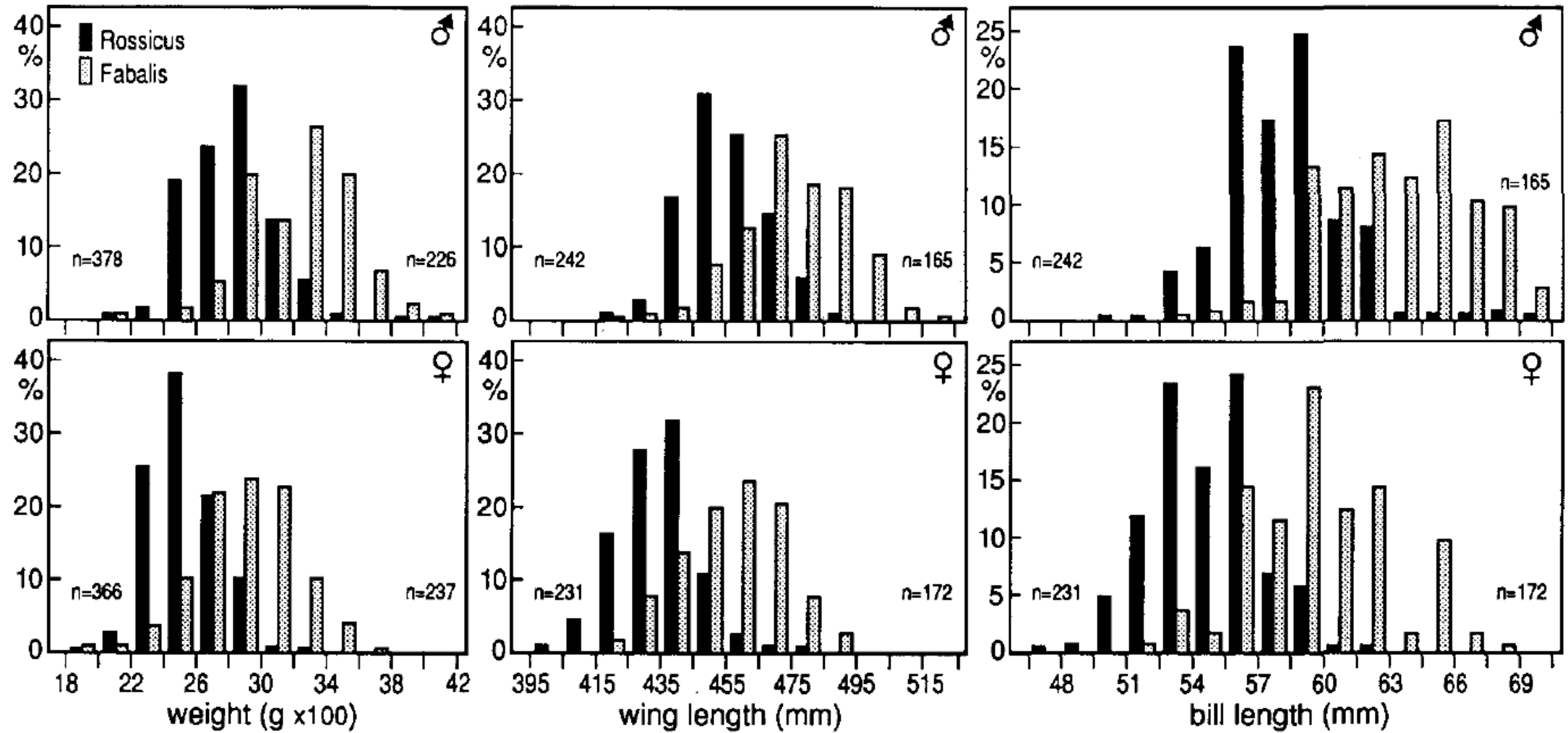


Fig. 3. Frequency distributions of weight, wing and bill lengths of adult *rossicus* (black) and adult *fabalis* geese (white).

Different breeding sites and migration routes

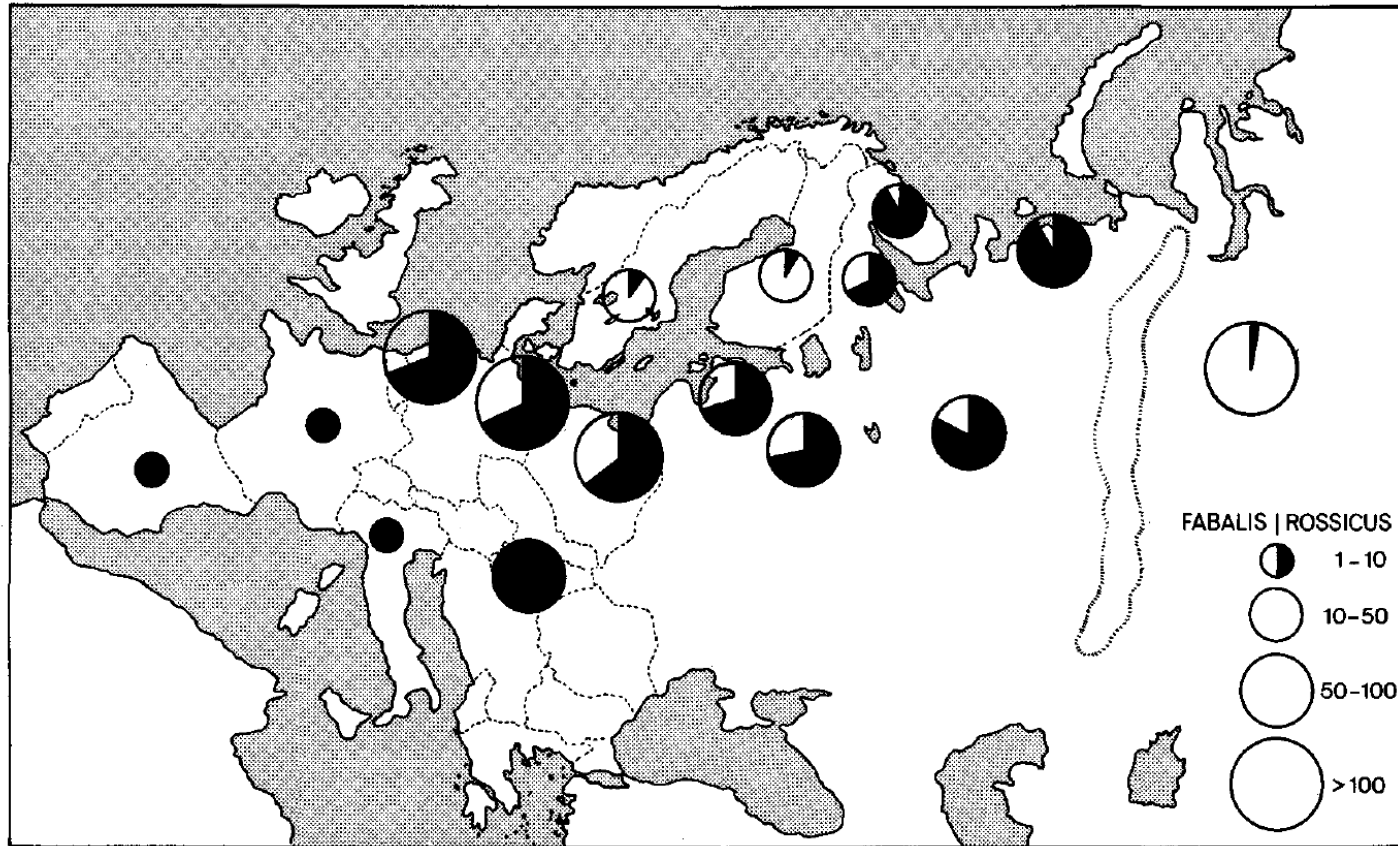


Fig. 4. Proportional Bean Goose recoveries per country or per area.

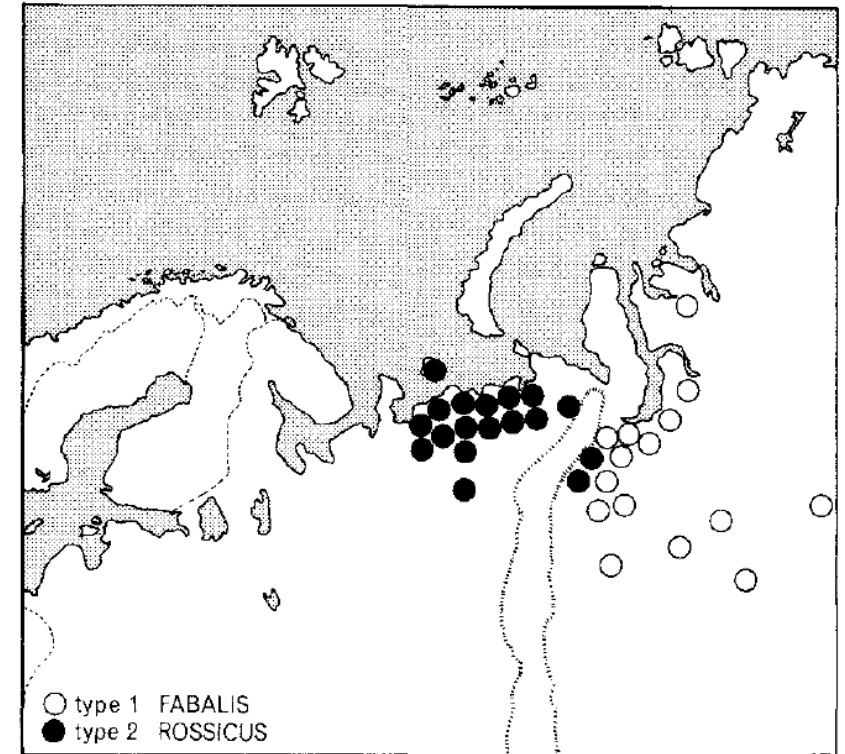
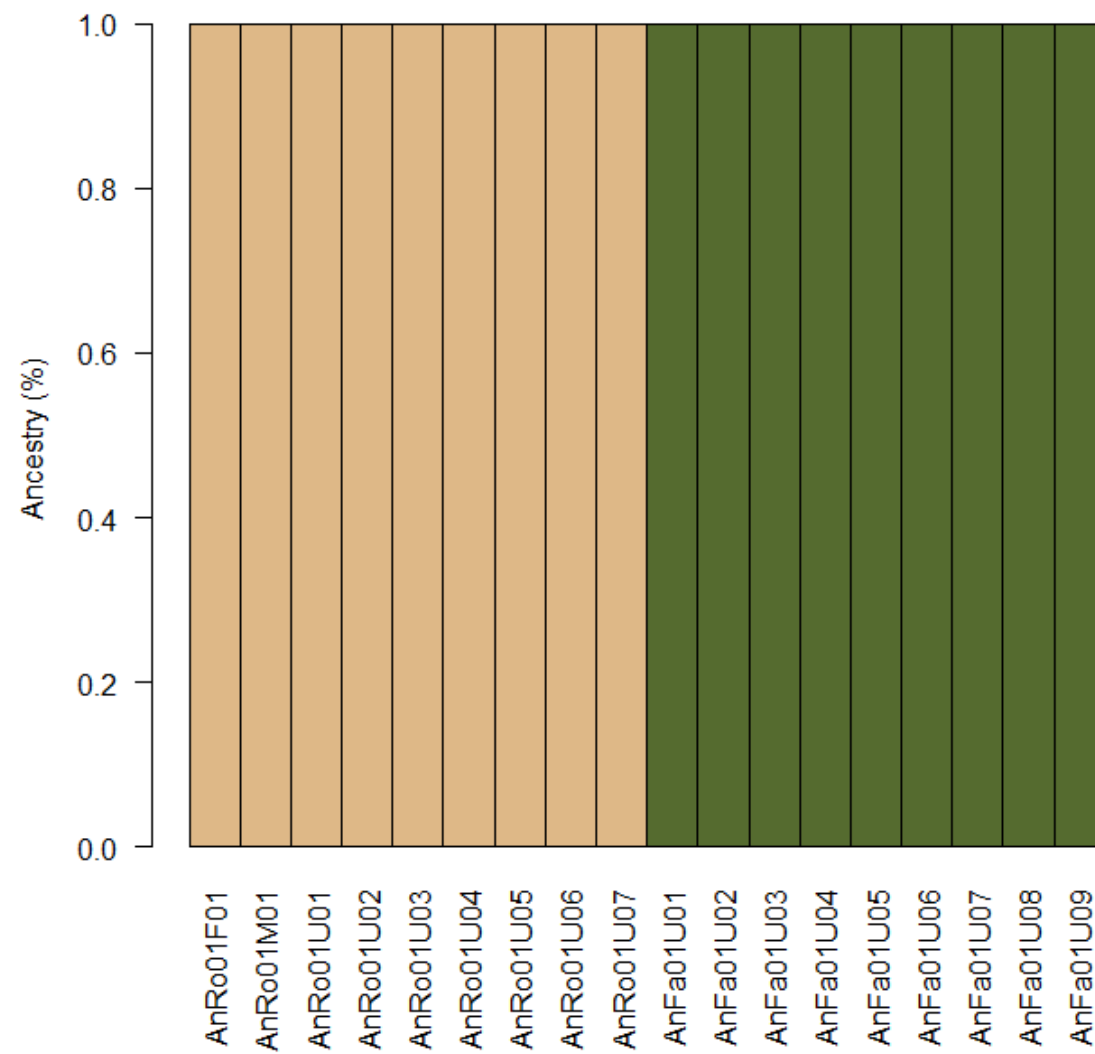
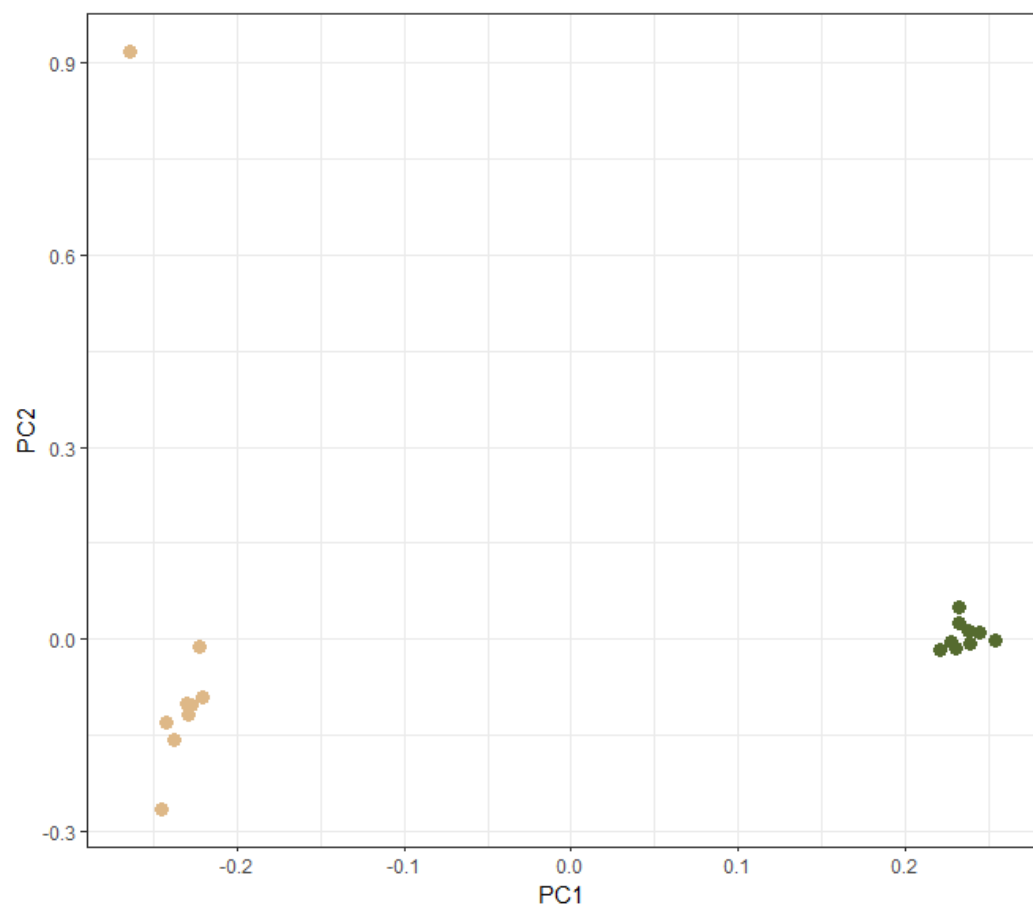
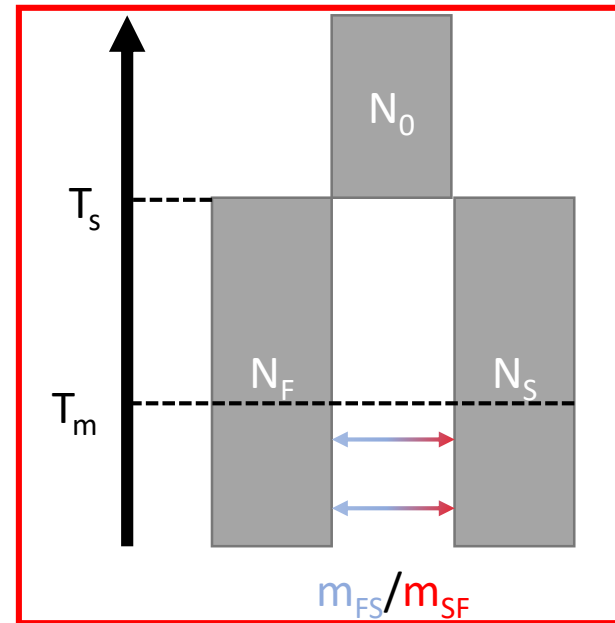
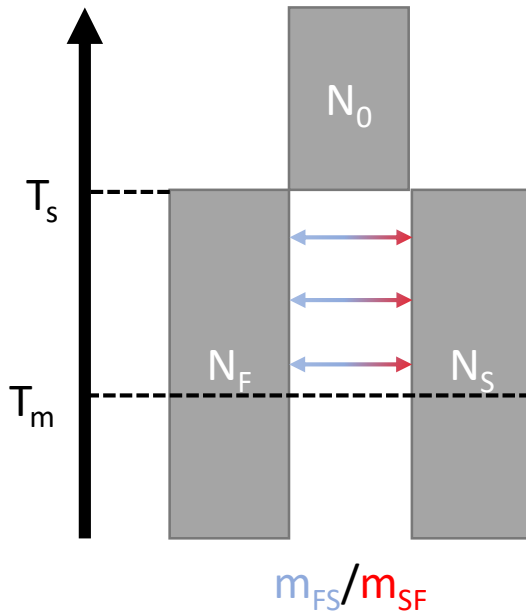
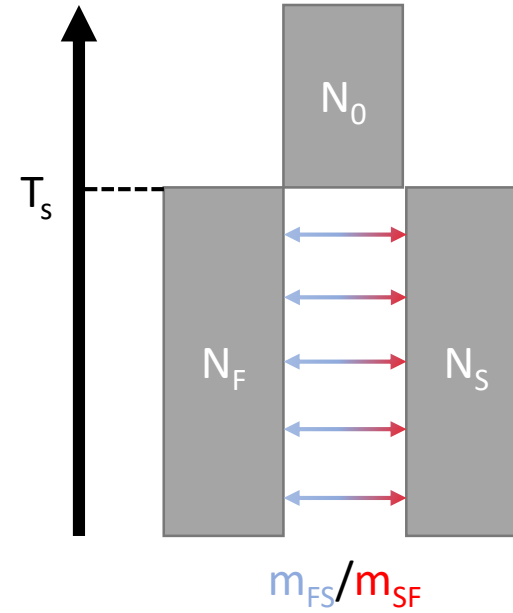
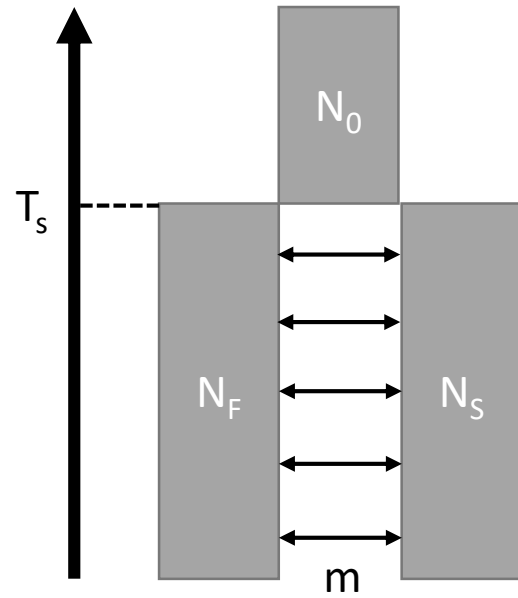


Fig. 6. Recoveries of Bean Geese during the breeding season (freshly killed birds only).

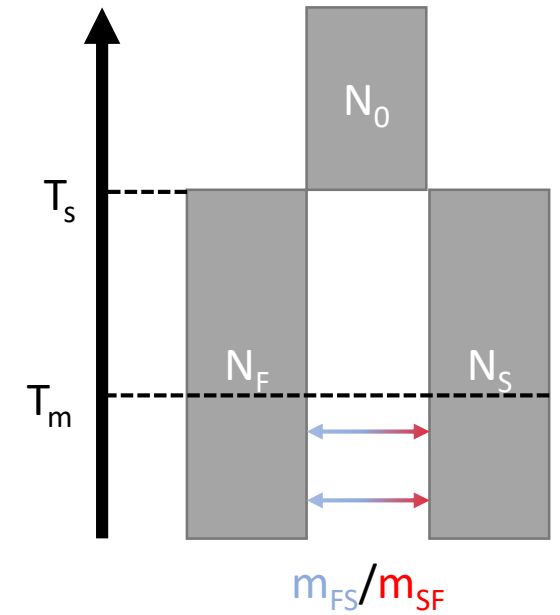
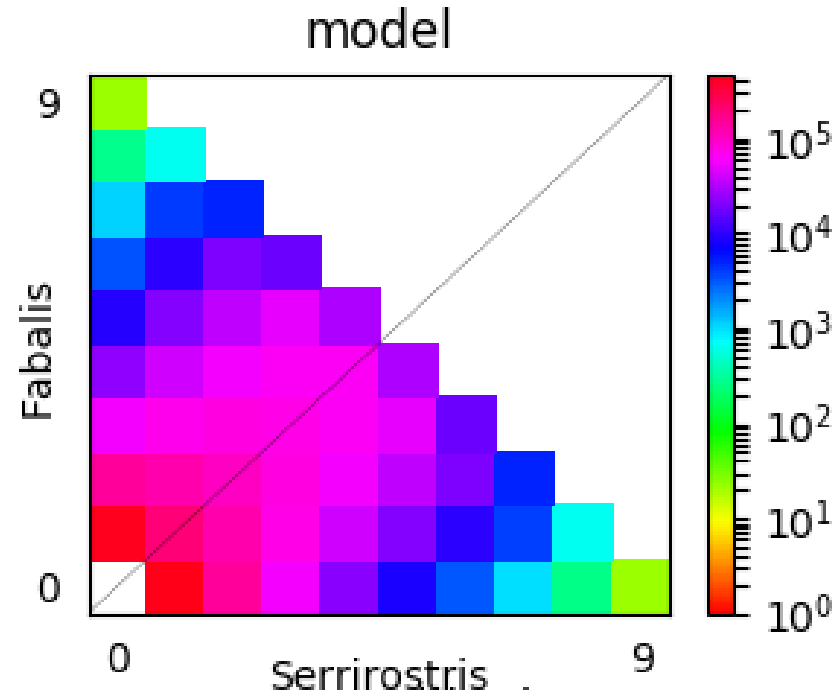
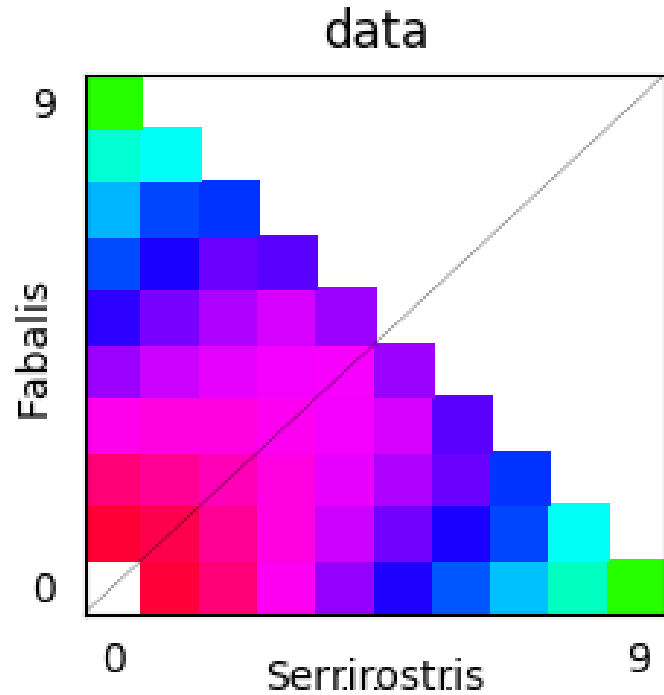
They can be separated genetically...



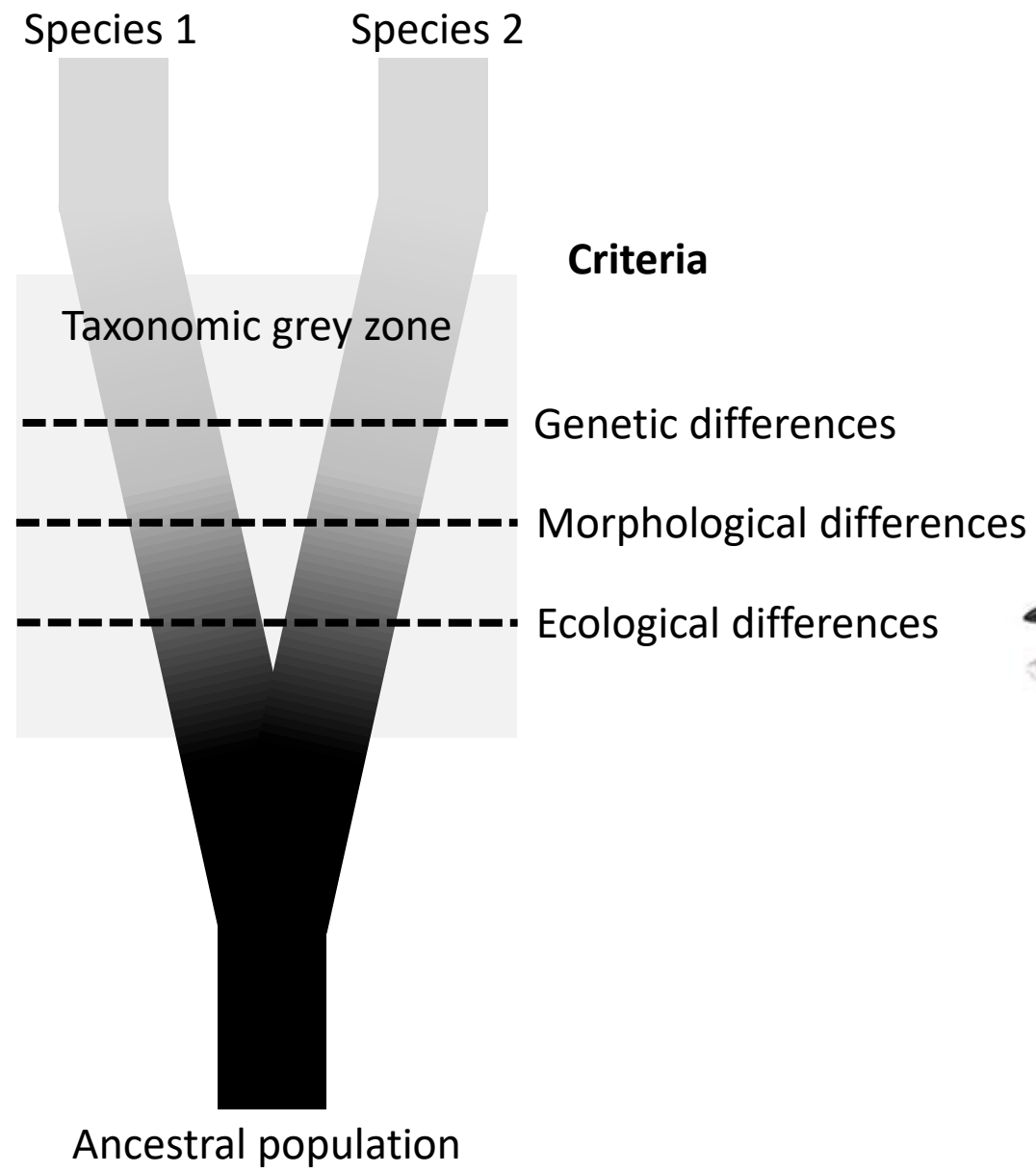
Did Taiga and Tundra Bean Goose exchange DNA?



**Taiga and Tundra Bean Goose separated about 2,5 million years ago,
but they started hybridizing ca. 60,000 years ago.**



Are they different species?



Taiga Bean Goose



Tundra Bean Goose

Any Questions?

