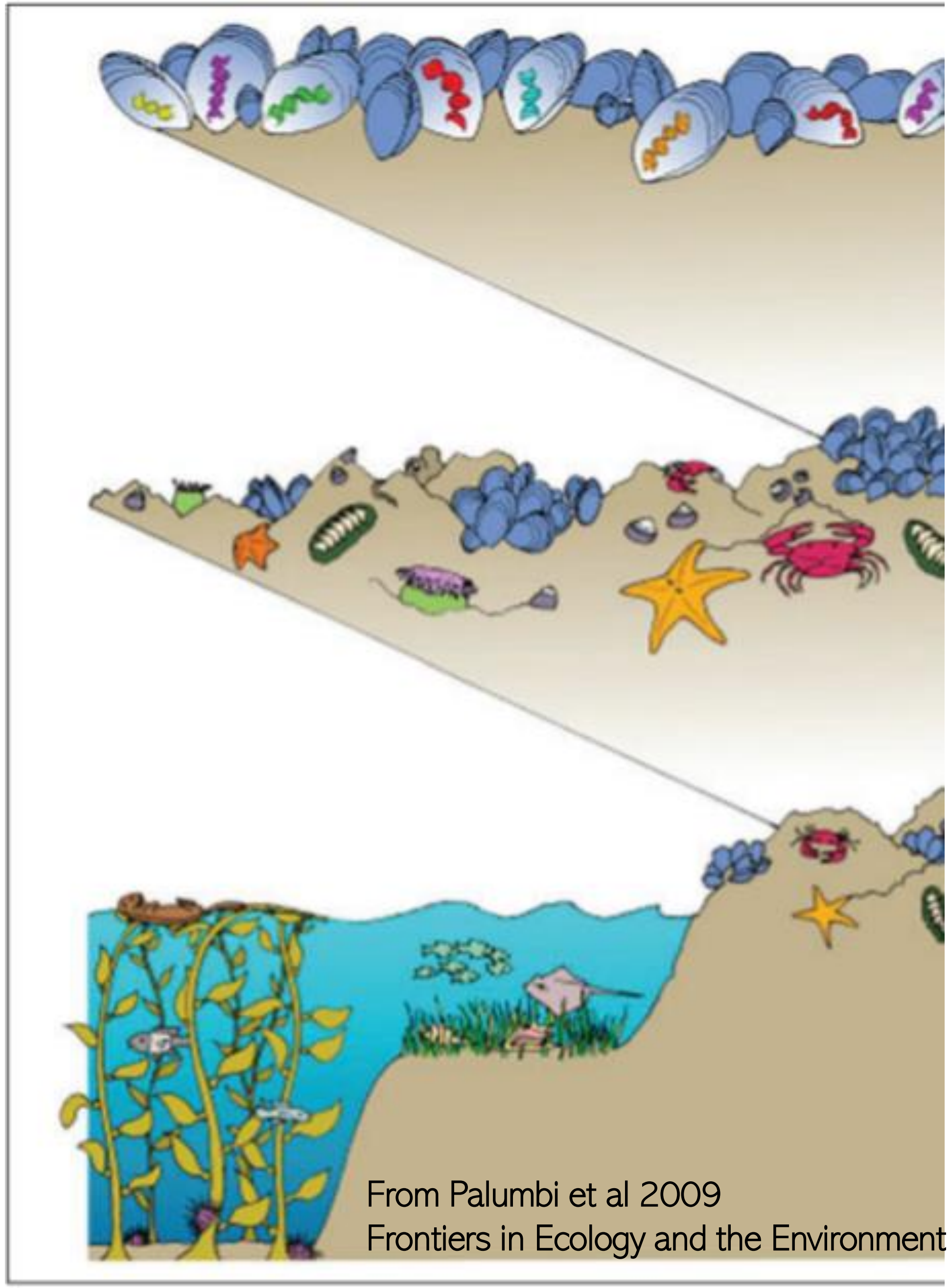
Génomique et Biodiversité

Alice Mouton,
Collaboratrice scientifique, Université de Liège (SEED)
TKT officer, Leibniz Institute for Zoo and Wildlife research (Berlin)
alicemoutonresearch@gmail.com

Séminaire 2 décembre 2022 Cours Biodiversité et Société, Arlon Campus Environnement

Biodiversité?

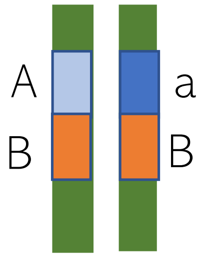


Genetic diversity

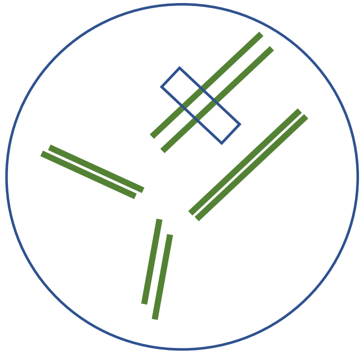
Species diversity

Community/ecosystem diversity

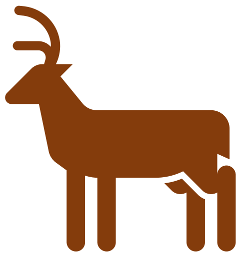
Variations génétiques : différents niveaux



Individuals genes
A and B



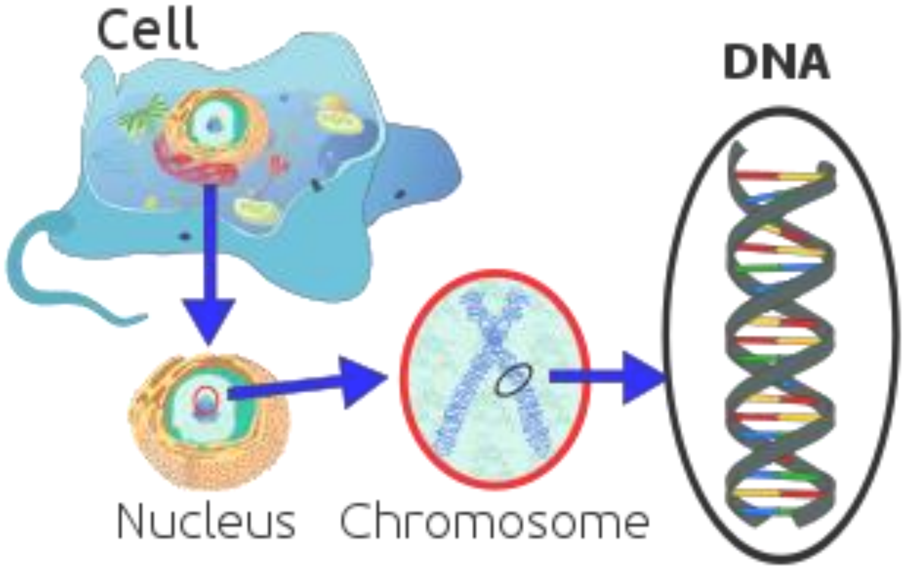
Chromosomes
(one from each parent)



Individual

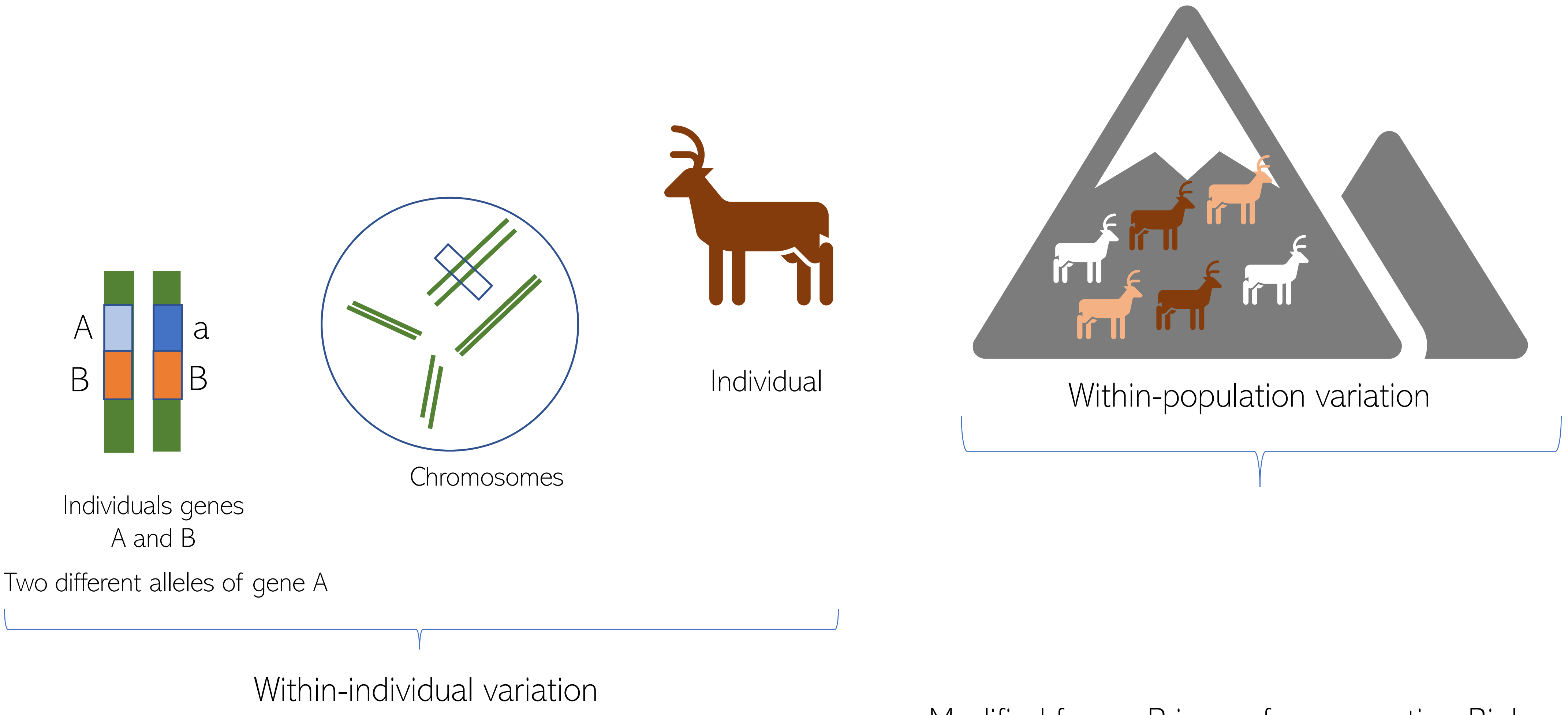
Two different alleles of gene A

Within-individual variation



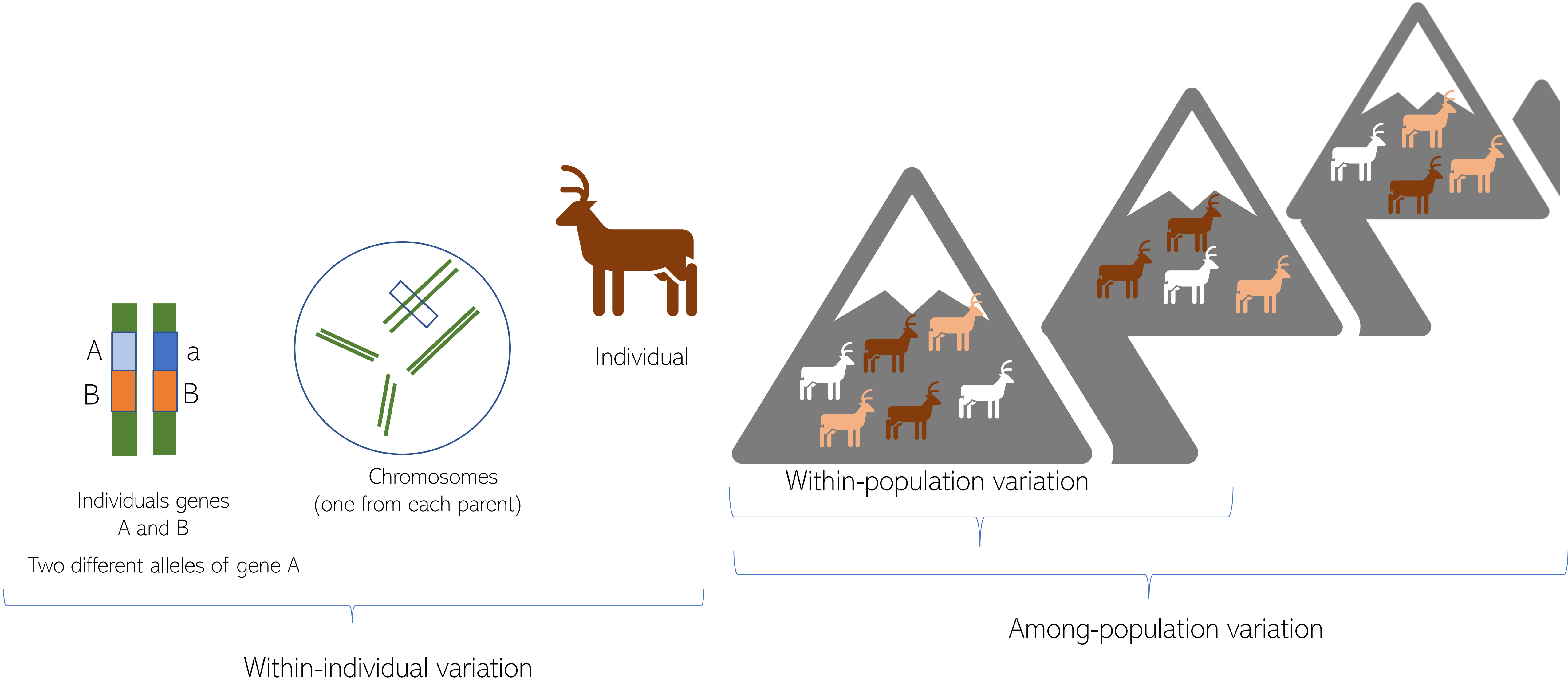
Modified from « Primer of conservation Biology, Primack 2012 »

Variations génétiques : différents niveaux



Modified from « Primer of conservation Biology, Primack 2012 »

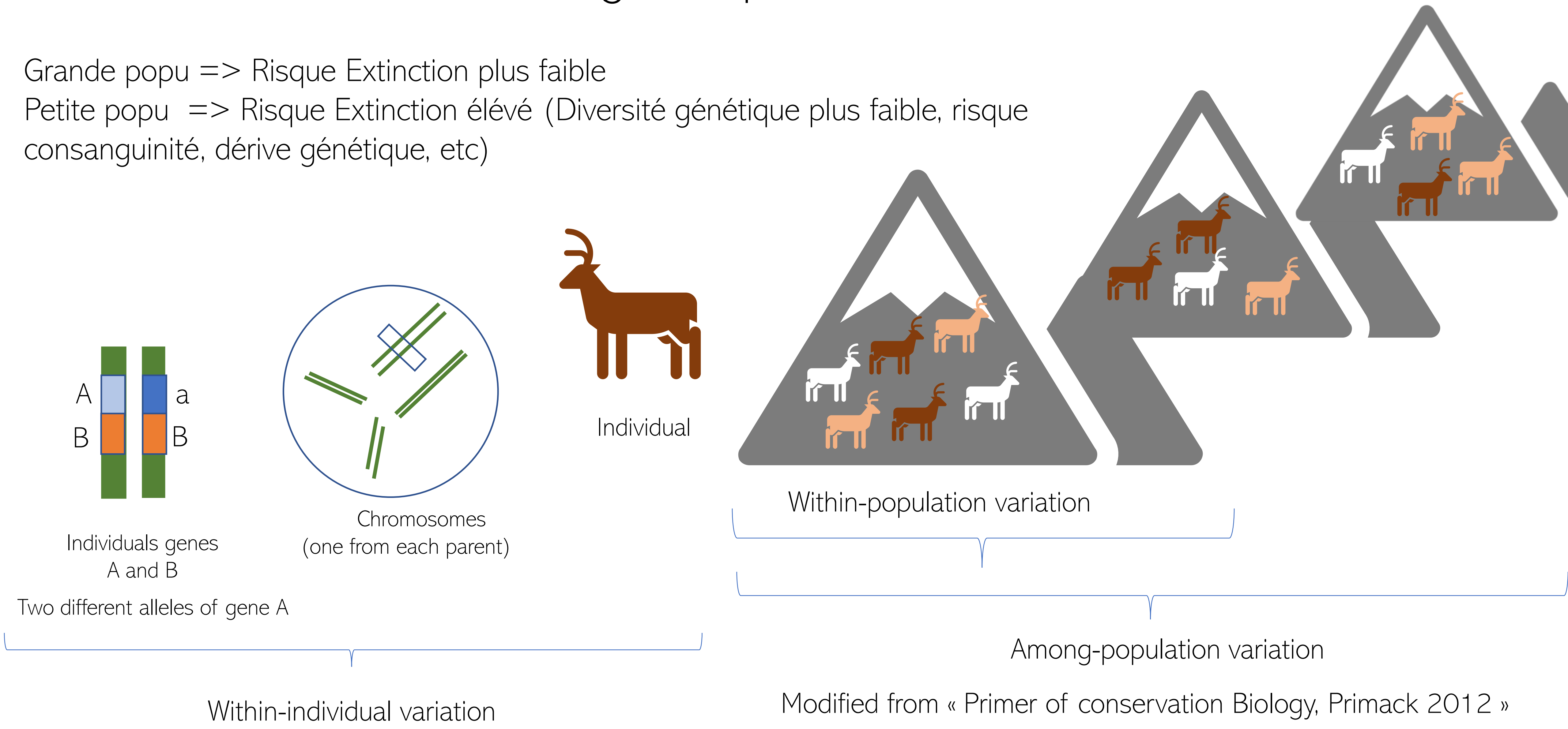
Variations génétiques : différents niveaux



Modified from « Primer of conservation Biology, Primack 2012 »

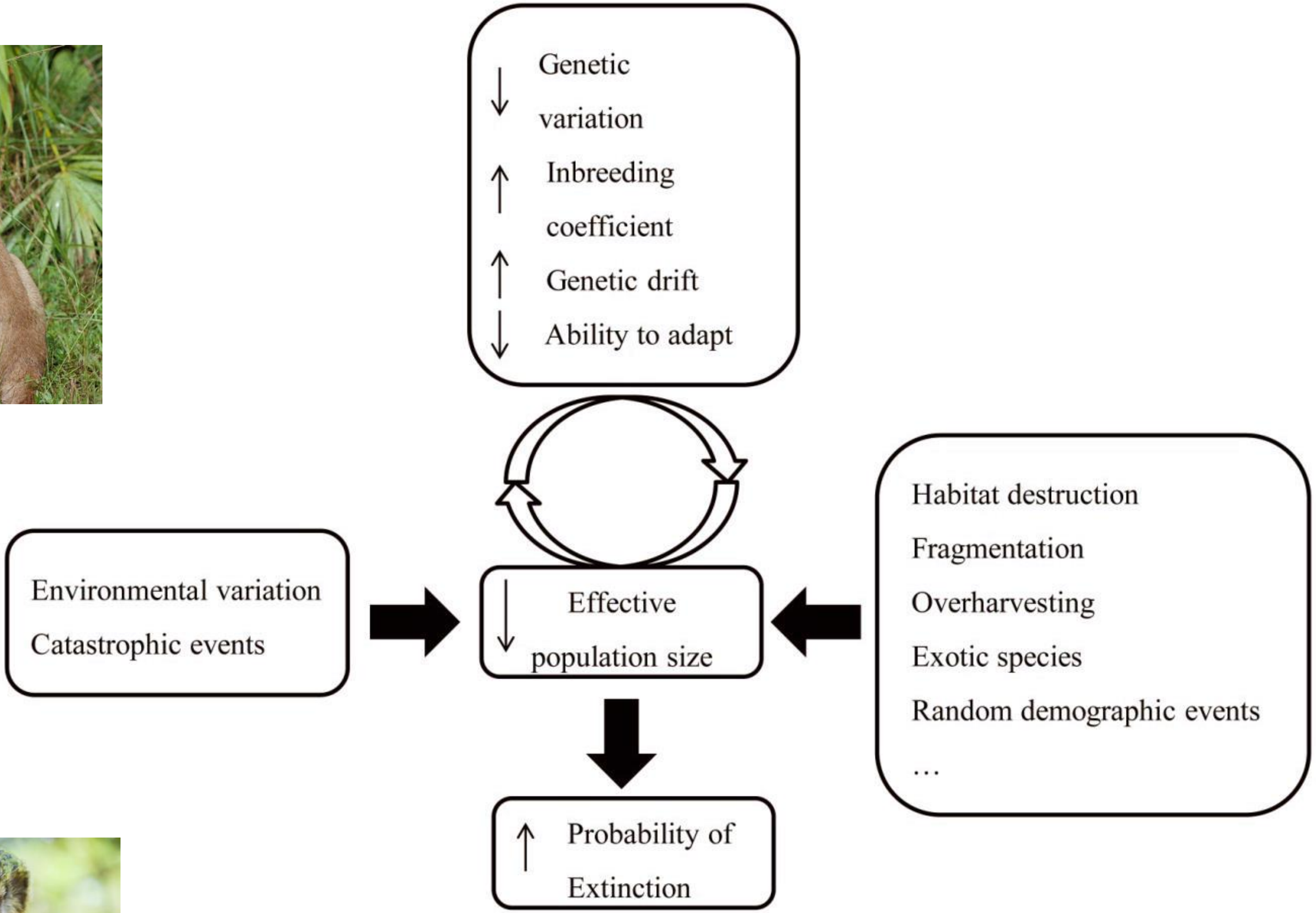
Variations génétiques

Grande popu => Risque Extinction plus faible
Petite popu => Risque Extinction élévé (Diversité génétique plus faible, risque consanguinité, dérive génétique, etc)



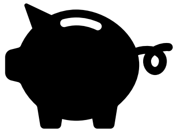
Modified from « Primer of conservation Biology, Primack 2012 »

Vortex de l'extinction



Modified from Allendorf et al 2007

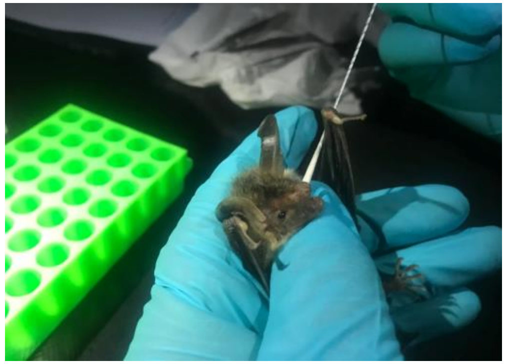
Moyens

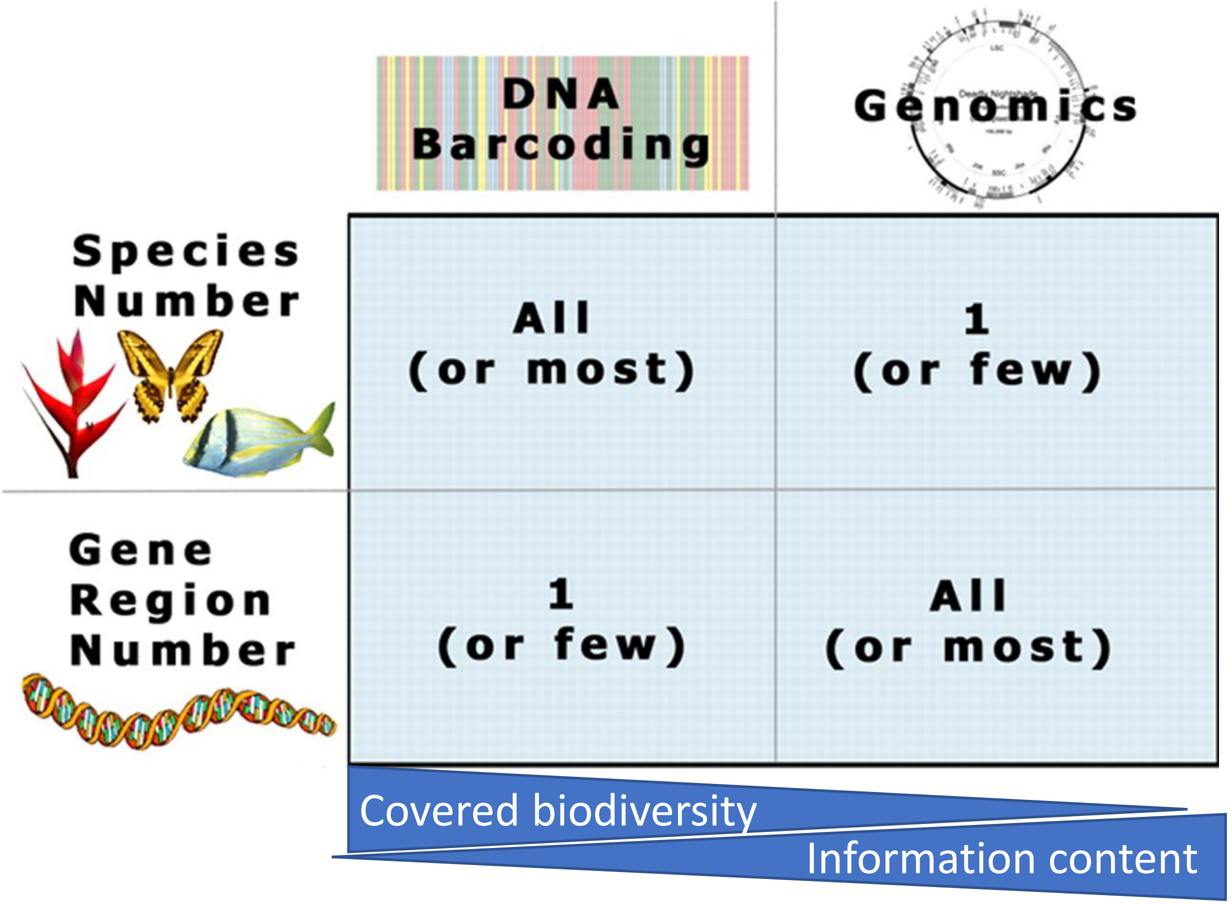
Moyens Financiers  $$$

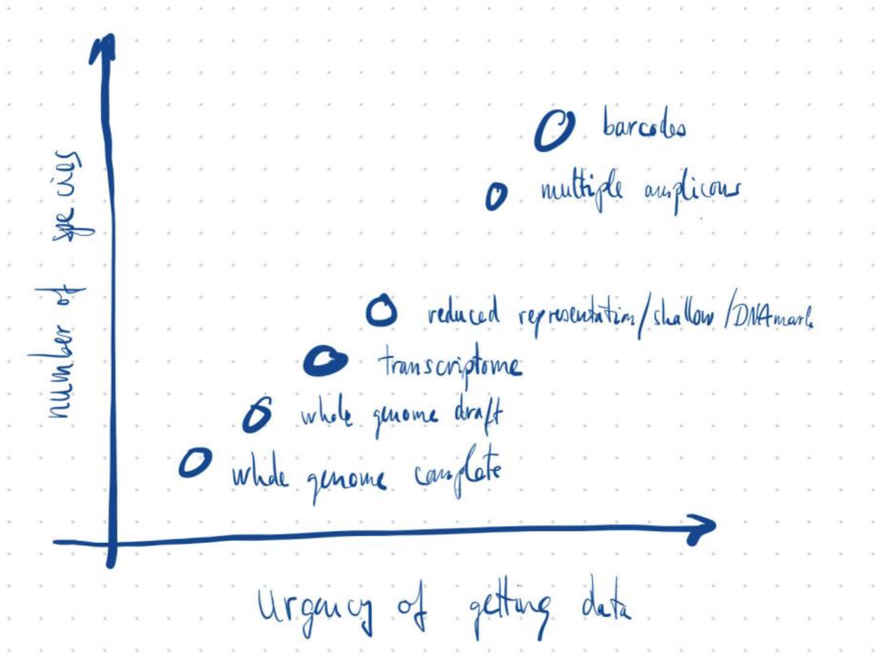
Questions?

Echantillons?

Echantillons

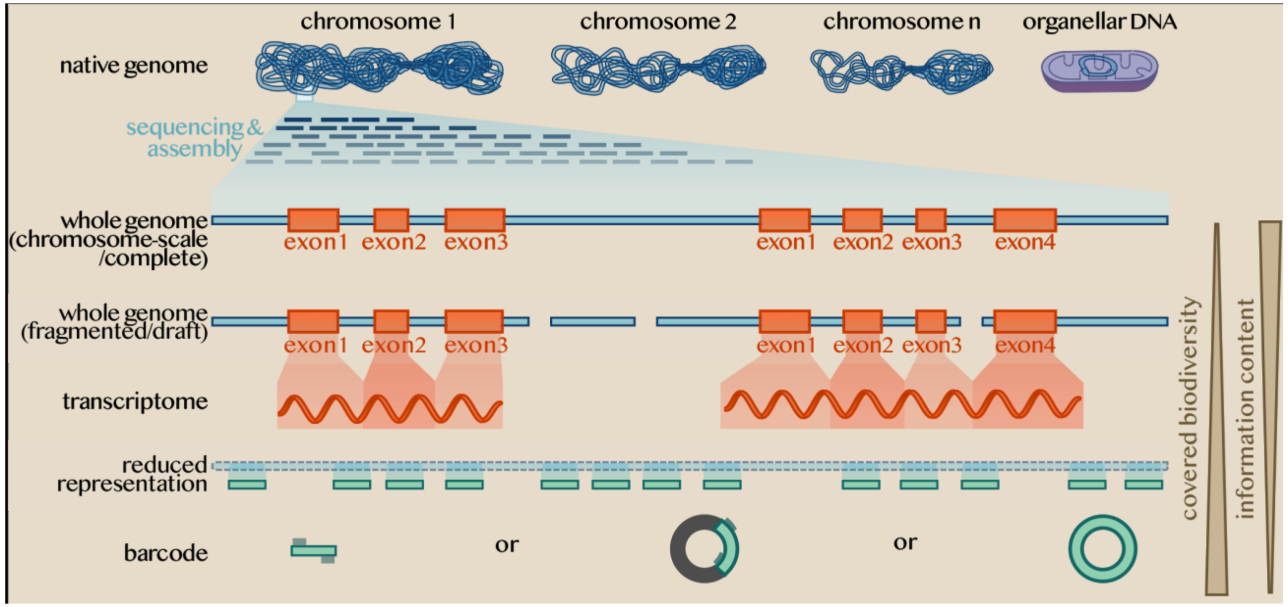






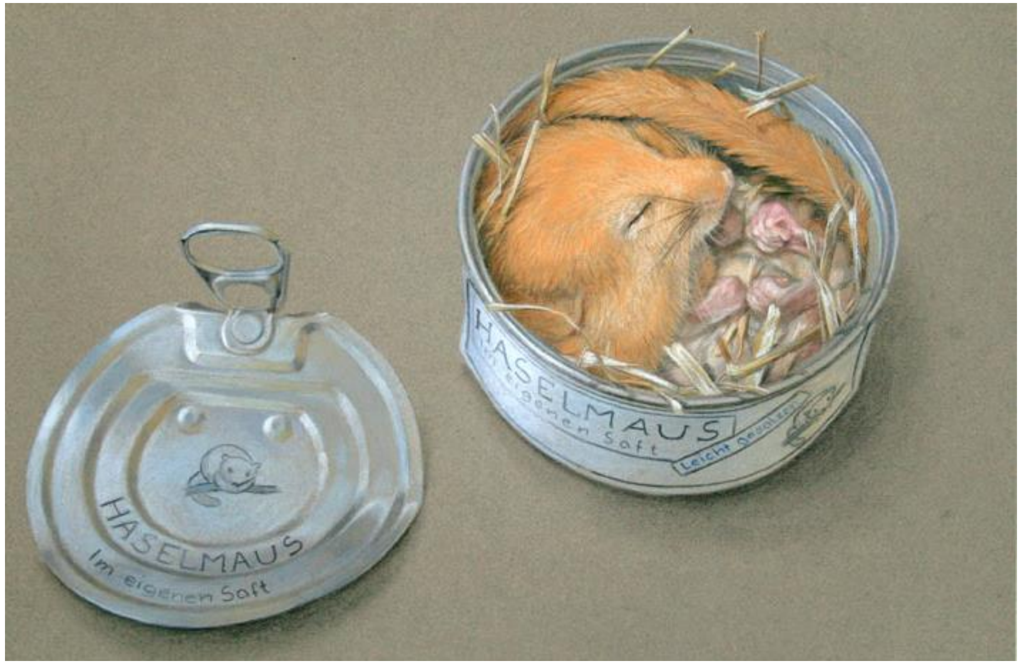
PNAS February 26, 2008 105 (8) 2761-2762; https://doi.org/10.1073/pnas.0800476105

Marqueurs?

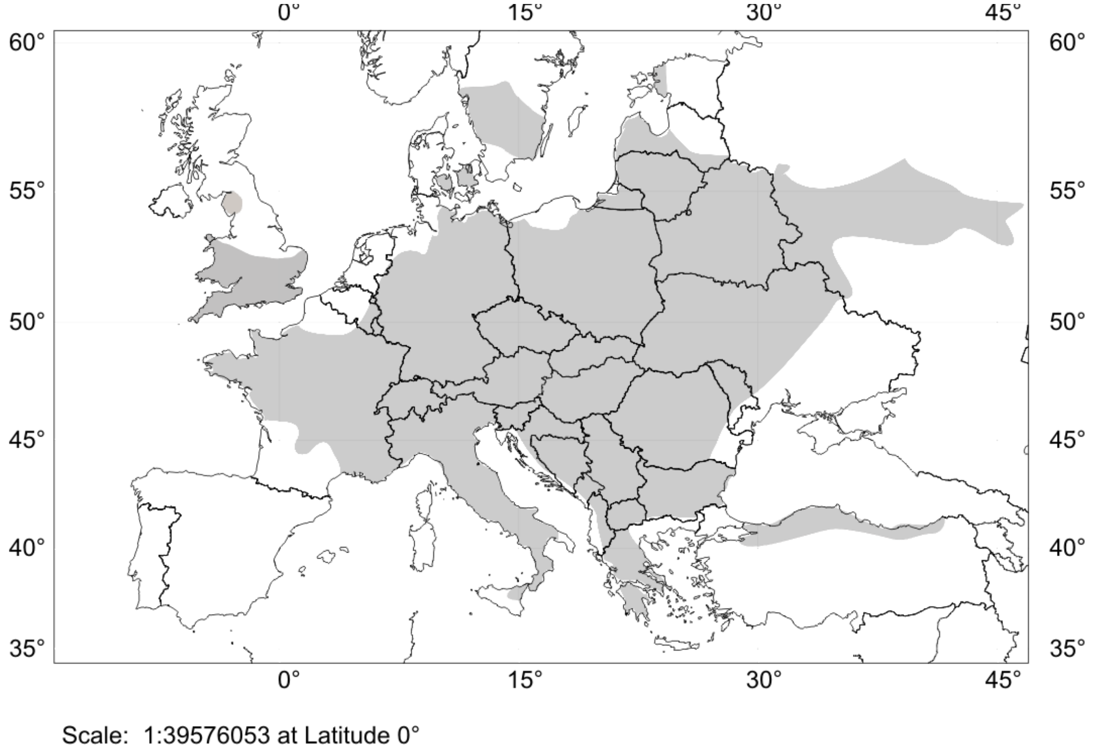


1. La conservation et le muscardin, *Muscardinus avellanarius*

La génétique pour la conservation de la biodiversité



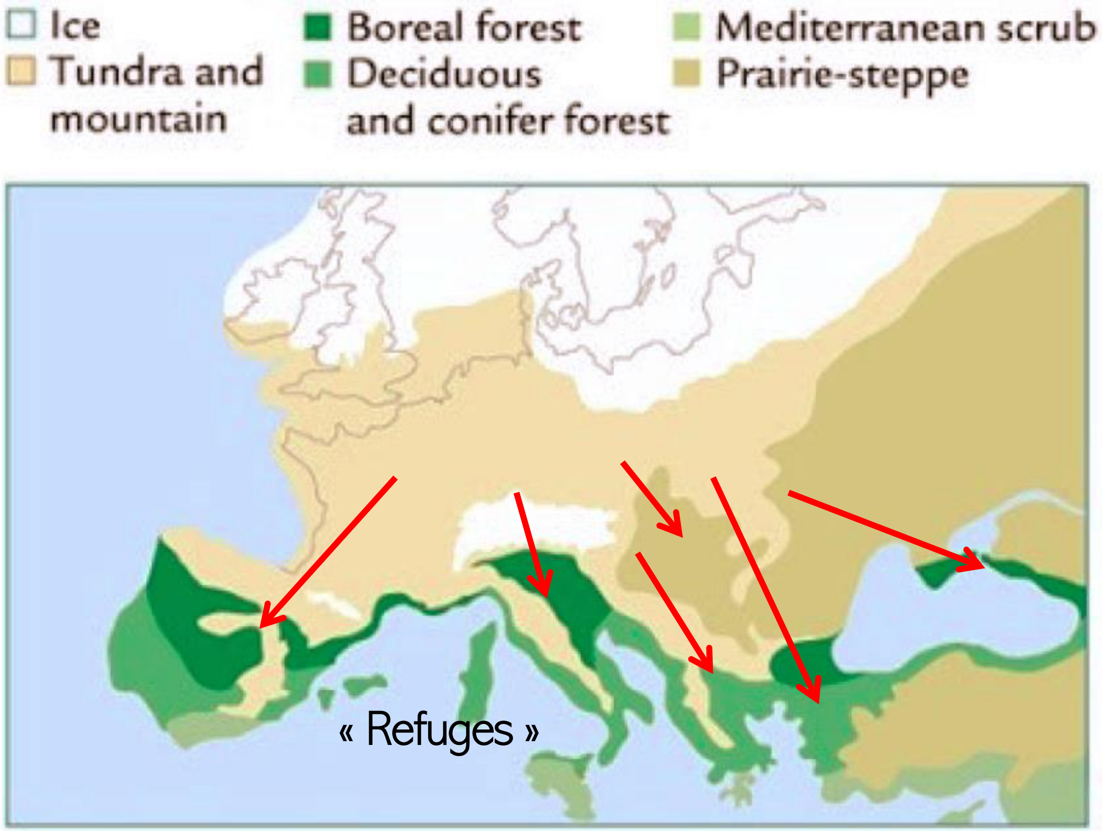
1. Le muscardin, *Muscardinus avellanarius*



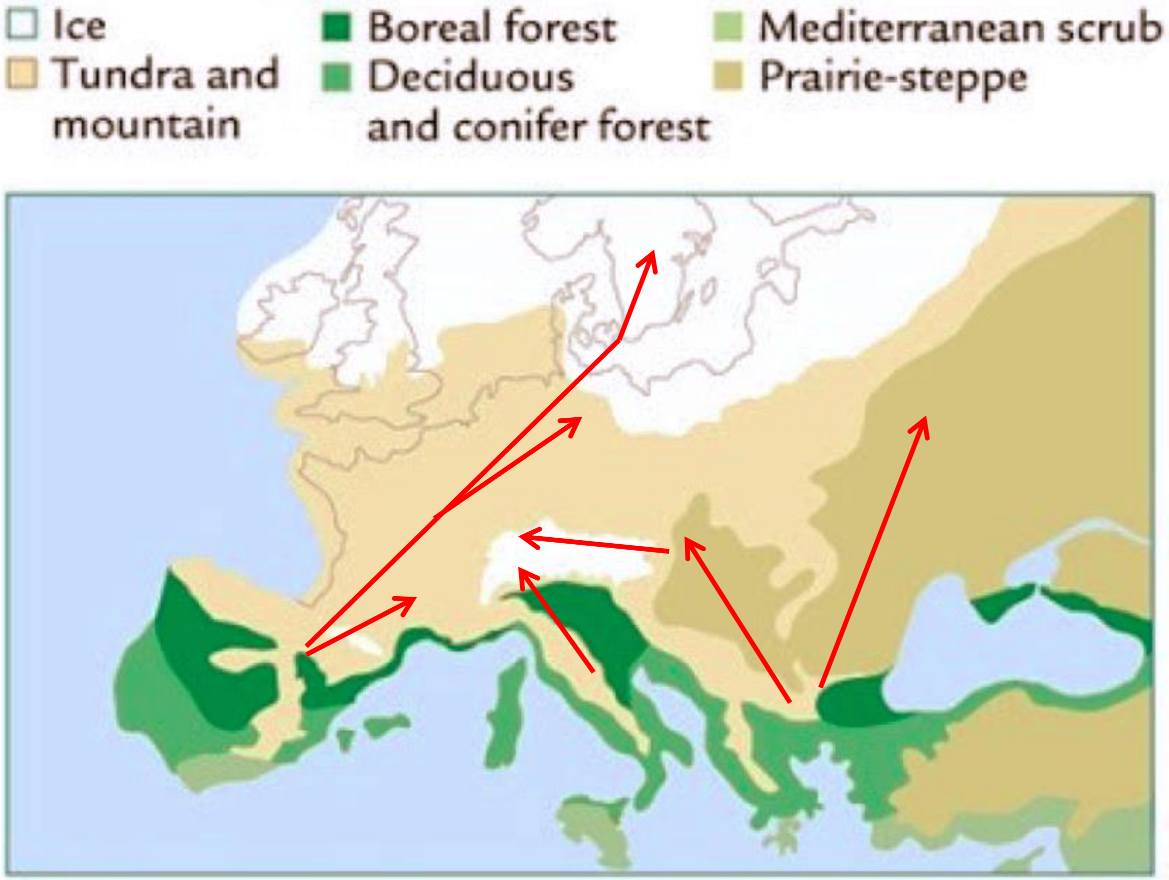
Annexe IV Directive Habitat
IUCN: Least concerned
Liste Rouge dans presque tous les pays

Hibernante, arboricole, nocturne

Glaciations quarternaires (+- 2 Ma) ⟶ Population structure!



Last Glacial Maximum in Europe (22000-14000 ans)
(Ruddiman 2008).

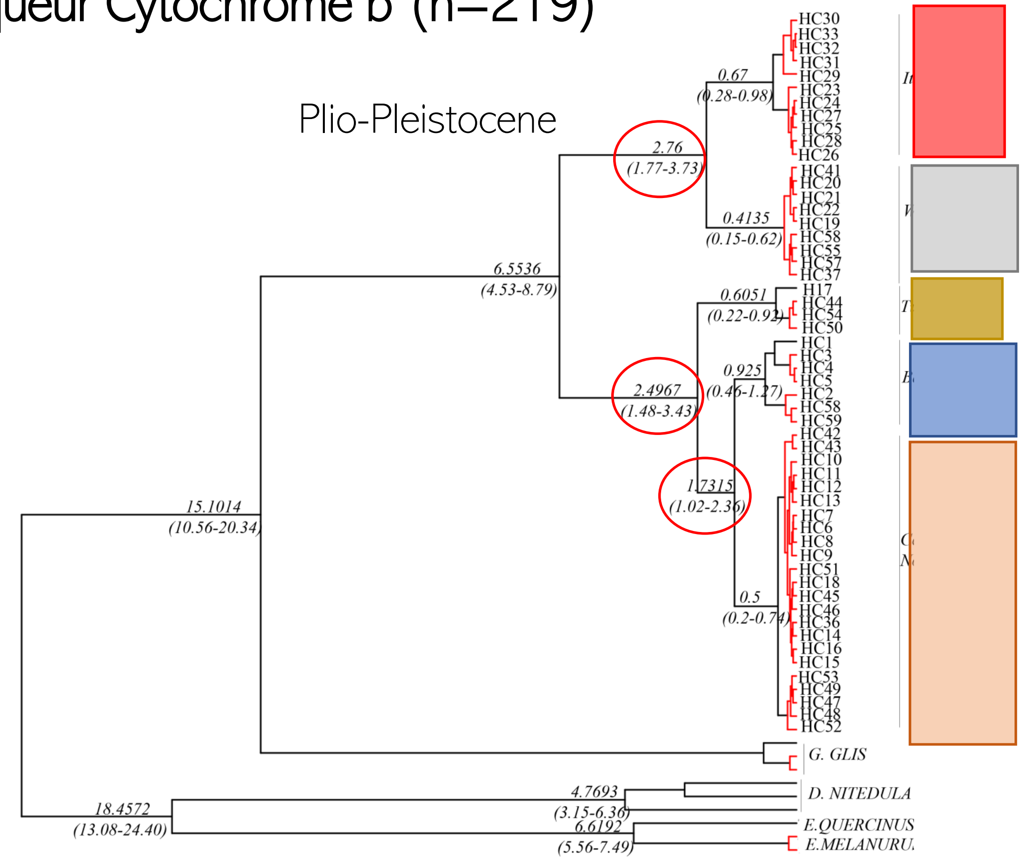


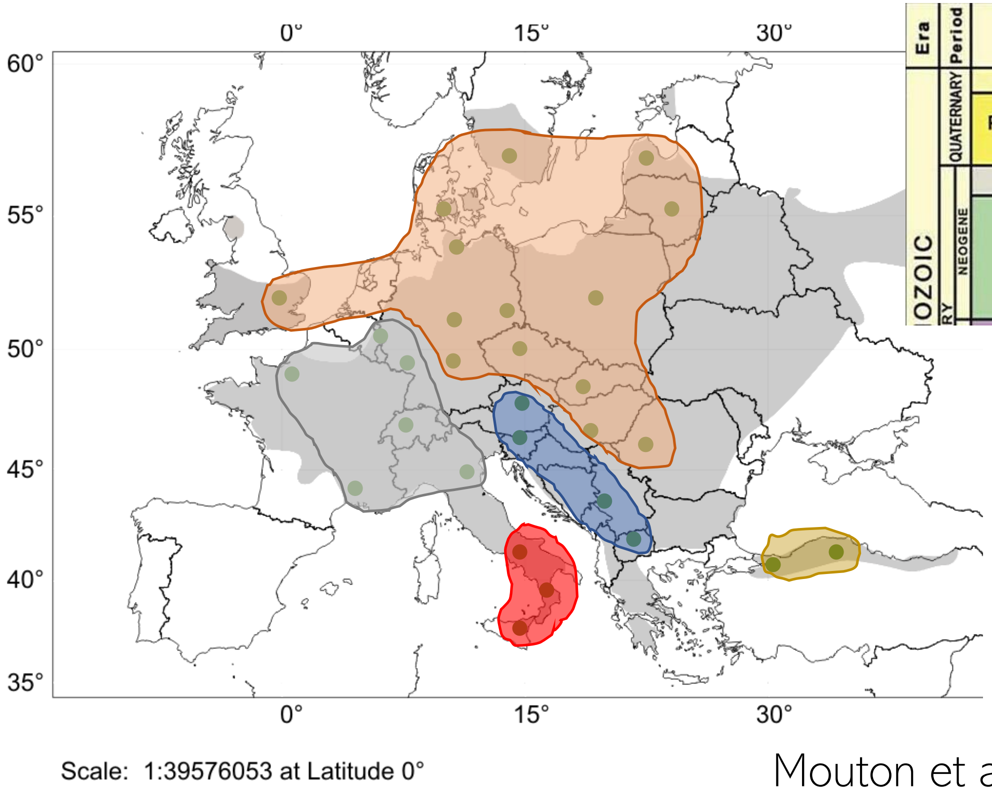
Recolonisation postglaciale

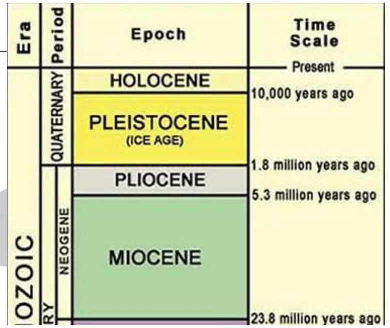
Refuge en Méditerrannée

1 marqueur Cytochrome b (n=219)

Plio-Pleistocene



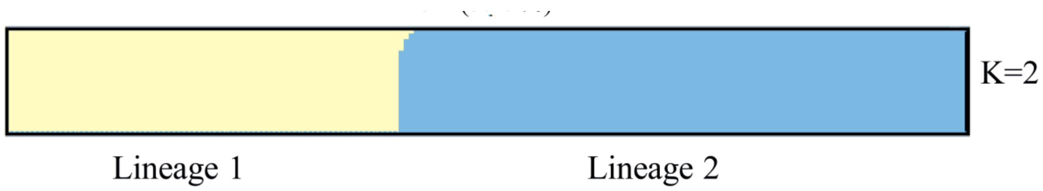




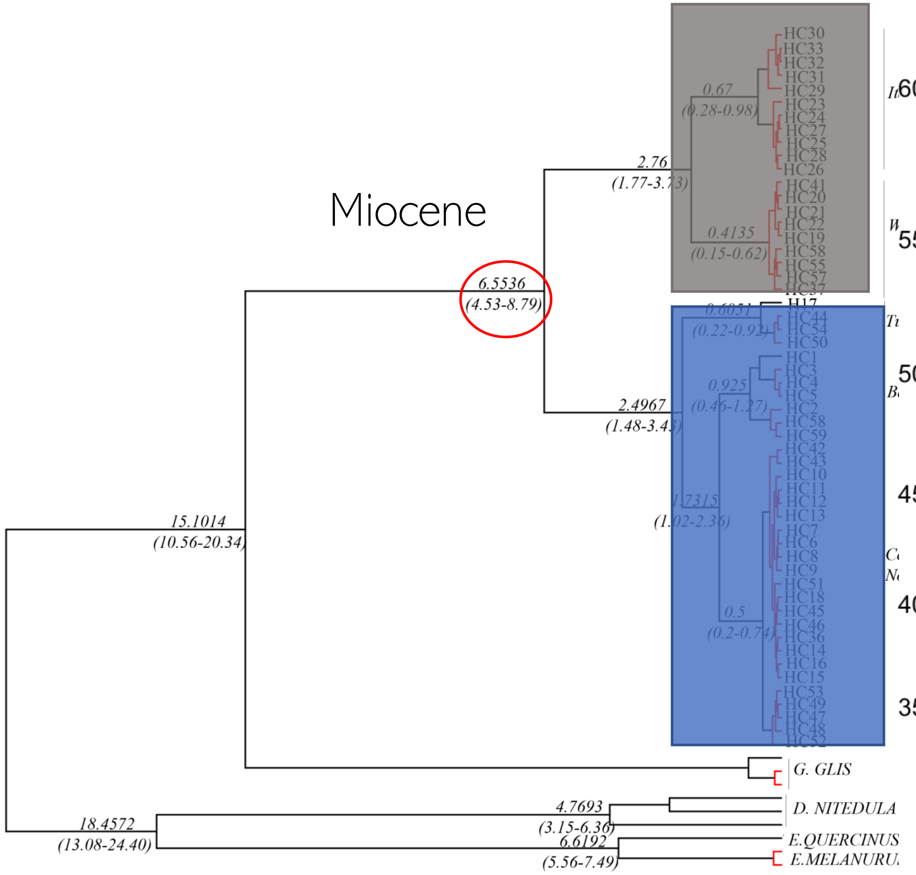
Mouton et al 2012, 2017

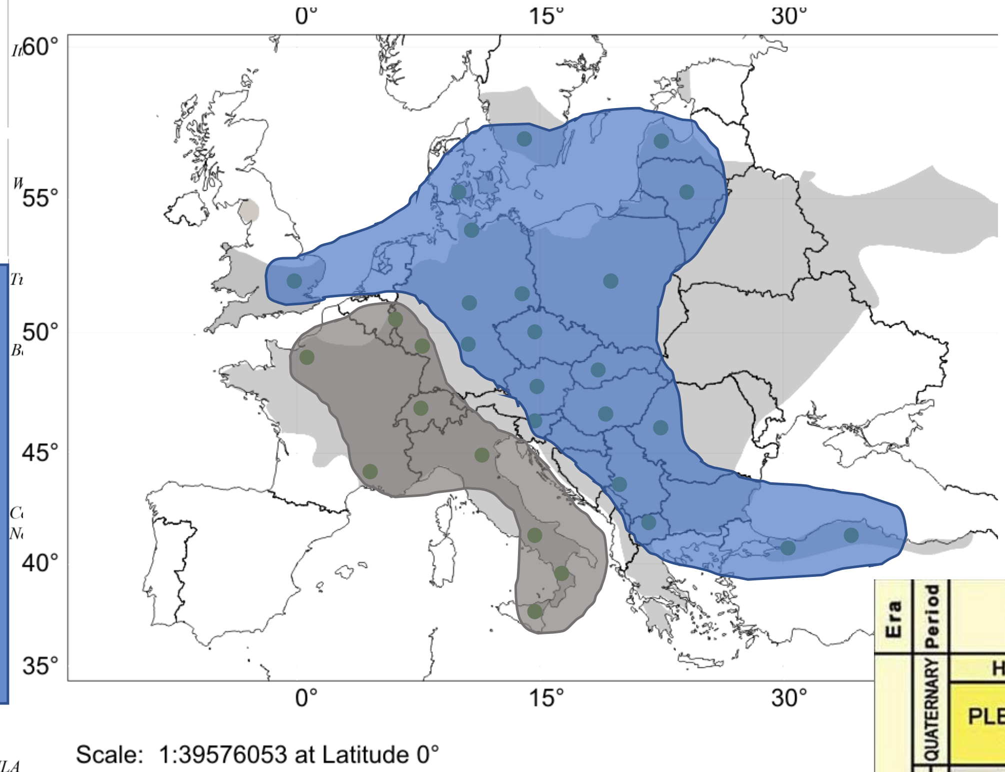
Mitochondrial marker : Cytochrome b

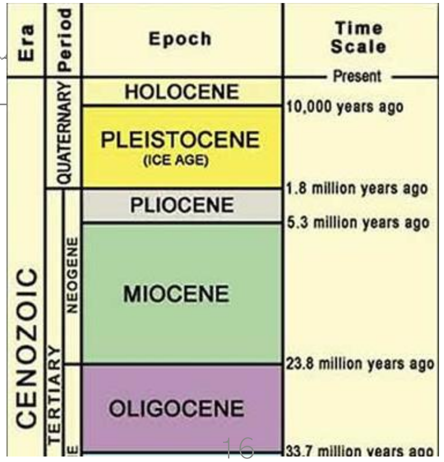
Nuclear marker : 10 microsatellites, 2 nuclear genes



Miocene







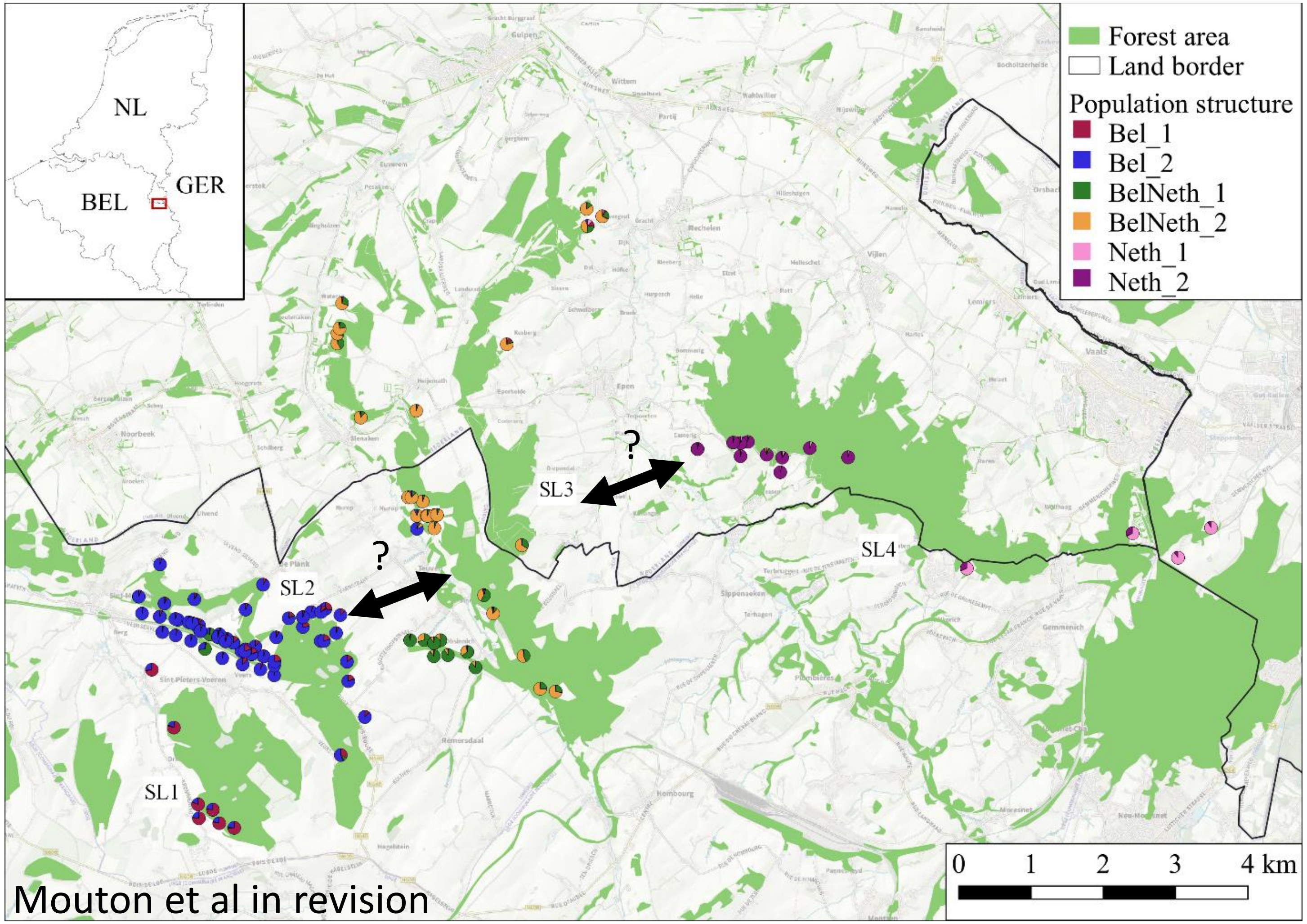
Variabilité intraspécifique forte

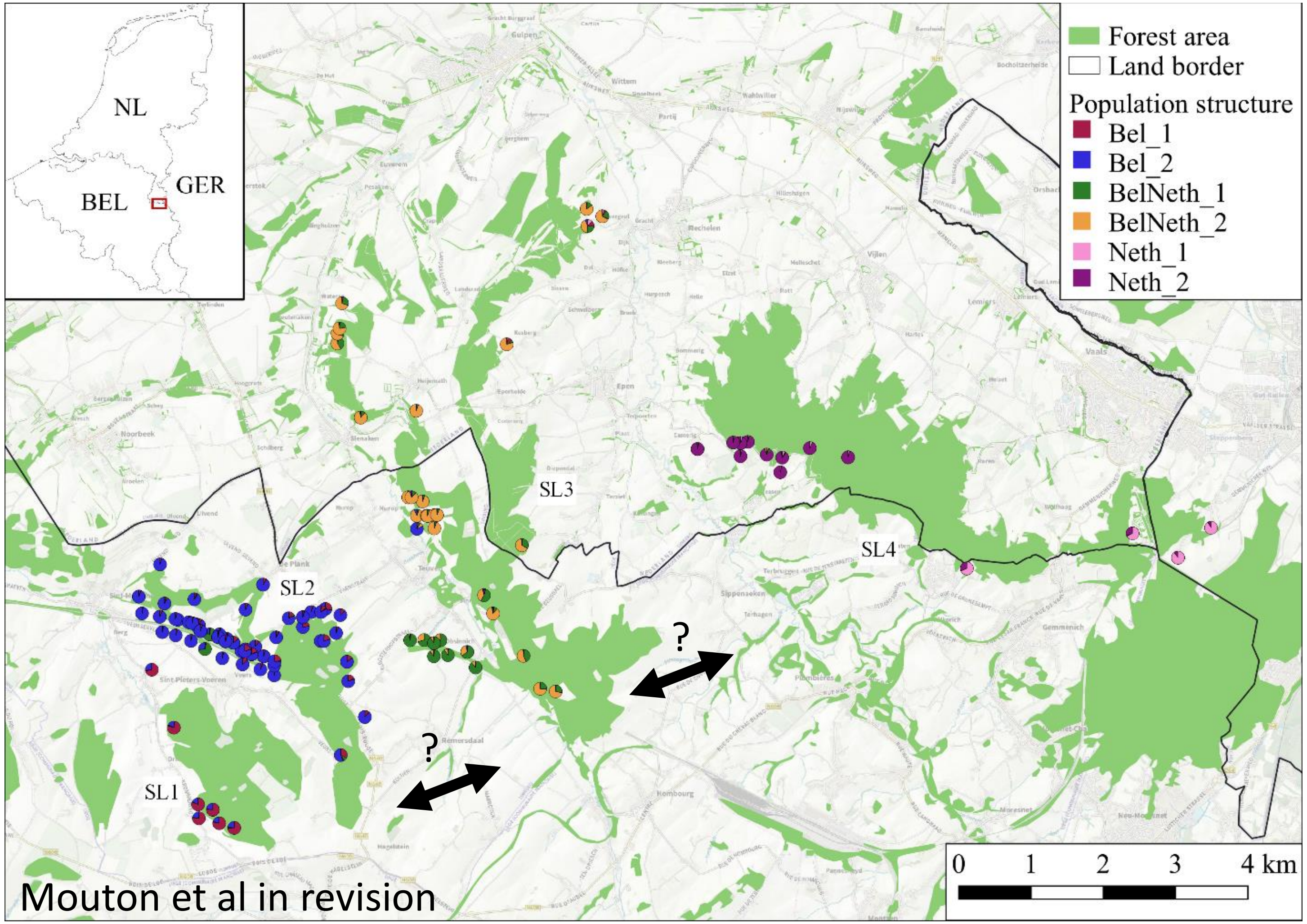
Changements géologiques et climatiques passés => Différentes lignées génétiques

2 espèces différentes ? => C'est quoi une espèce ?

Doit on prendre en considération les unités évolutives dans les plans de gestions de l'espèce? => marqueur génétique limité

Populations séparées? Consanguinités?





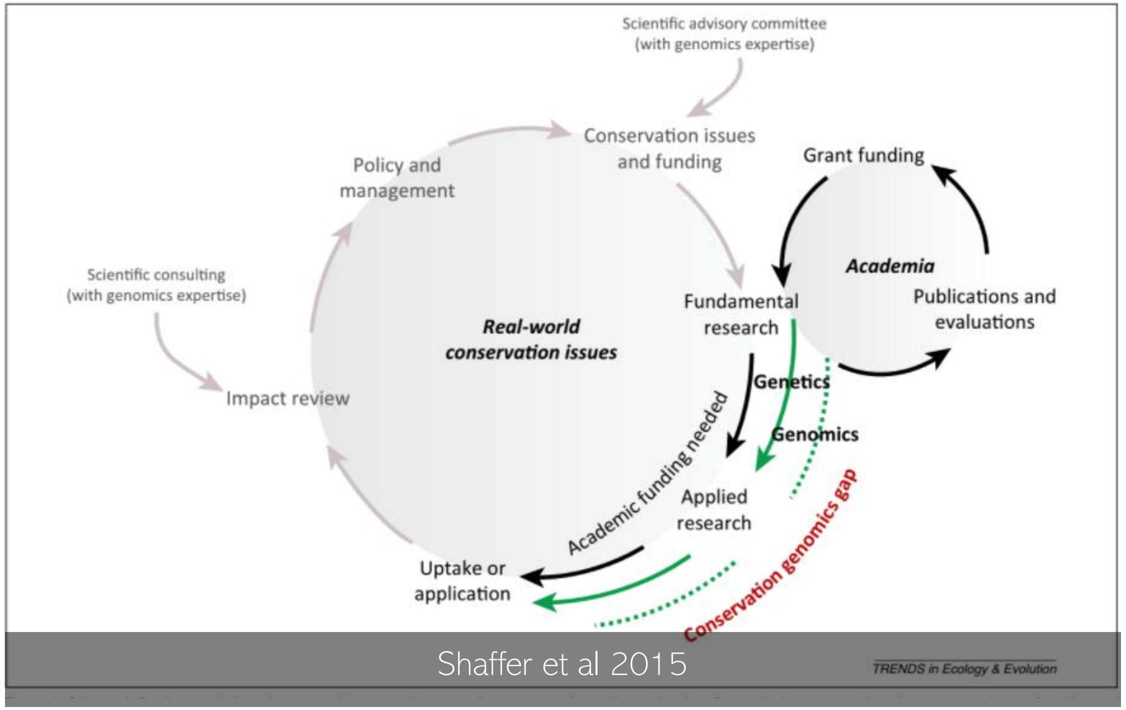
- Structuration génétique forte
- Aucun flux génique entre popu
- Légèrement consanguins

Action: Corridor ecologique entre SL2 et SL3

Gestion des populations le long des voies de chemin de fer avec INFRABEL

Challenge in conservation genetics

- Connecting genome biologist to conservation practitioners, policy makers
- Connecting genetic to IUCN evaluation



Shaffer et al 2015

Conservation Genetics
https://doi.org/10.1007/s10592-020-01301-6

PERSPECTIVE

Check for updates

IUCN Red List and the value of integrating genetics

Brittany A. Garner[1] · Sean Hoban[2] · Gordon Luikart[3]

Received: 2 January 2020 / Accepted: 4 August 2020

ELSEVIER
Global Ecology and Conservation
Volume 10, April 2017, Pages 231-242

Original research article

Bridging the conservation genetics gap by identifying barriers to implementation for conservation practitioners

Highlights

- Conservation practitioners want to use genetics, but do not routinely do so.
- This issue is most acute in control of disease and invasive species.
- The main barriers to use of genetics in conservation are funding and expertise.
- Practitioners want to work with geneticists, but are unsure how to reach them.
- Researchers must facilitate better communication with practitioners.

2. La mort au rat et le lynx (bobcat, *Lynx rufus*)

La transcriptomique pour étudier la biodiversité

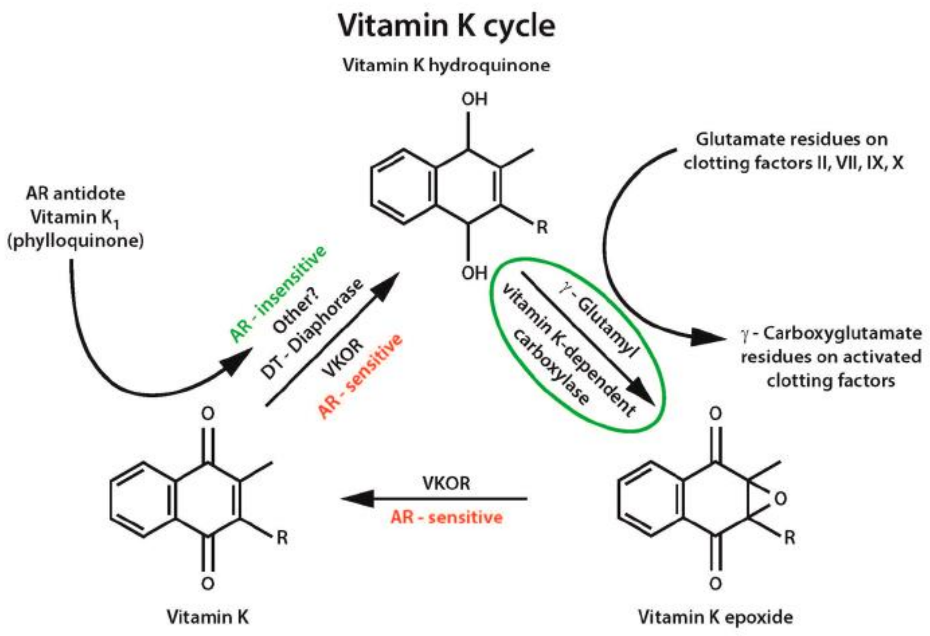
UCLA

BAEF The Belgian American Educational Foundation

UCLA QCBio Collaboratory

• Mort au rat est utilisée mondialement pour contrôler les ravageurs en milieu urbain, peri-urbain et en agriculture

• Fonctionnement



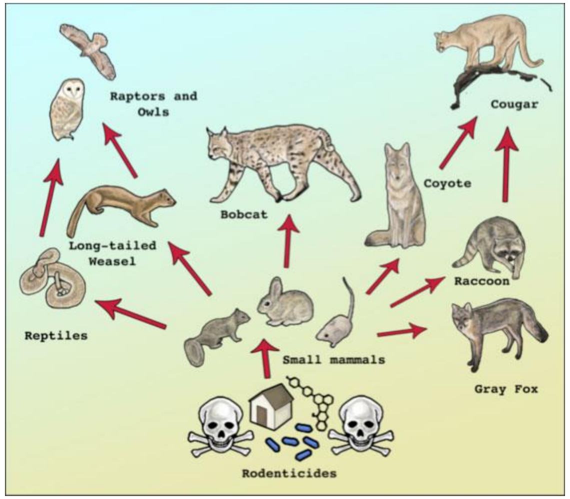
=> Hémorragie interne

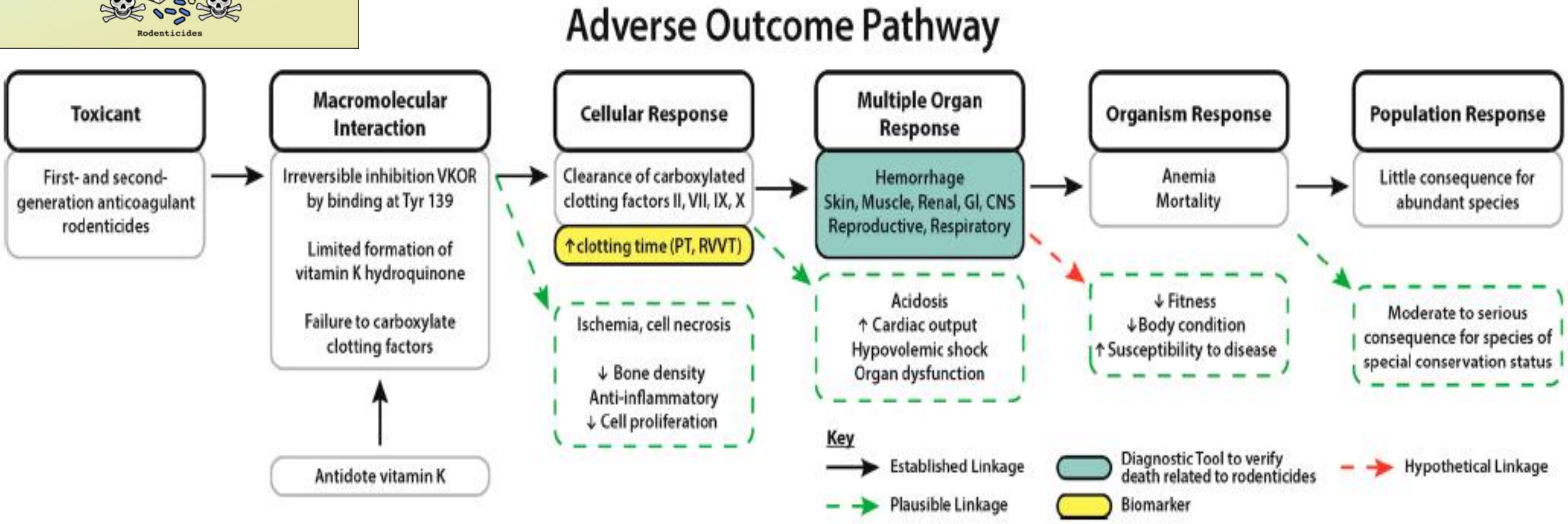
• 2 générations de mort au rat

- Première génération : Warfarine, chlorophacinone and diphacinone => mort en plusieurs fois (problème de résistance)

- Seconde génération : Bromadiolone, difenacoum, brodifacoum, flocoumafen, and difethialon => une seule fois (très toxique) and dans certains états (seulement des compagnies professionnelles)

Expositions secondaires aux rodenticides





Env.Sci.Technol 2014,48,8433-8445

Exposition secondaire aux rodenticides

=> 90 % fouines et hermines contaminés au Danemark (Elmeros et 2011).

=> 62.8% oiseaux proies en region méditerranéenne (Espagne) (Perea et al 2015)

⇒ Détectés dans 6 des 7 prédateurs à Cape Town, Afrique du Sud (Serieys et al 2019).

⇒ 4 espèces Mustelidae en France (Fournier-Chambrillon et al 2004)

⇒ Augmention des parasites et pathogènes chez le grand busard (Lemus et al 2011)

⇒ ……

Problèmes

Pas toujours de signes extérieurs d'empoisonnement (sensivité différentre en function des espèces)
Pas détectés dans les analyses de routine car les tests sont très spécifiques (et pas économiques)

Histoire du problème

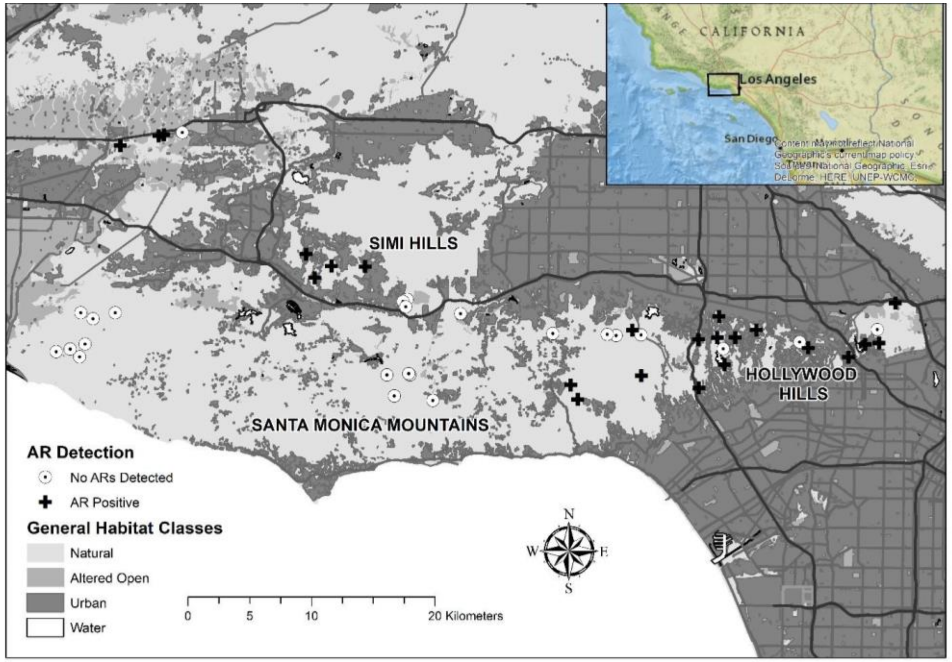
- ✓ Année 2000 : Le National Park Service démarre un suivi des carnivores (coyotes) dans les colines de Santa Monica (California, USA) => exposition aux rodenticides chroniques et léthales.

- ✓ En 2002-2005, déclin rapide de la population de lynx à cause de la gale notoédrique (acariose infectieuse), 50 % d'une population meurt de cette maladie bénigne en 2003 (Serieys et al. 2014).
- ✓ Nécropsie montre que 90% des bobcats sont positifs aux rodenticides
- ✓ Association forte en l'acariose et l'exposition aux rodenticides (Riley et al. 2007)
- ✓ Les lynx ne meurent pas d'hémorragies comme les autres espèces mais on peut voir un effet sur le temps de coagulation => moyen de controller si exposer ou non

Serieys et al 2013/ Serieys et al 2018 => Effet Immunotoxique des rodentifices

65 marqueurs immunitaires et fonctionnelles dans 124 bobcats in the SMMNRP

data parameter	test (sample type)
anticoagulants	residue analysis for exposure (whole blood and serum)
	PIVKA clotting time (plasma)
	prothrombin clotting time (whole blood)
health parameters	general (whole blood and serum)
	immunophenotype (lymphocytes in whole blood profiled by flow cytometry)
	cytokine concentrations (serum)
	complete blood counts (whole blood)
	blood chemistries (serum)
B cell clonality	immunofixation (serum)
	PARR (whole blood)
pathogen infection or exposure	exposure/infection (whole blood and serum)
land use	percentage urban area (buffer zones)



- Immunostimulation et Immunosuppression simultanées s
- Les animaux exposés ont une deregulation du systeme immunitaire
- Hypothèse : leur systeme immunitaire est tellement compromise qu'ils ne sont plus capables de developer une simple reponse immunitaire face par exemple à une acariose => mort.

Transcriptomique pour étudier les effets des rodenticides

1. Genes différemment exprimés entre lynx exposés et non exposés?

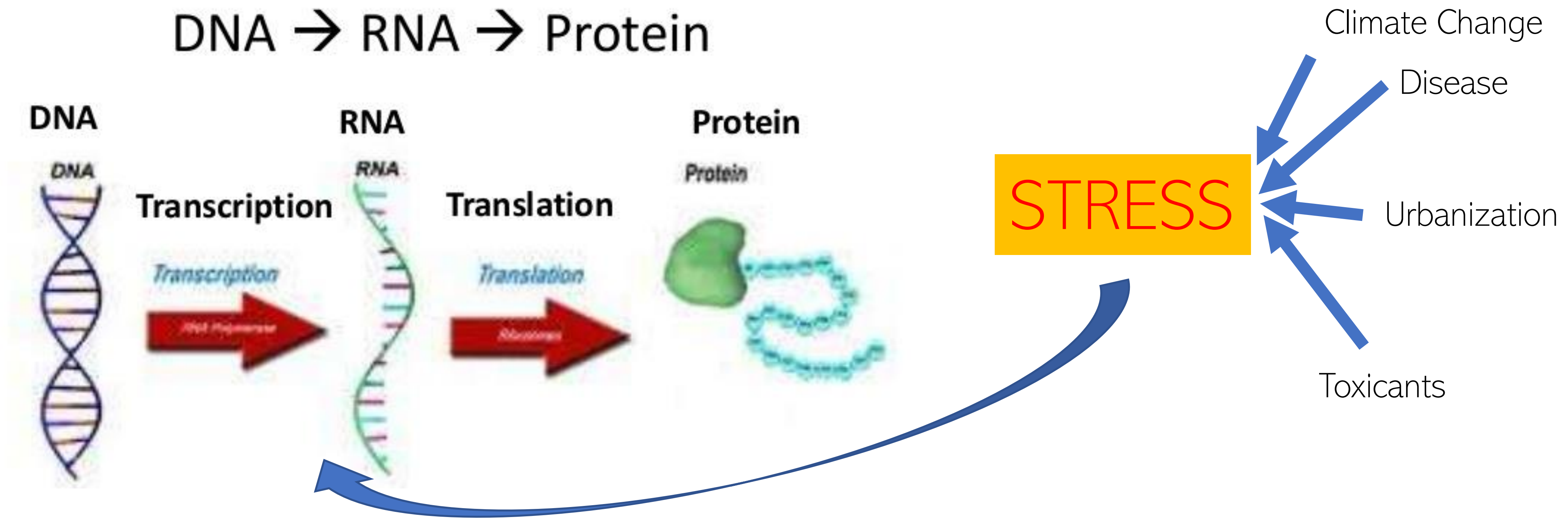
2. Processus biologiques impactés par les rodenticides?

3. Est ce qu’on peut trouver un lien possible entre la gale notoédrique et l’exposition aux rodenticides?

Gene Expression Modulates Organismal Response to Environmental Change

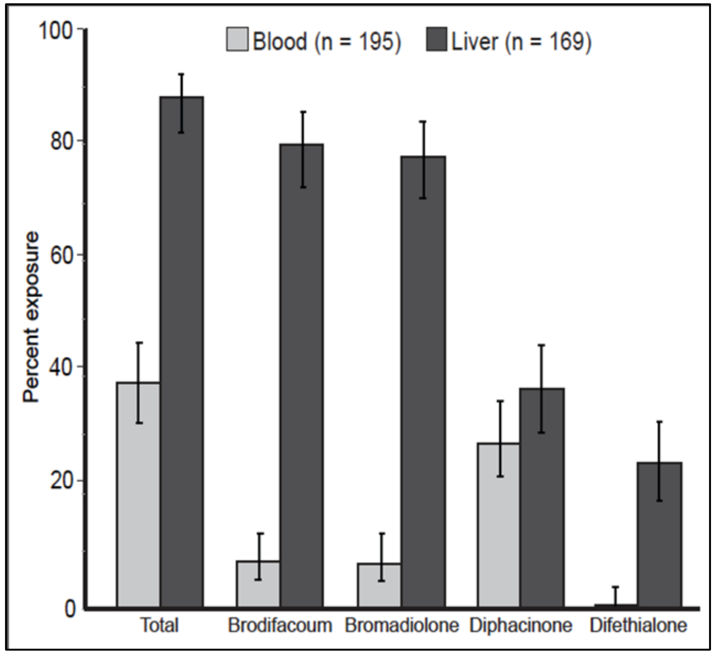
Phenotypic Plasticity in Gene Expression is Critical to an Organisms Immediate and Prolonged Response to Environmental Change

DNA → RNA → Protein

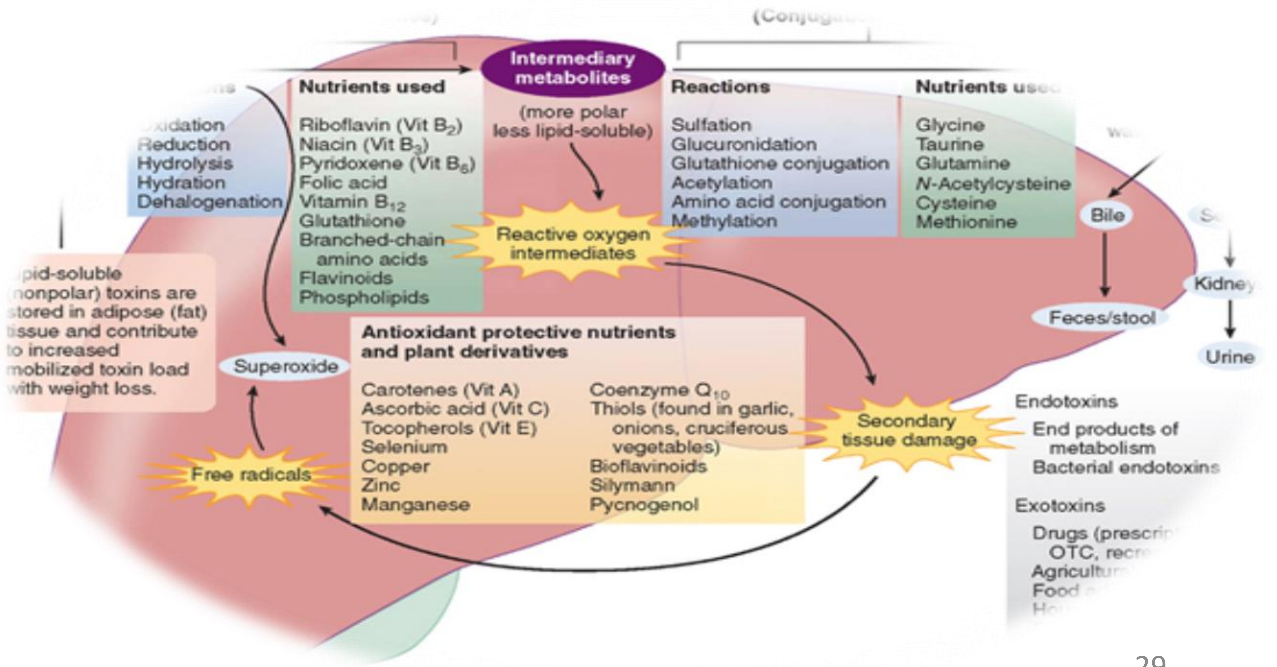


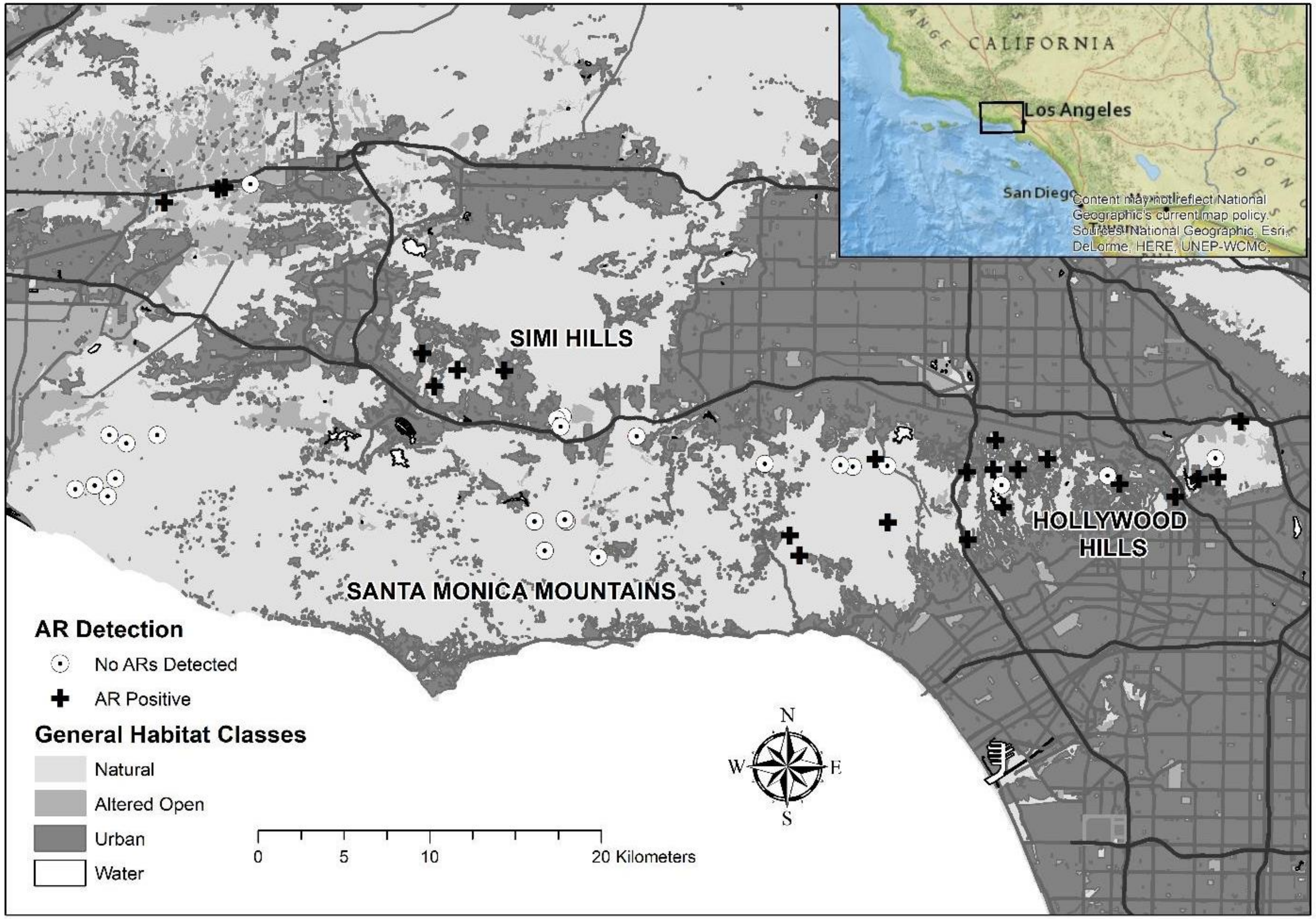
Challenge de la transcriptomique dans notre cas

- Echantillonnage opportuniste – aucune information sur les experiences vécues de l'animal avant ou après l'échantillonnage (infections, toxines, nourriture, etc.)
- Détection des rodenticides dans le sang indique une exposition récente (pas longue)



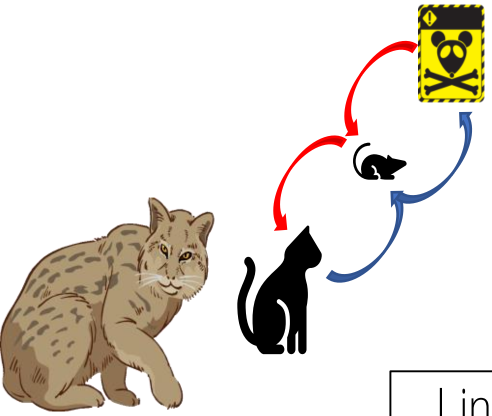
- Impossibilité de travailler sur le tissus ideal (e.g. foie)





Fraser et al. (2018) *Molecular Ecology*

- ✓ 52 RNA samples from blood (26 exposed/ 26 non exposed)
- ✓ Balancing with age and sex
- ✓ Metadata (disease, RIN, sequencer, season,location…)



26 bobcats exposed and 26 non exposed

Linear Model (limma) | WGCNA

GO Enrichment

TOA/TRA

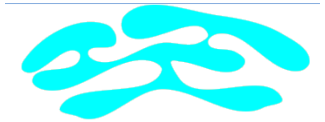
10 functional categories

↓ Keratinocyte proliferation

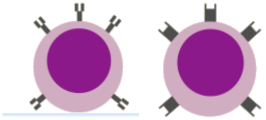
↓ Coagulation and Wound Healing

↓ Inflammatory Response

Notoedrus cati



↑ ER stress response



Immune suppression and activation

Impact on fitness

1) Decreased defense against extracellular pathogens and allergens
2) Immune activation leading to immune exhaustion
3) Increased cell death
4) Reduced epithelial integrity, more vulnerable to ectoparasites

Fraser *et al* 2018 Molecular Ecology

Conservation action

Raptors Are The Solution (RATS)
September 27 ·

Anticoagulant rat poisons can weaken an animal's immune system, which in turn can make the animal more susceptible to mange. Please don't use rat poison and help us spread the word.

DAILYNEWS.COM

First mountain lion to die of mange had five different rat poison chemicals in her system

Los Angeles Times

CALIFORNIA

Two mountain lions found dead in Santa Monica Mountains had ingested rat poison

P-30 and P-53 were found dead in September and August, respectively. Both had rat poison in their systems. (National Park Service)

Conservation action

1 September 2020

California Legislature Passes Bill to Protect Wildlife From Super-toxic Rat Poisons

Moratorium on Dangerous Rodenticides Heads to Governor's Desk

SACRAMENTO, *Calif.*— The California legislature has passed a bill that would place a moratorium on super-toxic rodenticides until state agencies can develop better safeguards to protect wildlife from the dangerous, long-lasting poisons.

The California Ecosystems Protection Act (A.B. 1788) was passed late Monday just before the end of the session. The bill now goes to Gov. Gavin Newsom.

29 September 2020

Gov. Newsom Signs Bill Protecting Wild Animals from Super-toxic Rat Poisons

California Leads the Nation on Safeguards for Second-generation Anticoagulant Rodenticides

The law means California is the first state in the country to impose an all-out ban on SGARs with a few exceptions that include:

- Warehouses used to store foods for human or animal consumption.
- Agricultural food production sites, including, but not limited to, a slaughterhouse and cannery.
- A factory, brewery, or winery.
- Medical facilities, and drug and medical equipment manufacturing facilities.

Places where people eat, shop, live and work — such as restaurants, grocery stores, homes, housing facilities, schools, and office buildings — are not exempt. SGARs also may be used during public health emergencies the bill did not define.

ystems Protection Act (AB 1788) into law
e of second-generation anticoagulant

a), requires state regulators to reduce the
anticoagulant rodenticides can be lifted.

3. Le canidae déguisé en loup : le direwolf ou loup terrible (‘*Canis’ dirus*)

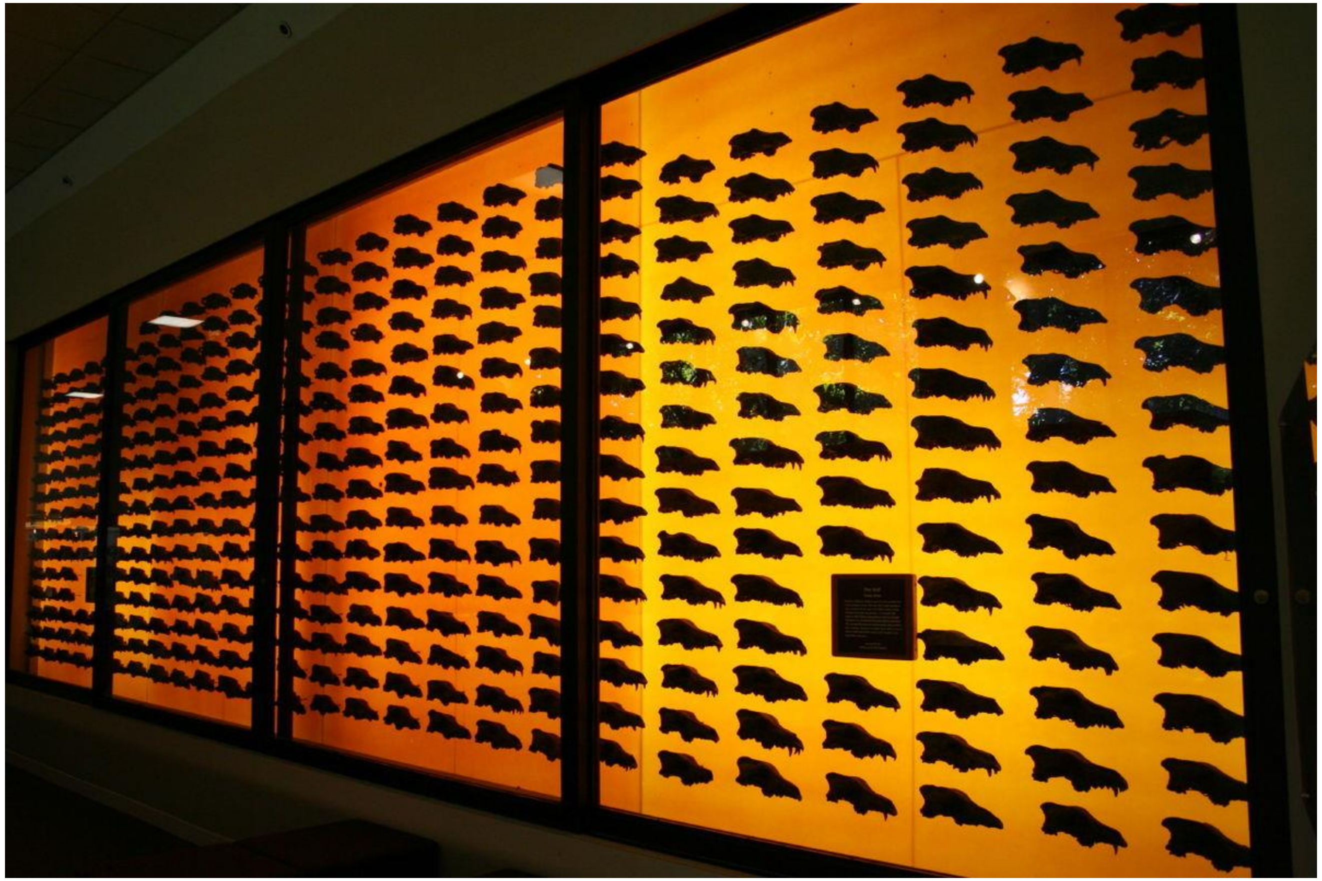
Mauricio Anton

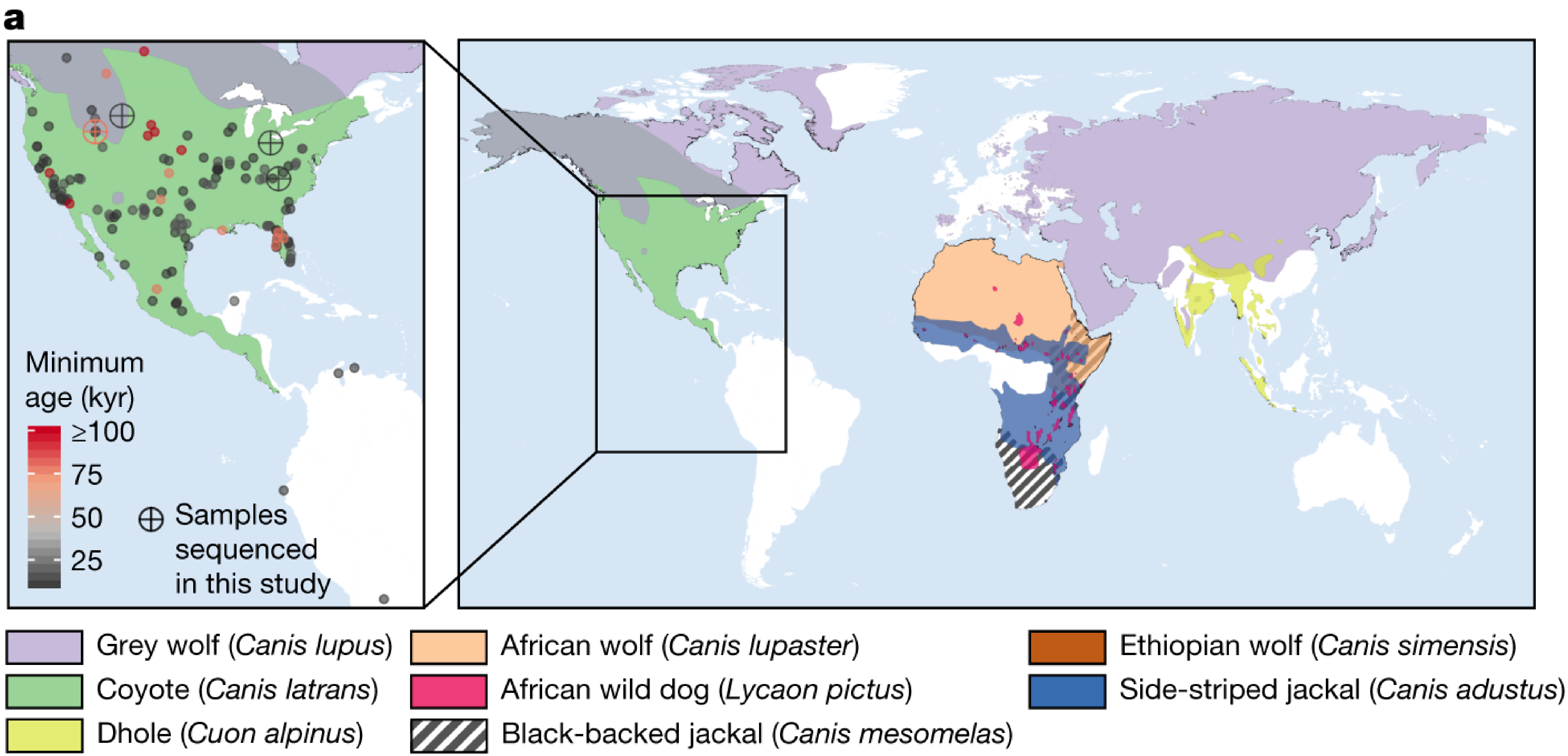
Perri, Mitchell, Mouton et al., Nature 2021

La paleogénomique pour étudier l’histoire des espèces disparues

Durham University in the U.K.,
Australia’s University of Adelaide and
Germany’s Ludwig Maximilian
University,
UCLA (USA)

- Abundance of dire wolf fossils (~4000 La Brea Tar pit, Los Angeles)
- Taxonomic relationships unclear => but described as sister species of even conspecific with the grey wolf for 100 years



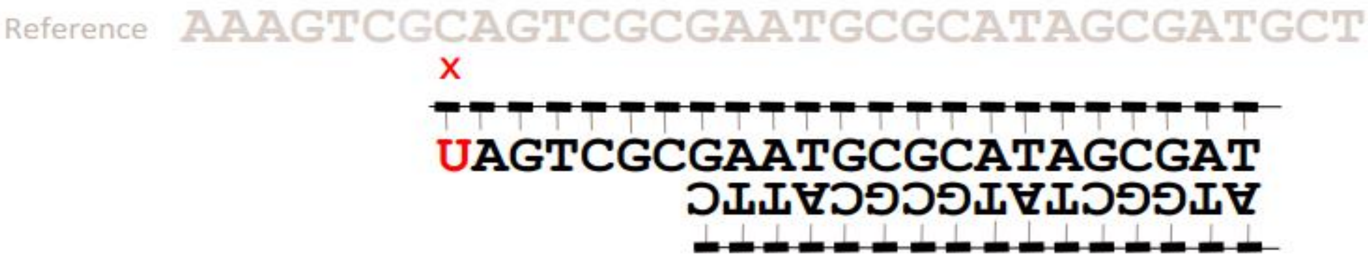

a
Minimum
age (kyr)
≥100
75
50
25
Samples
sequenced
in this study
Grey wolf (*Canis lupus*)
Coyote (*Canis latrans*)
Dhole (*Cuon alpinus*)
African wolf (*Canis lupaster*)
African wild dog (*Lycaon pictus*)
Black-backed jackal (*Canis mesomelas*)
Ethiopian wolf (*Canis simensis*)
Side-striped jackal (*Canis adustus*)

Working with aDNA…. is challenging…

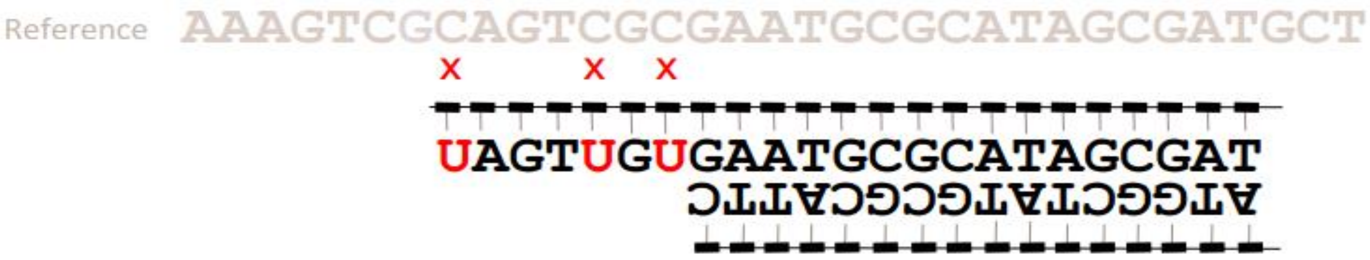
1. Short fragments
2. Losts of exogenous contaminants that can be mistaken for endogenous DNA
3. Chemical damage

Depurination leads to fragmentation

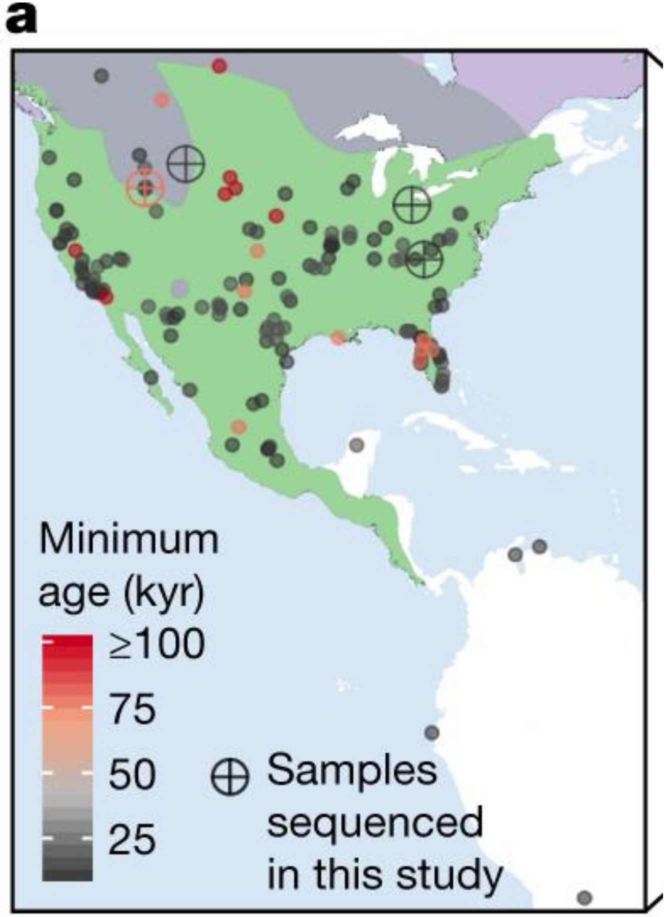
Cytosine deamination to uracil



« U » will cause A to be inserted to the opposite site and cause a C:G to T:A transition when DNA is replicated

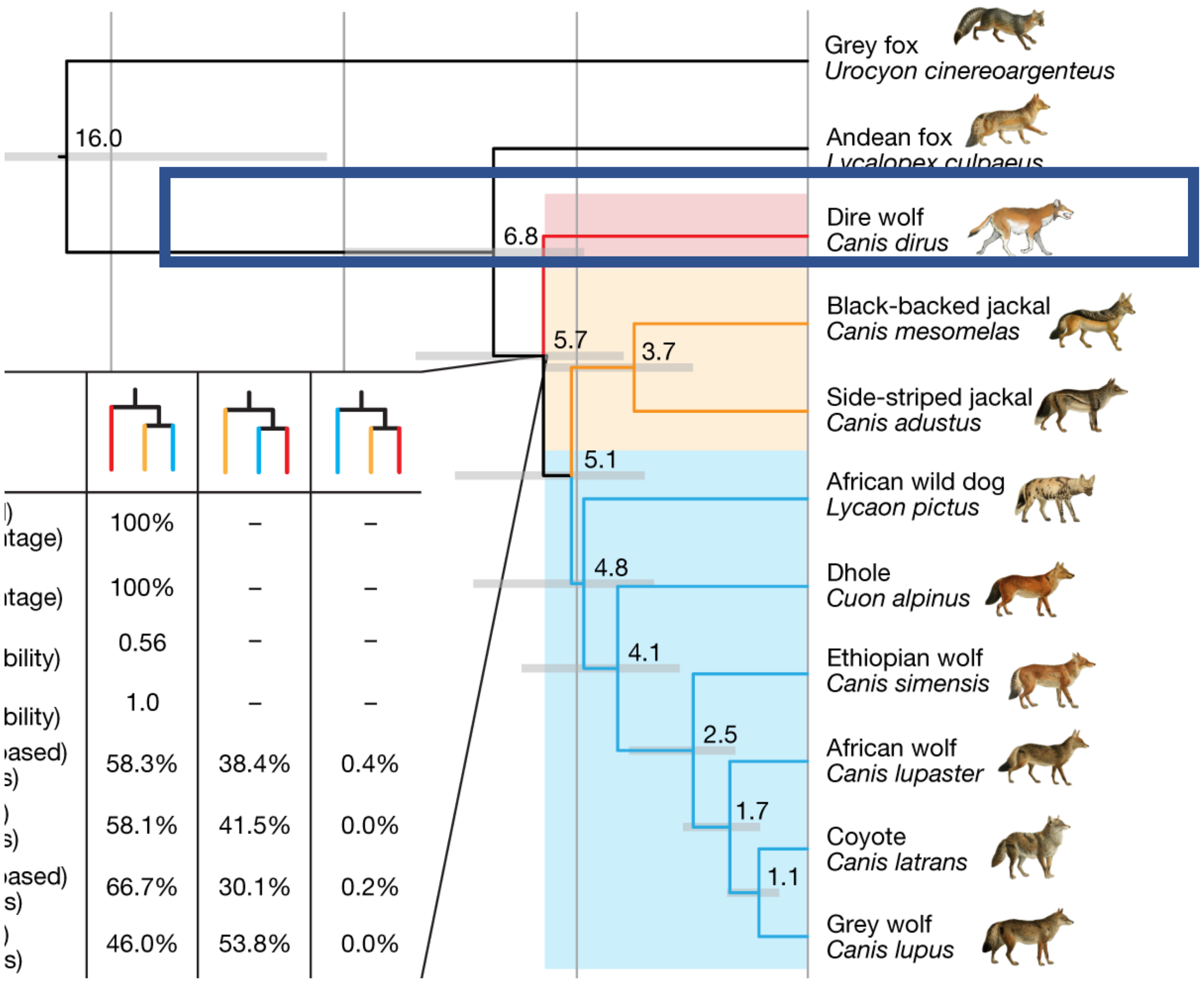


Orlando 2016



- Screening of 46 sub-fossil specimens for the presence of preserved genomic DNA
- 5 samples from Idaho (DireAFR & DireGB), Ohio (DireSP), Tennessee (DireGWC) and Wyoming (DireNTC), dating to between 12,900 and more than 50,000 years ago,

McClung museum



- Basal position in the canidae phylogenetic tree
- No ancestry from grey wolves, coyotes
- Did not survive the Late pleiostocene megafaunal Extinctions

⇒ Less dietary flexibility ?

- Inability to interbreed might be the reason they got extinct (exemple Dog/wolf)

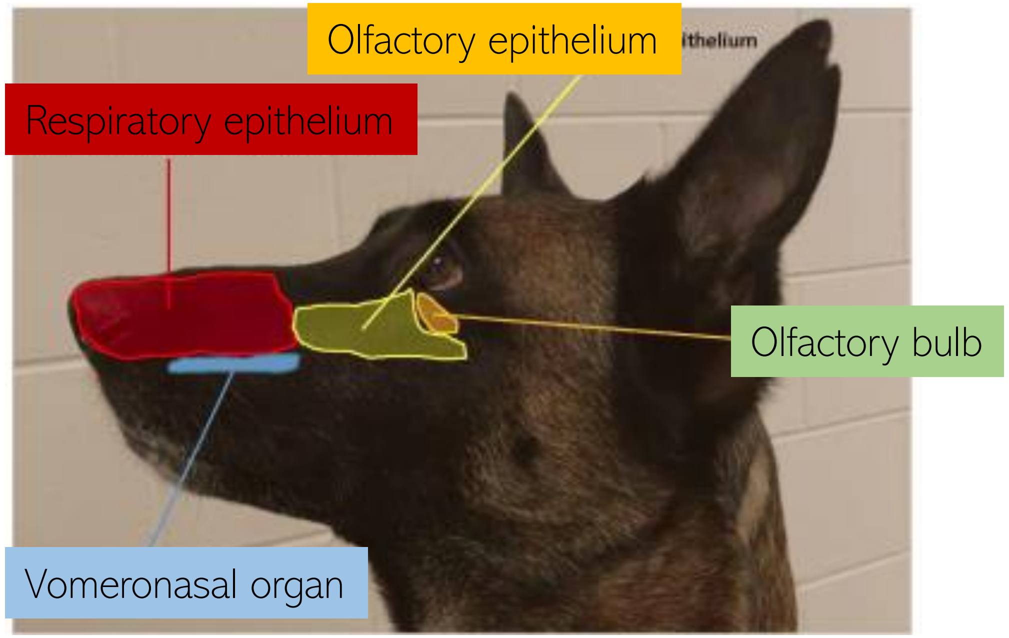
=> *Canis dirus* is not correct

Mauricio Anton

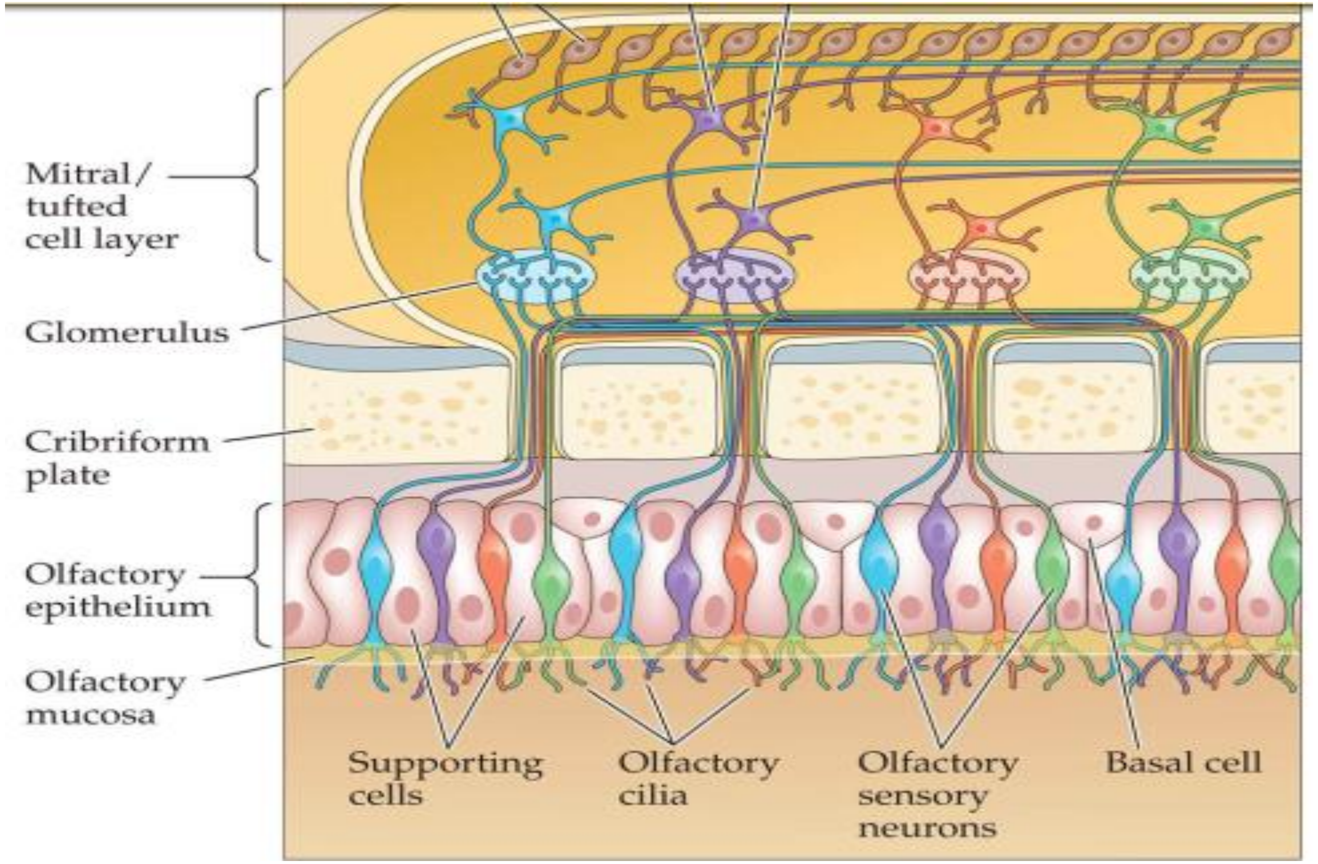
4. Déconstruire les mythes : l'odorat chez le chien

Une approche interdisciplinaire: génomique et la morphometrie

Comparaison de la sensibilité olfactive au sein des races de chien et en lien avec la domestication
Mouton, Bird et al. In Review



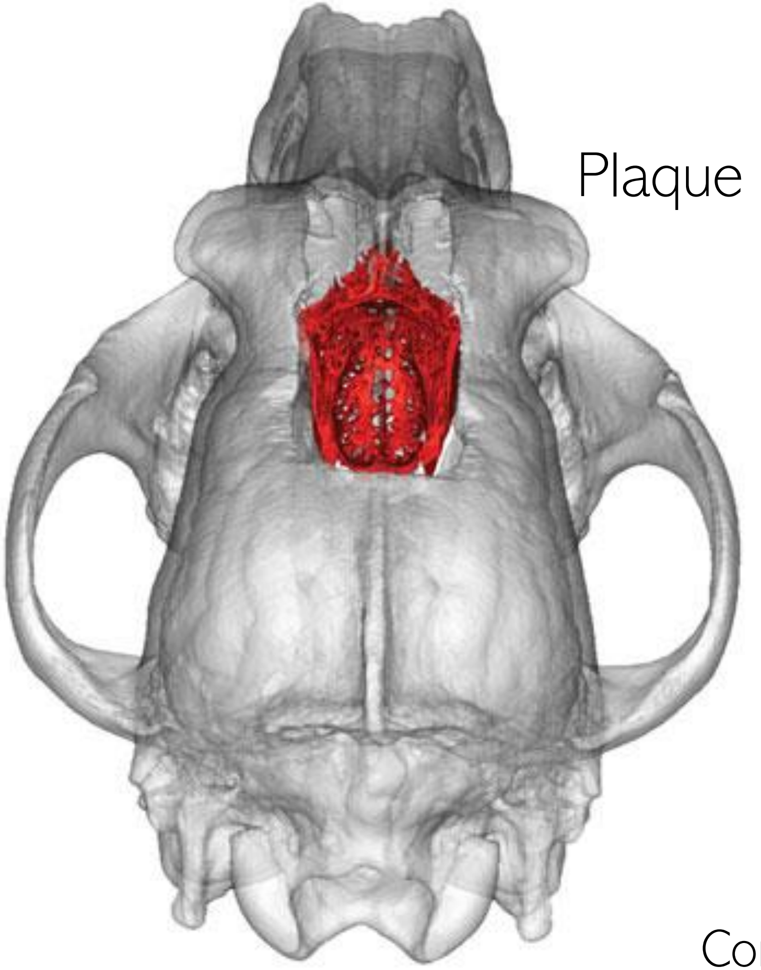
Jenkins et al 2018 (Photo Adrien-Maxence Hespel)



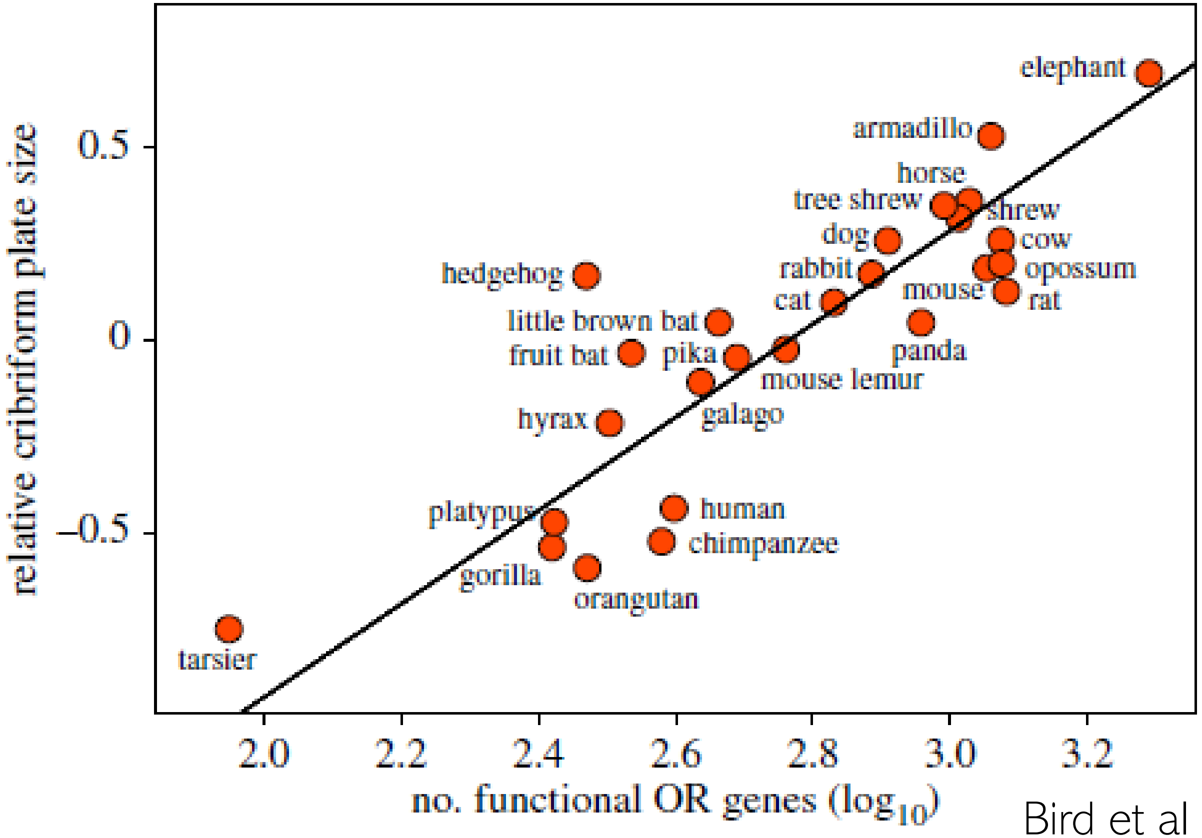
Sensory and perceptions 2015, Fig 14.3

OR genes :
largest gene family in terrestrial mammals
6 % coding genes

Only one olfactory receptors is selected to be expressed in a given OSN



Plaque cribriforme



Bird et al 2018

Bird et al 2018

Correlation entre la taille relative de la plaque et le le nombre de génes olfactifs

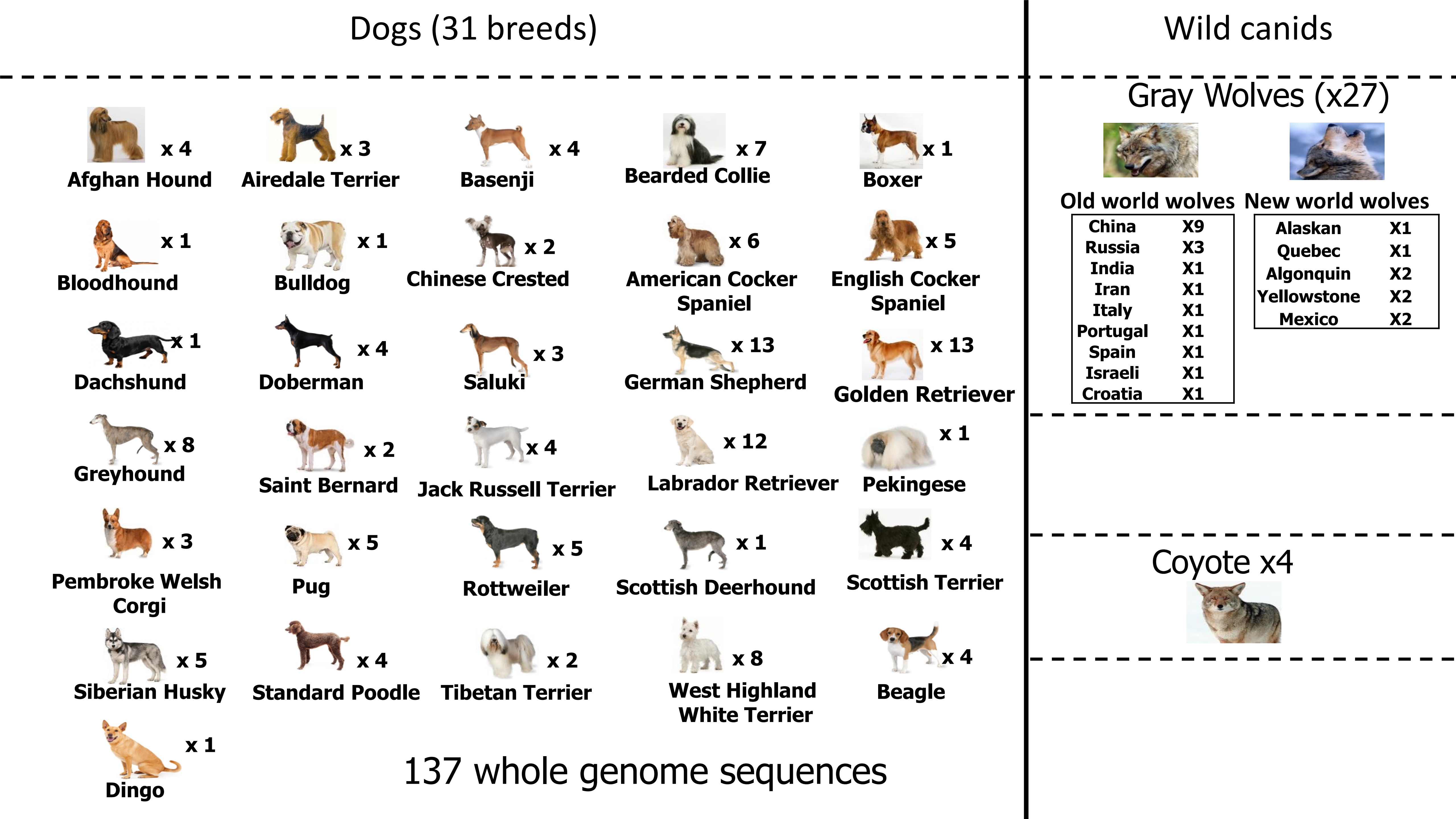
Diminution de la plaque entre le loup et le chien (domestication?)

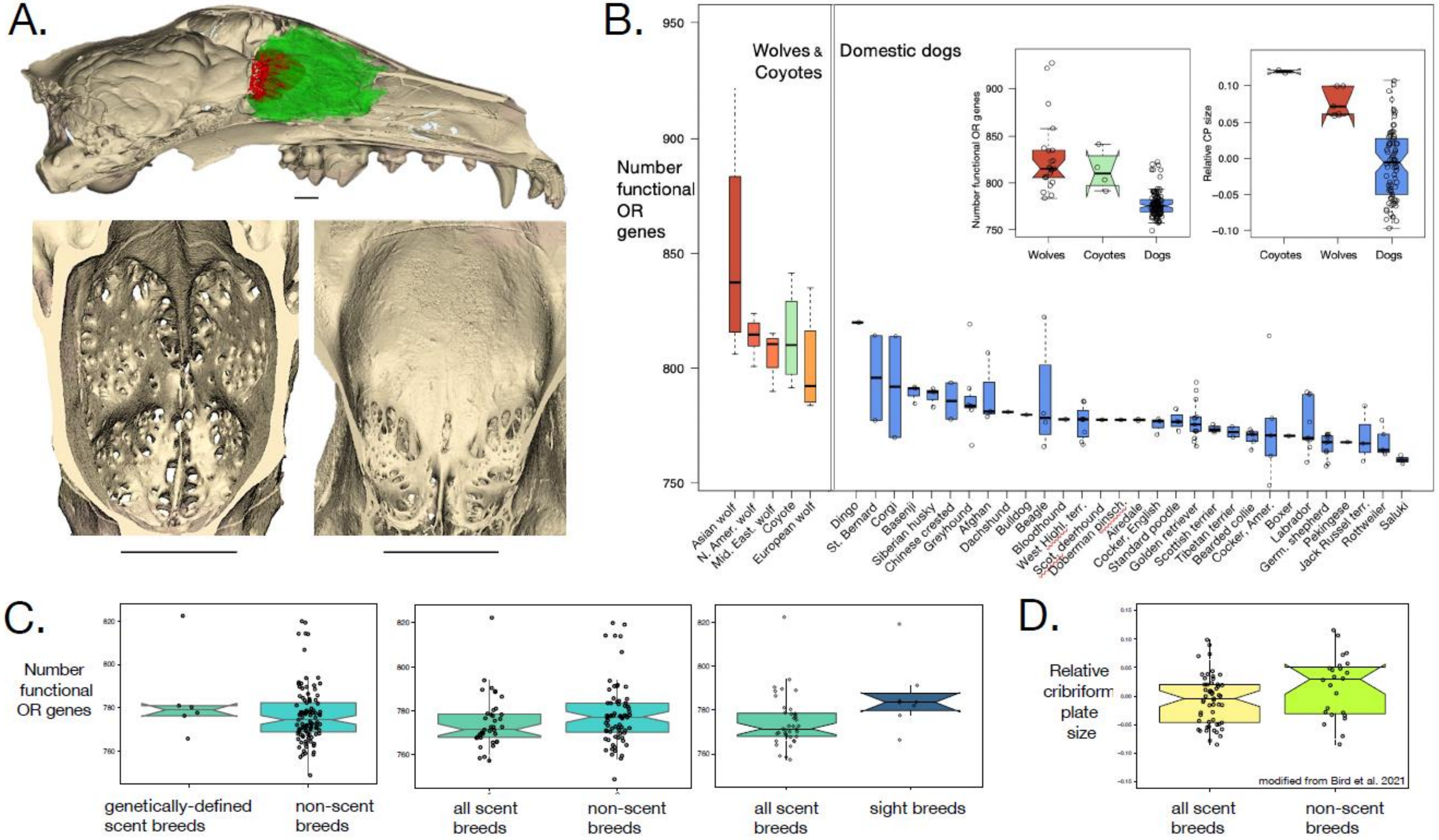
Hypothèses

Perte du répertoire olfactif du à la domestication

Certaines races de chien qui ont soi disant un meilleur odorat ont récupéré cette perte

Les races de chien anciennes ont conservé un nombre plus élevé de récepteurs olfactifs


Dogs (31 breeds)
Wild canids
x 4
Afghan Hound
x 3
Airedale Terrier
x 4
Basenji
x 7
Bearded Collie
x 1
Boxer
x 1
Bloodhound
x 1
Bulldog
x 2
Chinese Crested
x 6
American Cocker Spaniel
x 5
English Cocker Spaniel
x 1
Dachshund
x 4
Doberman
x 3
Saluki
x 13
German Shepherd
x 13
Golden Retriever
x 8
Greyhound
x 2
Saint Bernard
x 4
Jack Russell Terrier
x 12
Labrador Retriever
x 1
Pekingese
x 3
Pembroke Welsh Corgi
x 5
Pug
x 5
Rottweiler
x 1
Scottish Deerhound
x 4
Scottish Terrier
x 5
Siberian Husky
x 4
Standard Poodle
x 2
Tibetan Terrier
x 8
West Highland White Terrier
x 4
Beagle
x 1
Dingo
137 whole genome sequences
Gray Wolves (x27)
Old world wolves
China X9
Russia X3
India X1
Iran X1
Italy X1
Portugal X1
Spain X1
Israeli X1
Croatia X1
New world wolves
Alaskan X1
Quebec X1
Algonquin X2
Yellowstone X2
Mexico X2
Coyote x4



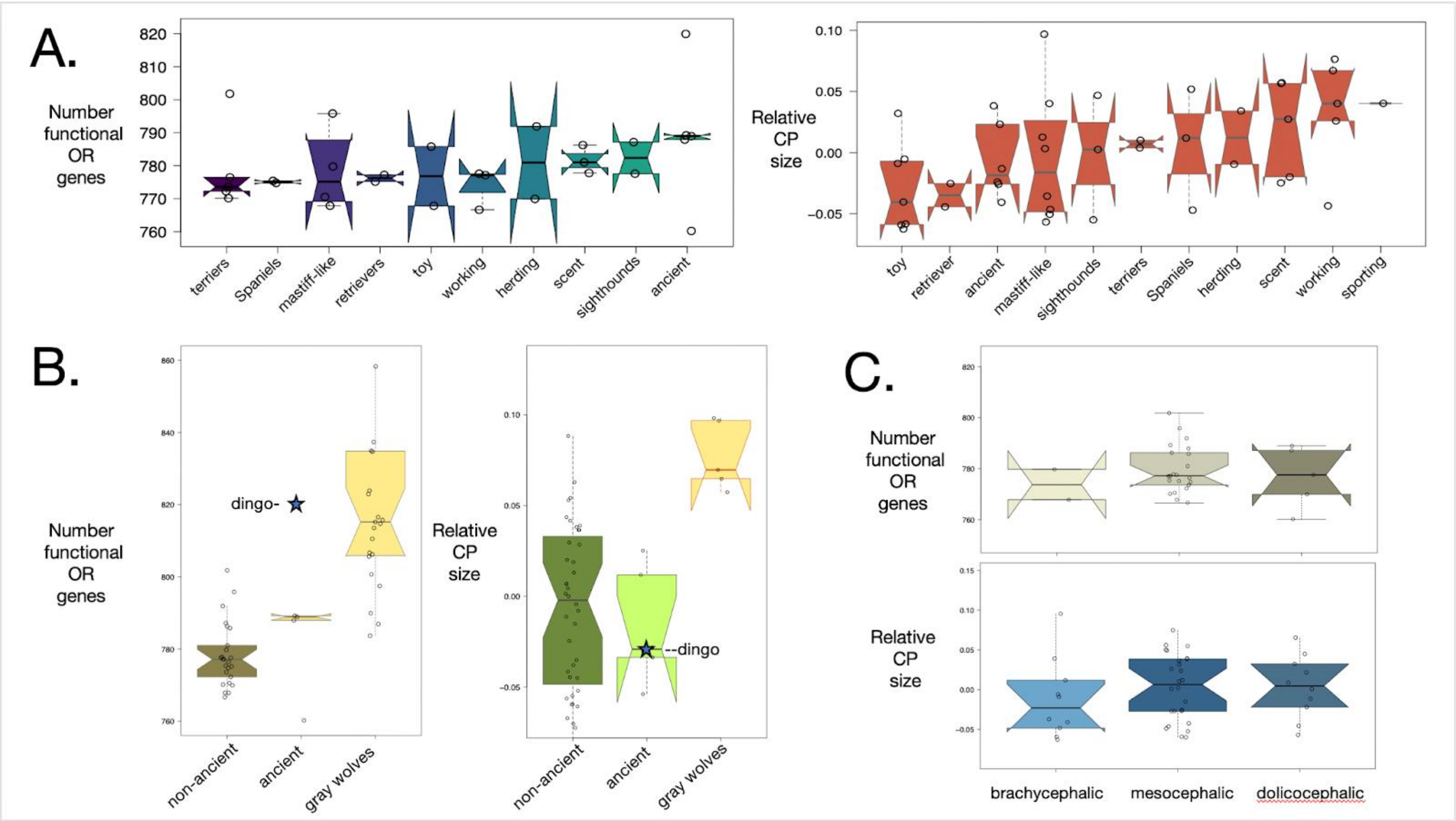
Mouton, Bird et al. In Review

- significant loss of functional OR genes in dogs relative to wild canines

⇒ Selective pressure for olfactory function has been relaxed in dogs? (e.g. amylase, isotope)

⇒ drift-related olfactory gene diversity loss due to at least two bottleneck events

- No differences between coyotes and wolves
- Differences among wolves
- No difference within dogs



- no significant differences between commonly used breed groupings

- Ancient dogs appear to occupy an intermediate position between domestic dogs and wolves but significant only with the Dingo

⇒ Isolation for thousands of years, feral, less reliant to human food than dog, one copy of amylase

- No difference in OR with snout differences

Mouton, Bird et al. In Review

- Loss due to domestication
- No genetic or morphological profile shared among functional or genealogical breed groupings, such as scent hounds, that might indicate evidence of any human-directed selection for enhanced olfaction.

=> Training and behavior

5. Un Atlas de génome : la communauté scientifique autour d'un objectif commun,

Sauvegarder la biodiversité

EARTH BIOGENOME PROJECT
sequencing life for the futu

African BioGenome Project
Genomics for the future of biological diversity across Africa

eRGA
European Reference Genome Atlas
https://www.erga-biodiversity.eu/

VGP VERTEBRATE GENOMES PROJECT
A PROJECT OF THE G10K CONSORTIUM

B10K

GIGA

i5K

BAT 1K

Darwin TREE of LIFE

BIO GENOMA

ENDEMIXIT
Population Genomics of Italian Endemics

EUROPEAN REFERENCE GENOME ATLAS

Generate reference genome assemblies of **European eukaryotic species** across the tree of life, including threatened, endemic, and keystone, as well as species important to agriculture, fisheries, pests, and to ecosystem function and stability.

Total species ~ 200K, endangered ~ 20%

- 48% shrubs
- 42% trees
- 37% freshwater fishes
- 29% grasshoppers
- 25% amphibians
- 22% non-marine mollusks
- 20% reptiles
- 20% ferns
- 18% beetles
- 15% mammals
- 13% birds
- 9% bees
- 9% butterflies
- 7.5% marine fishes

Source: IUCN RED LIST

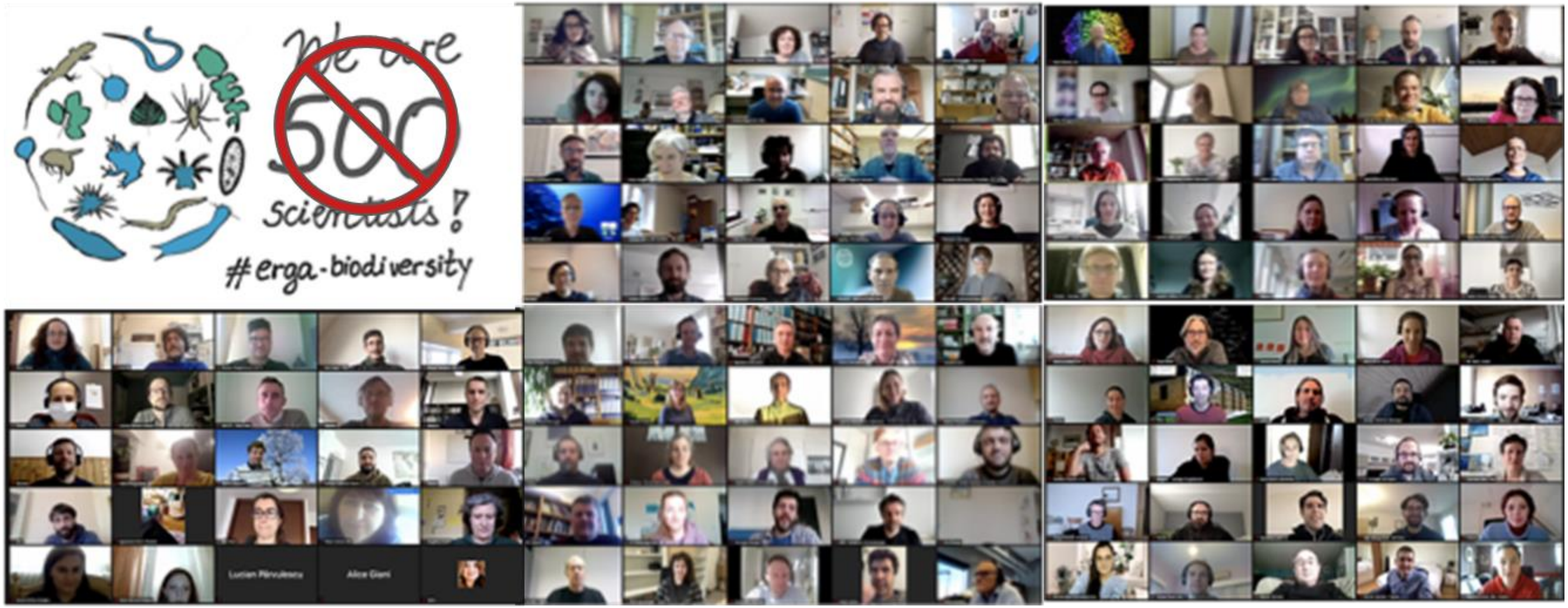
erga-biodiversity.eu

Follow: @erga_biodiv

eRGA

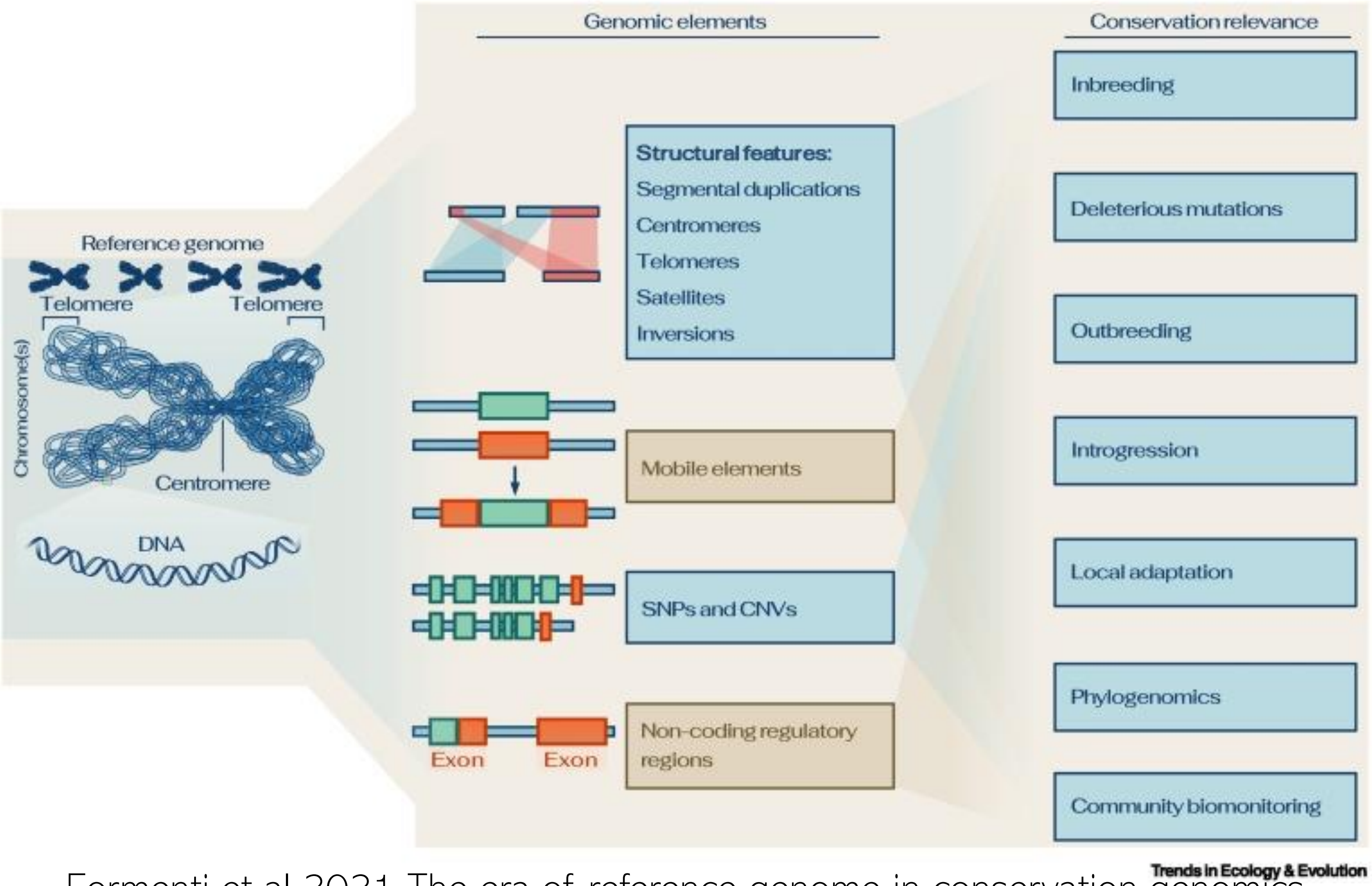
EUROPEAN REFERENCE GENOME ATLAS

>600 Members & growing!



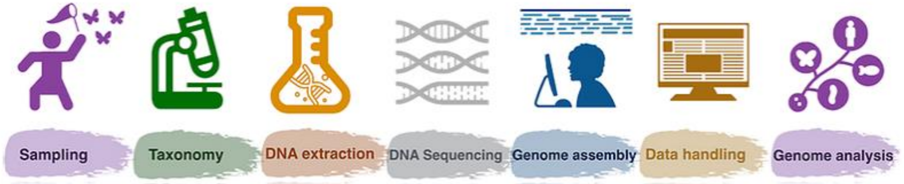
A bottom-up iniative

Follow: @erga_biodiv



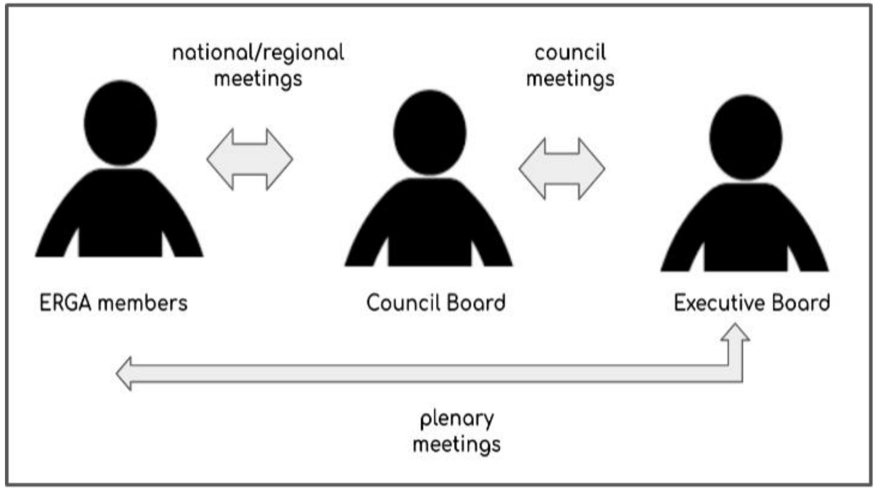
Formenti et al 2021 The era of reference genome in conservation genomics

eRGA
European Reference Genome Atlas



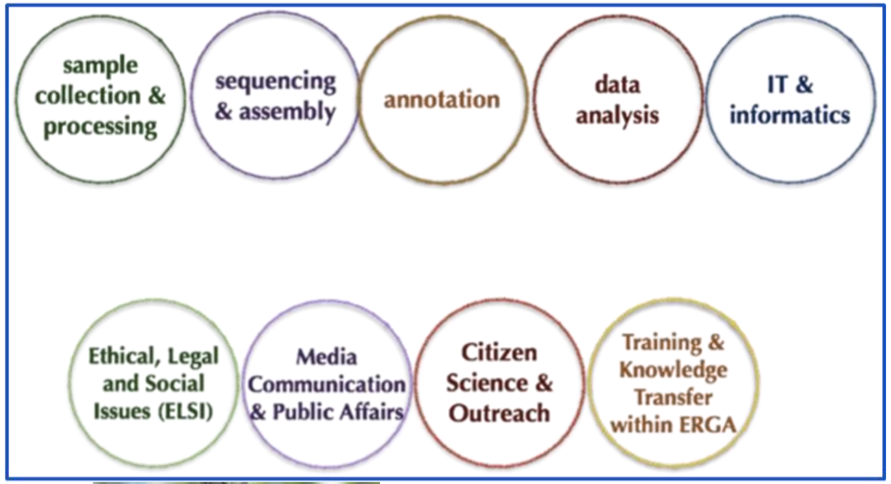
Dr Claudio Ciofi, (Vice Chair), Italy
Dr. Camila Mazzoni, Chair, ERGA, Germany.
Dr Robert Waterhouse, (Vice Chair), Switzerland

Council



Two Council Representatives per country

Committees



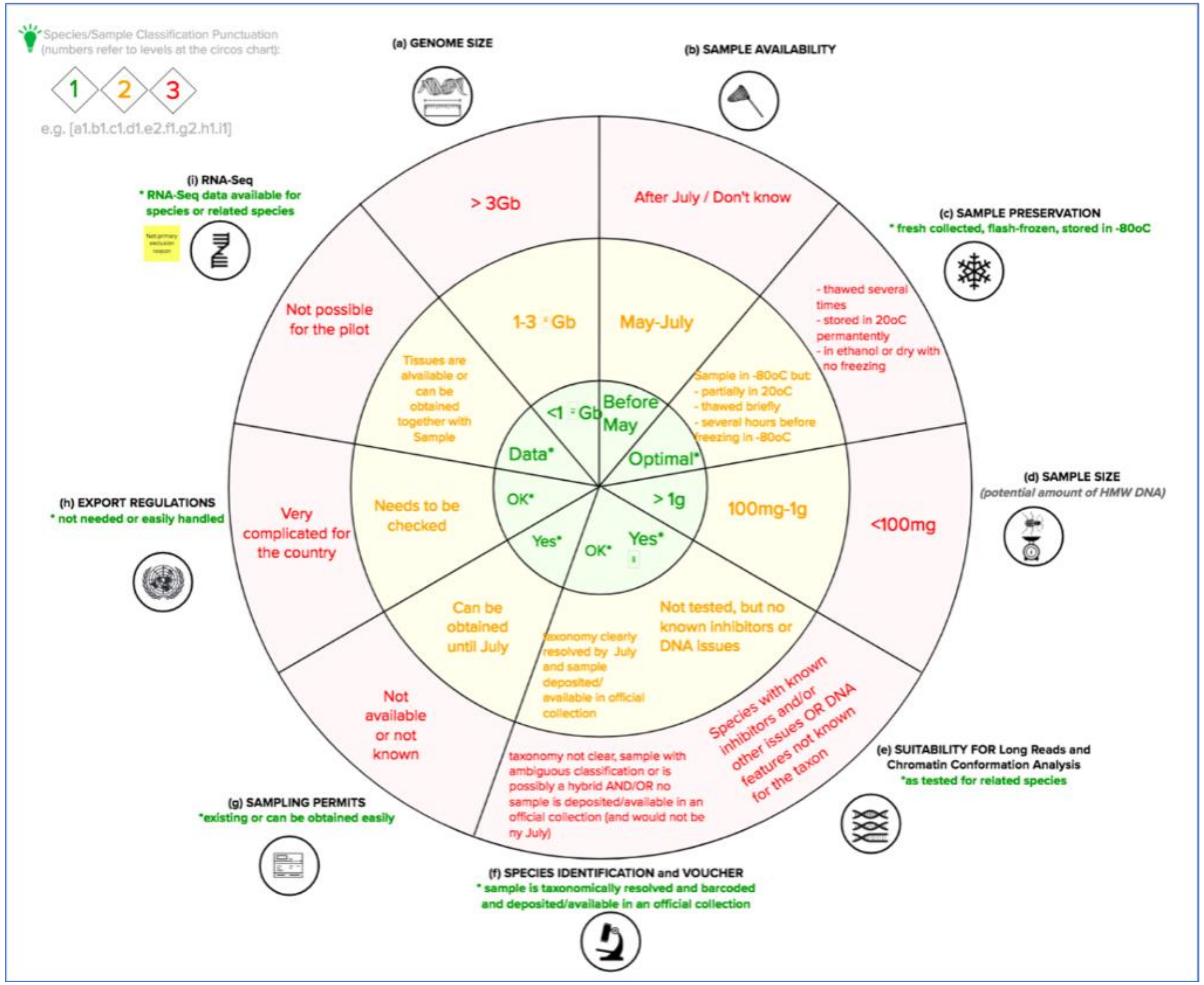
Belgium@erga-biodiversity.eu

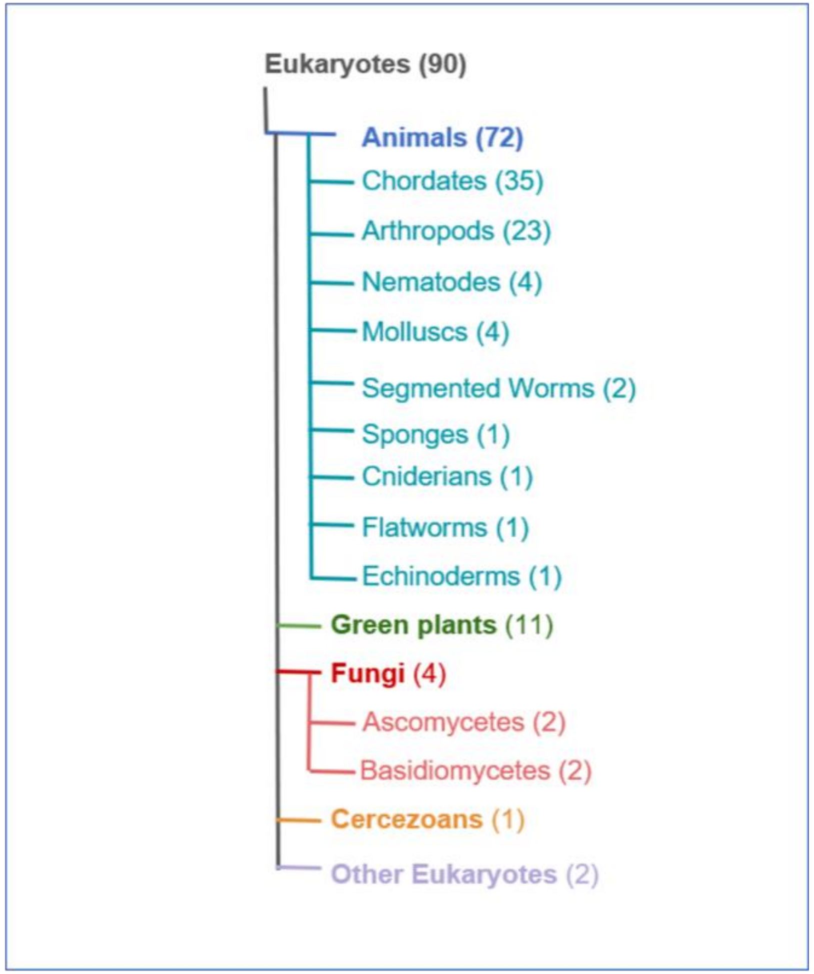
Hannes Svardal (U. Antwerp)
Alice Mouton (U. Liege)

Follow: @erga_biodiv

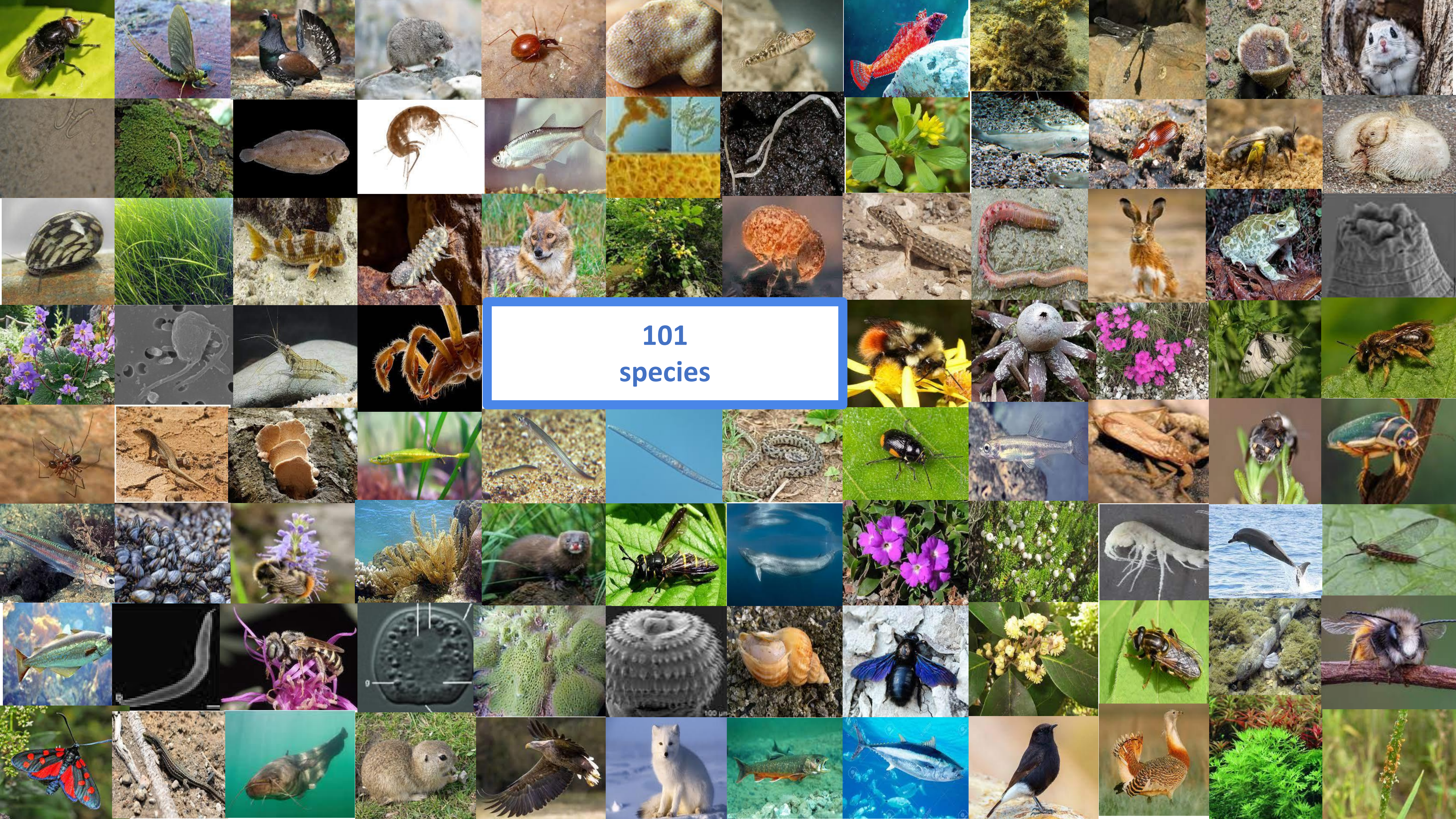
EUROPEAN REFERENCE GENOME ATLAS

The ERGA Pilot Project



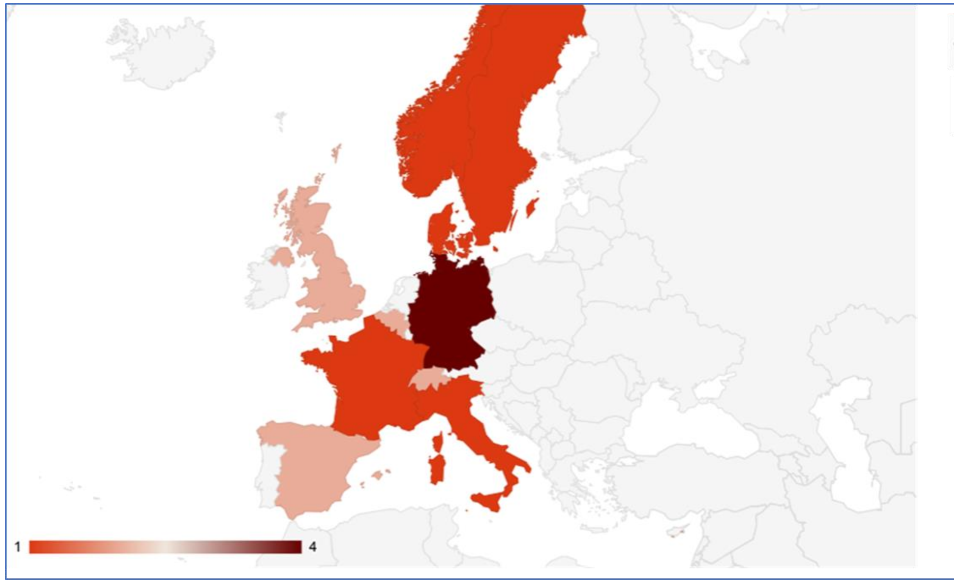


Complete list of species on https://goat.genomehubs.org/projects/ERGA


101
species

EUROPEAN REFERENCE GENOME ATLAS

Pan-European Sequencing Centre Support



Centro Nacional de Análisis Genómico (Spain)

Earlham Institute (UK)

University of Florence (Italy)

Functional Genomics Center Zurich (Switzerland)

Genoscope (France)

GIGA-Genomics core facility (Belgium)

Lausanne Genomic Technologies Facility (Switzerland)

Max Planck Institute Dresden (Germany)

NGS Competence Center Tübingen (Germany

SciLifeLab (Sweden)

Vlaams Instituut voor Biotechnologie - Antwerp (Belgium)

WGCC - Cologne, Düsseldorf, Bonn (Germany)

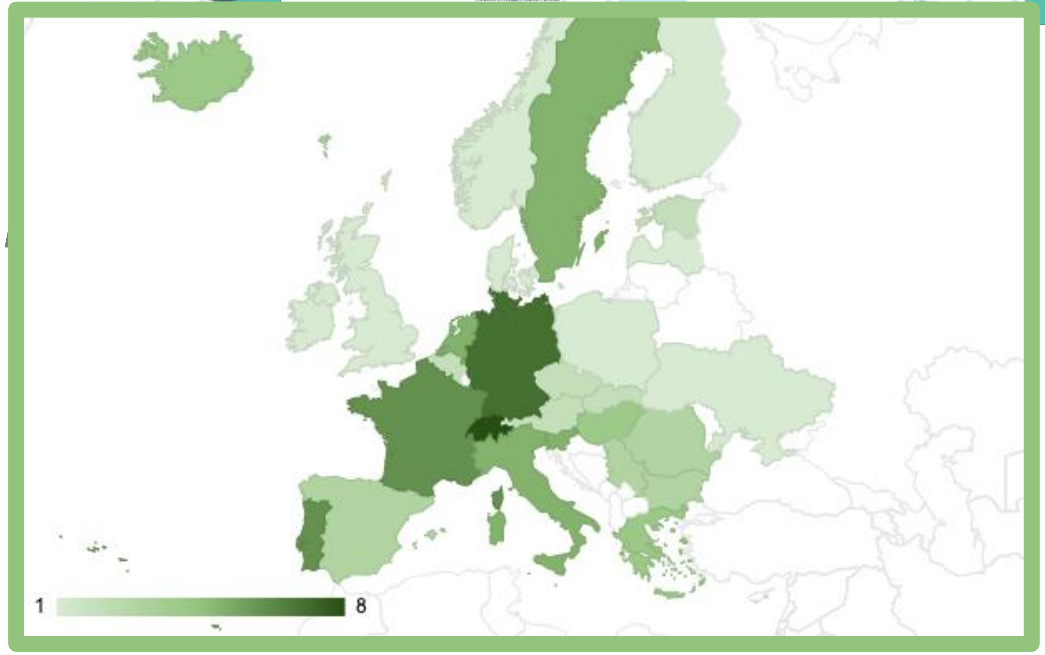
Next-Generation Sequencing Platform - Bern (Switzerland)

Norwegian Sequencing Centre (Norway)

Wellcome Sanger Institute (UK)

Transborder Multidisciplinary Genome Teams

1) Sample collector and/or sample provider
2) Taxonomy classification and/or vouchering
3) Sample ambassador/*coordinator and usually the*
4) Wet-lab processing
5) Computational resources and/or support
6) Genome assembly and/or curation
7) Genome annotation and/or genome analysis

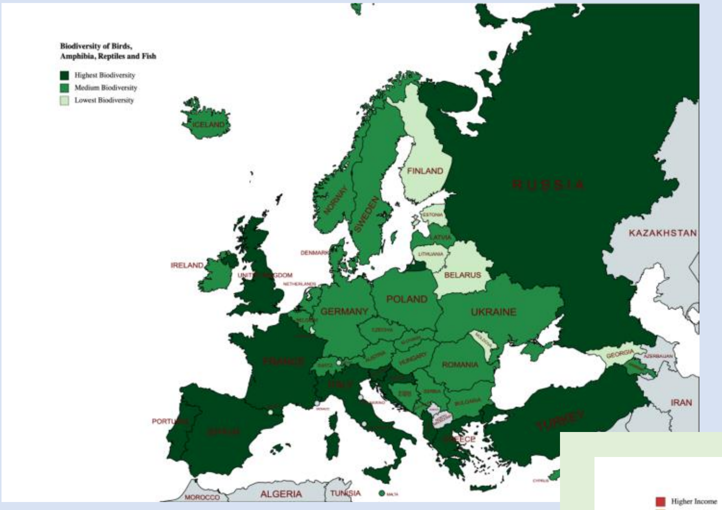


Sample contributors

Credit: ERGA Media Committee, Lúisa Marins

Follow: @erga_biodiv

Genomics for all – Genomics by all!



Biodiversity of birds, amphibia, reptiles and fish

GNI per Capita

R&D Expenditure (%GDP)

** Biodiversity Stats based on [Source: Plant data is from the World Conservation Monitoring Centre of the United Nations Environment Programme (UNEP-WCMC), 2004. Species Data. Fish: Fishbase; Birds: Birdlife International; Amphibians: AmphibiaWeb; Mammals: IUCN; Reptiles: the Reptile Database.] GNI an R&D Stats based off World Bank.

RNA sequence Coordination Centres

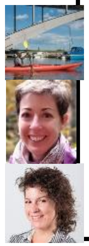
Svardal Lab

Florence Genomics Lab

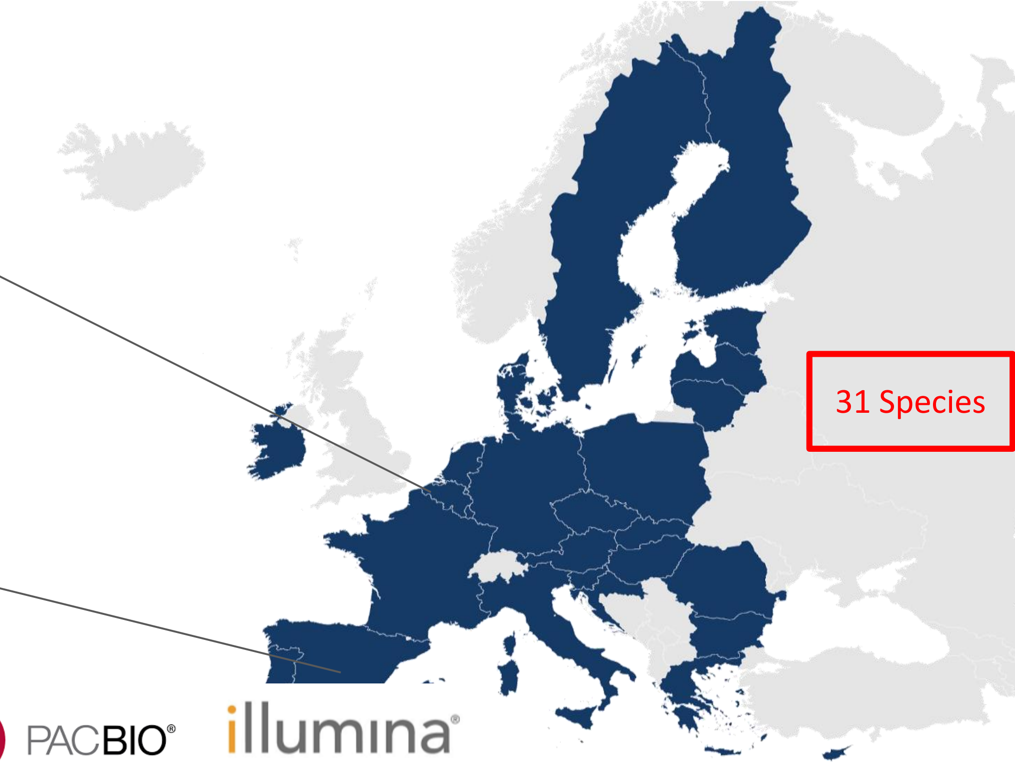
33 Species

HiC Coordination Centres

Svardal Lab



Metazoa Phylogenomics & worm~lab



31 Species

Agilent ARIMA GENOMICS ThermoFisher SCIENTIFIC MAGBIO "WE MAKE NGS BETTER" Dovetail GENOMICS PACBIO illumina


TKT - Training and Knowledge Transfer
CS - Citizen Science
SAC - Sequencing and Assembly Committee
DAC - Data Analysis Committee
ELSI - Ethical, Legal, and Socia Issues
Media & Website
SSP - Sampling and Sample Processing
ITIC - IT & Infrastructure Committee
Annot - Annotation Committee
Dovetail Genomics
Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EMBL-EBI
COPO
describe deposit discover
Local Contexts
elixir
ENA
European Nucleotide Archive
Galaxy PROJECT
IDT
INTEGRATED DNA TECHNOLOGIES
MAGBIO
"WE MAKE NGS BETTER"
fisher scientific
part of Thermo Fisher Scientific
NCCT
NGS Competence Center Tübingen
VIB
science meets life
f·g·c·z
functional genomics center zurich
PacBio
ZYMO RESEARCH
illumina
Agilent Technologies
wellcome sanger institute
cnag
ARIMA GENOMICS
CBG
Max Planck Institute of Molecular Cell Biology and Genetics
WEST GERMAN GENOME CENTER
LIÈGE université GIGA
UNIVERSITÄT BERN
NSC
NORWEGIAN SEQUENCING CENTRE
FORSCHUNGS museum KOENIG
Earlham Institute
Centre National de Séquençage
GENOSCOPE
SciLifeLab

6. Le milieu urbain, laboratoire de l'évolution

https://www.schoolofcities.utoronto.ca/science-cities/urban-genome-project

Milieu urbain

- 1 % surface de la terre

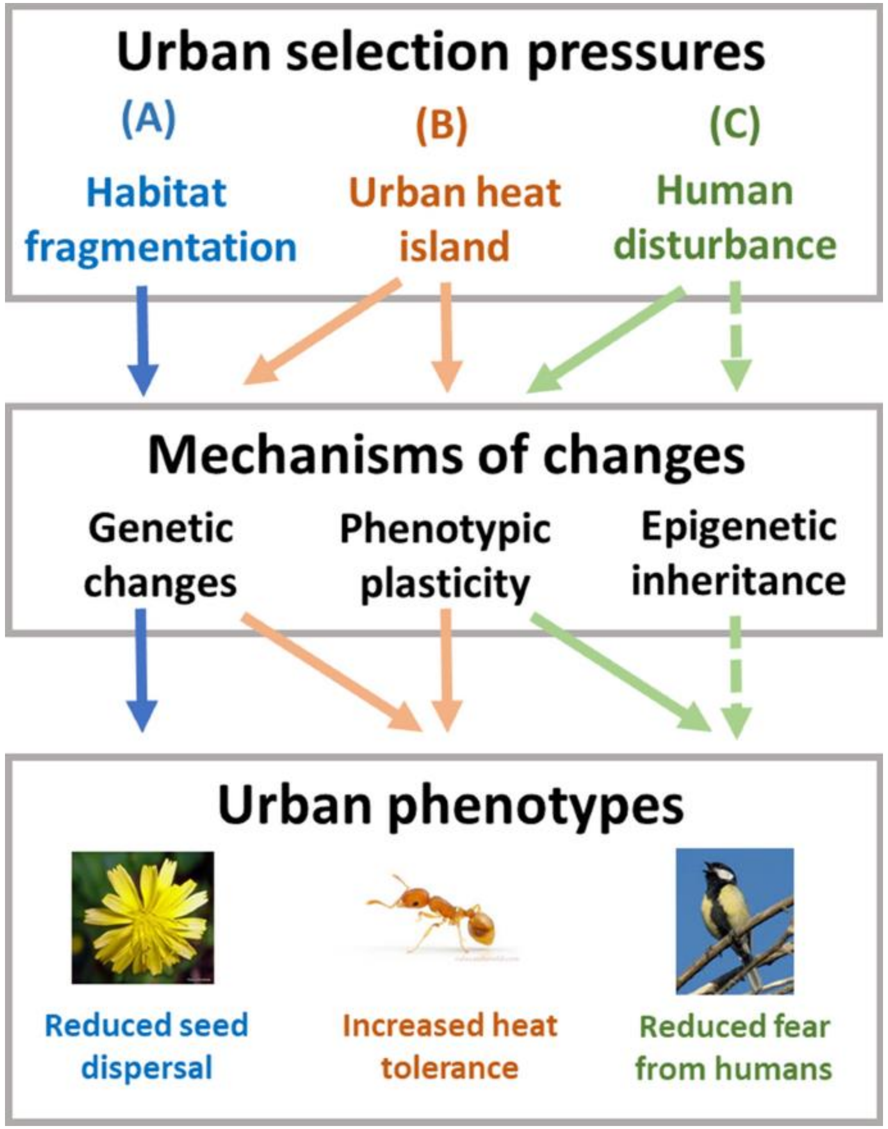
- En 2050 environ 70% de la population mondiale vivra en milieu urbain (United Nations, 2019)

- Urbanisation => perte de biodiversité mondiale

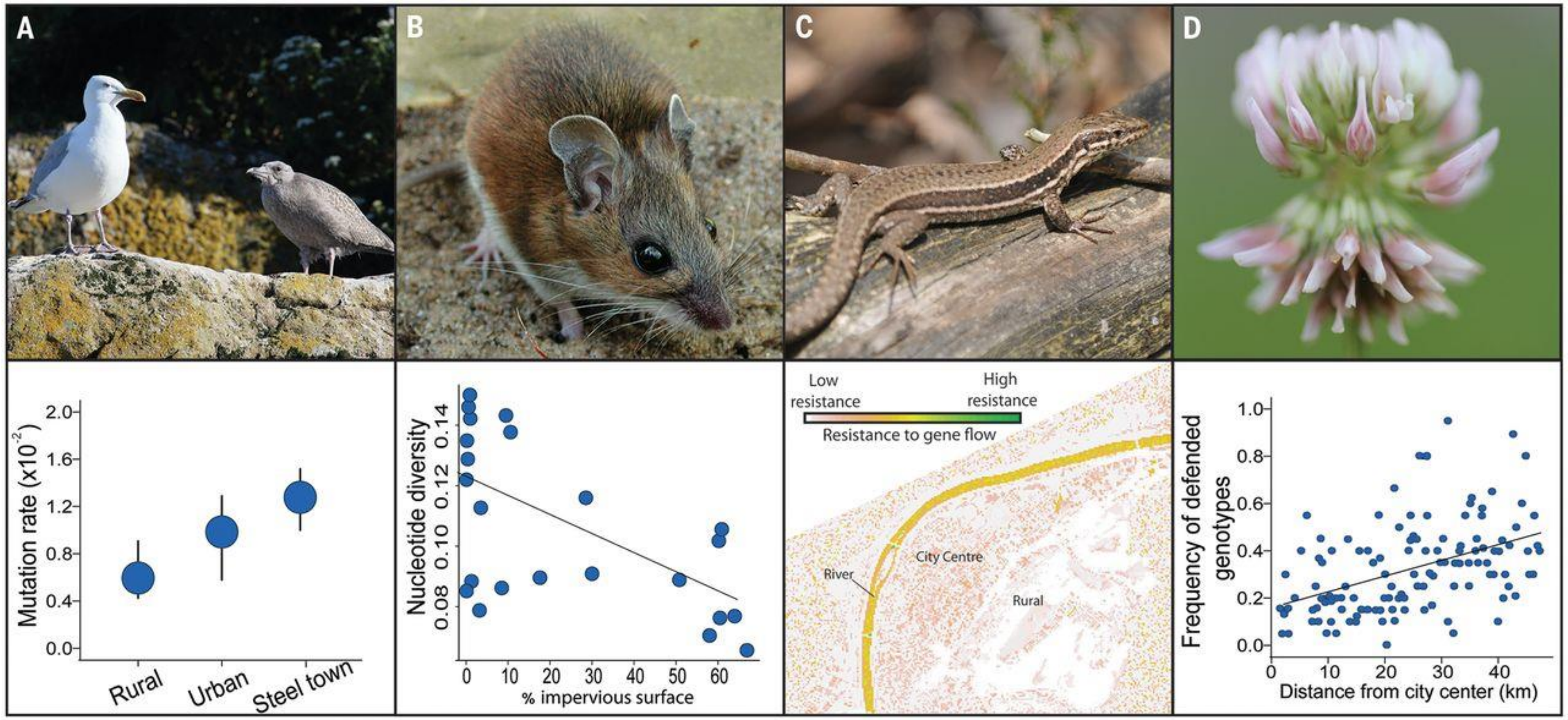
- Changement environnementaux similaires (ilot de chaleur, imperméabilisation des sols, pollution (aérienne, acoustique, lumineuse)

Nouvelles conditions environnementales dans un espace-temps très contraignant
Conditions idéales pour amorcer des changements évolutifs.

=> La ville = Laboratoire idéal pour étudier l'évolution

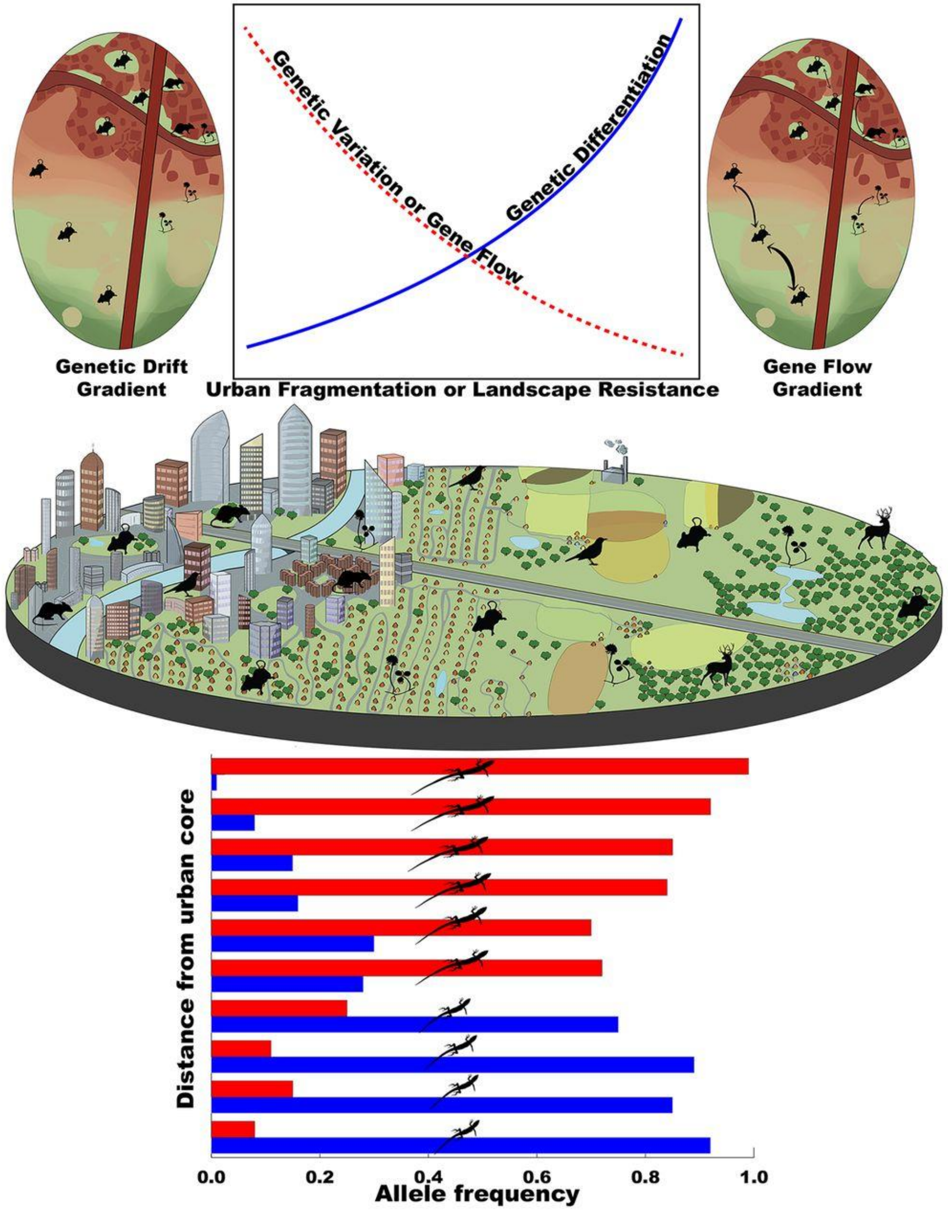


Liker, 2020

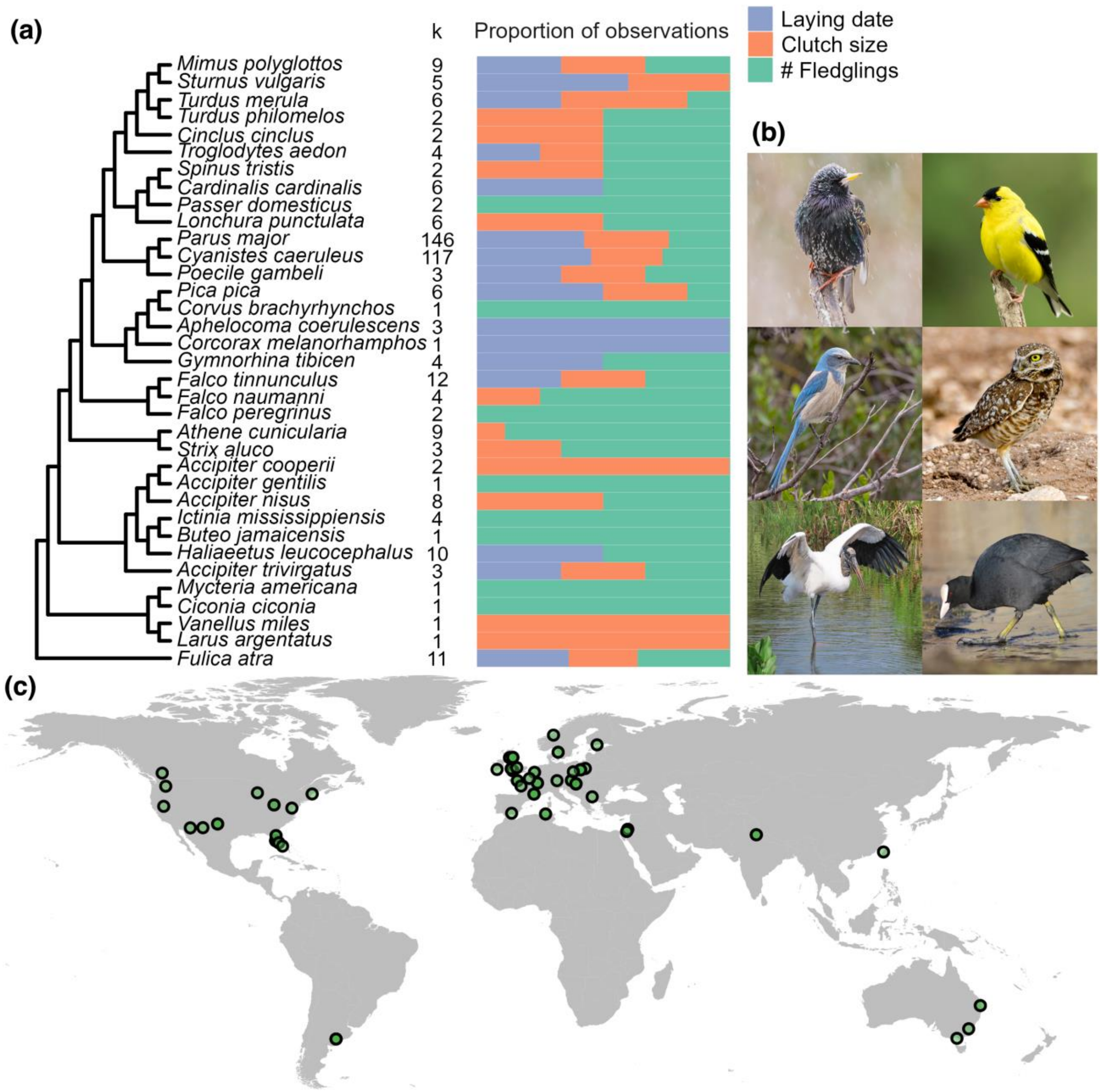


Johnson & Munshi-South 2017

Figure from https://colindonihue.com/2014/09/03/adaptive-evolution-in-urban-ecosystems-2/



Johnson & Munshi-south 2017, Science

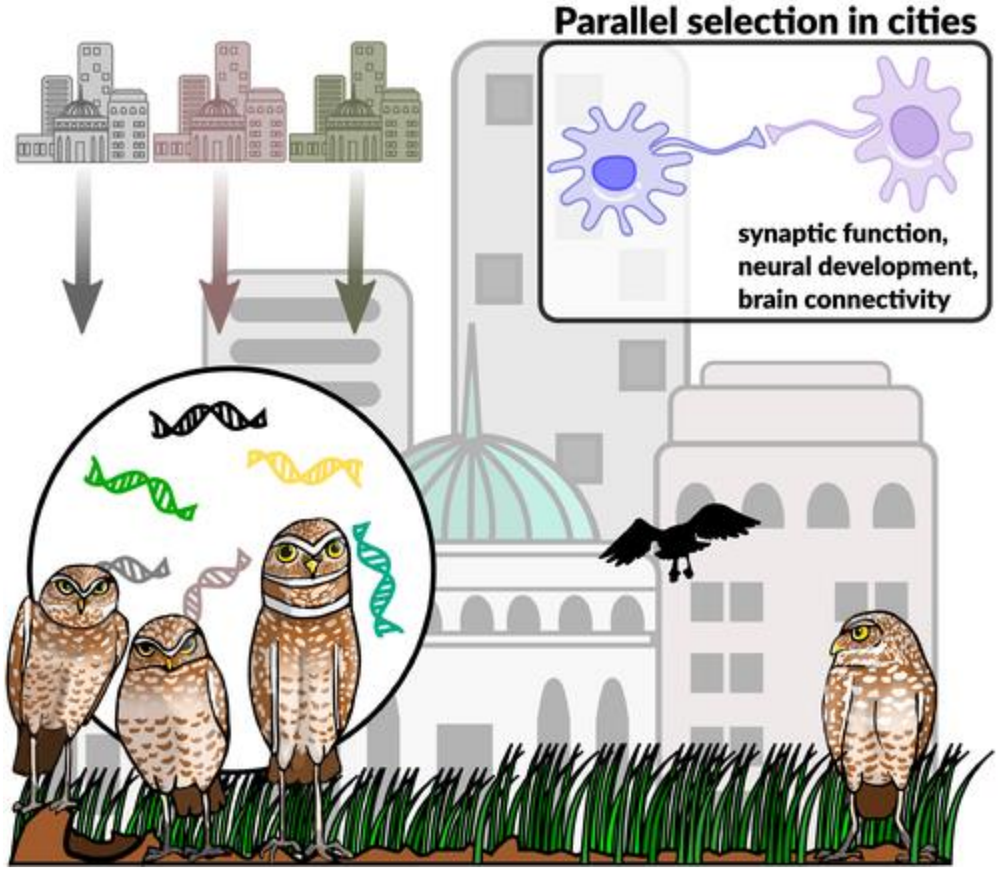


Capilla-Lasheras et al 2022, Ecology Letter

Meta-analyse sur 35 oiseaux comparant urbain ><non urbain

- Reproduction plus tôt
- Taille des nichées plus petites
- Variation plus grande dans la date de ponte

Chevêche des terriers (*Athene cunicularia*)



Mueller et al.'s (2018, 2020)

Présent dans les villes depuis peu (quelques dizaines d'années)

3 populations dans 3 villes en Argentine

Populations urbaines sont génétiquement différentes l'une de l'autre
Populations rurales ne sont pas trop différentes
Flux génique faible entre milieu rural et urbain mais aucun flux entre villes
Colonisation indépendante de la ville (//mésange, merle)

Sélection de genes liés aux fonctions cognitives and comportementales

https://onlinelibrary.wiley.com/doi/full/10.1111/mec.15589

Le merle (*Turdus merula*)

Différence chant, temps de reproduction, du comportement migratoire, forme des ailes

Evans et al Proc. R. Soc. B (2009)

- Colonisation dans les villes s'est produite de manière indépendante et plusieurs fois
- Diversité génétique réduite en ville
- Population urbaines sont plus différentes les unes des autres que les populations rurales

12 villes , 30 individus par paire
Microsatellites

Independent colonization of multiple urban centres by a formerly forest specialist bird species

Karl L. Evans[1,*], Kevin J. Gaston[1], Alain C. Frantz[1], Michelle Simeoni[1], Stuart P. Sharp[1,†], Andrew McGowan[1,‡], Deborah A. Dawson[1], Kazimierz Walasz[2], Jesko Partecke[3], Terry Burke[1] and Ben J. Hatchwell[1]

Le merle (*Turdus merula*)

Mueller et al 2013

16 gènes candidats (rythmes circadiens, évitement, migration, exploration
12 populations Europe , 792 individus

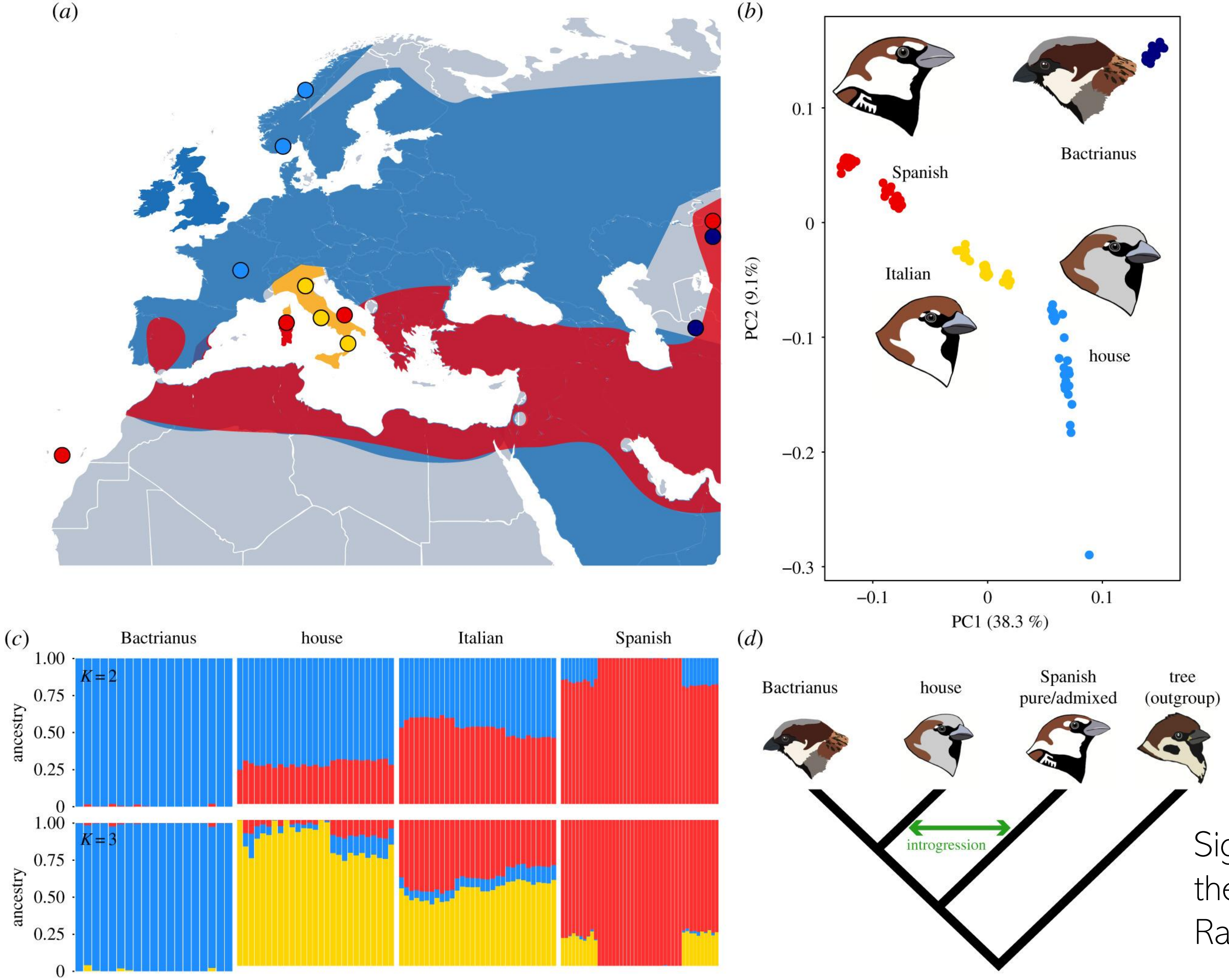
=> Variation au niveau d'un gène SERT (serotonin transporter) gene associé anxiété

// mésange charbonnière et le cygne noir

« Turdus urbanicus? »

Darwin Comes to Town: How the Urban Jungle Drives Evolution Menno Schilthuizen

Le moineau domestique, *Passer domesticus*

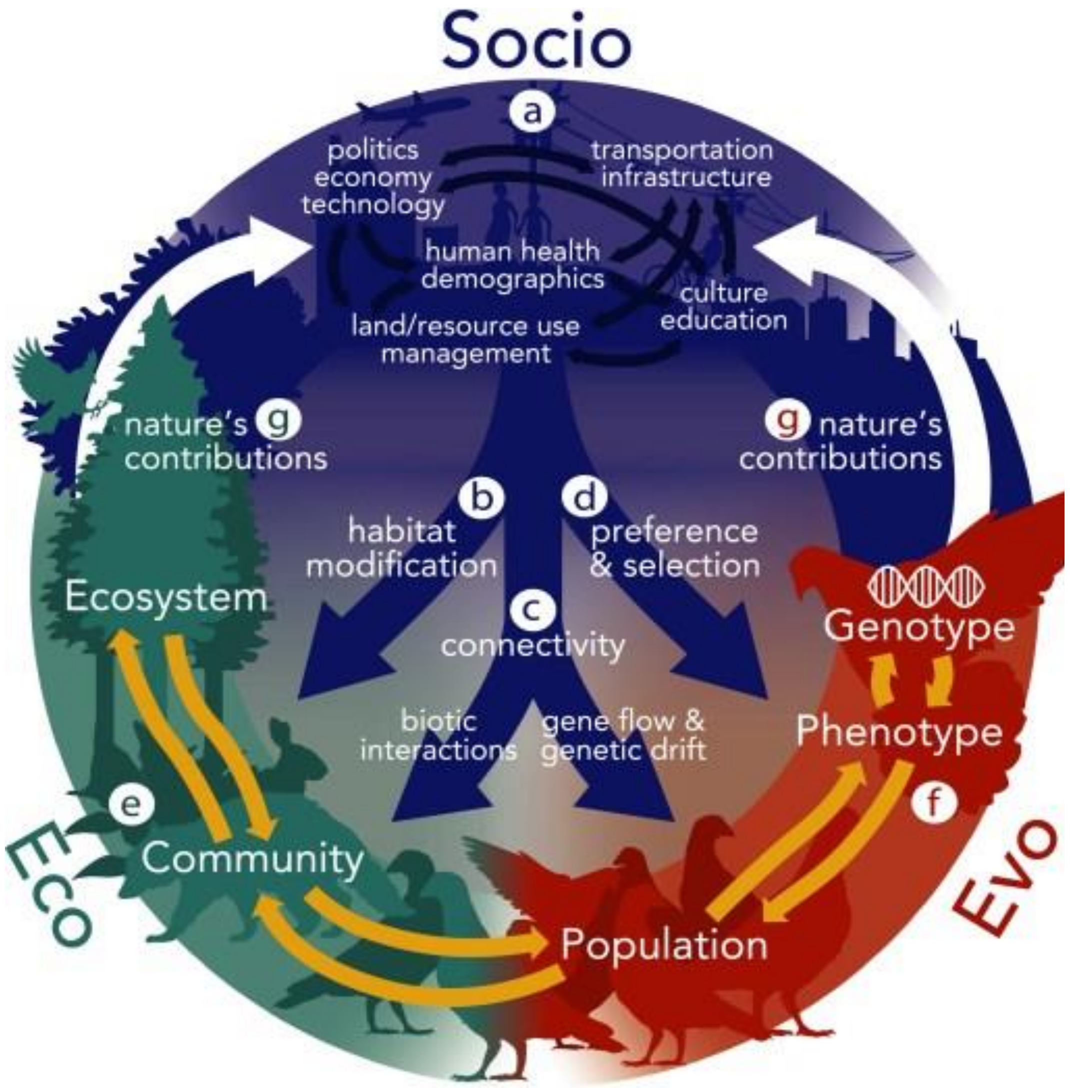


120 individus
sang

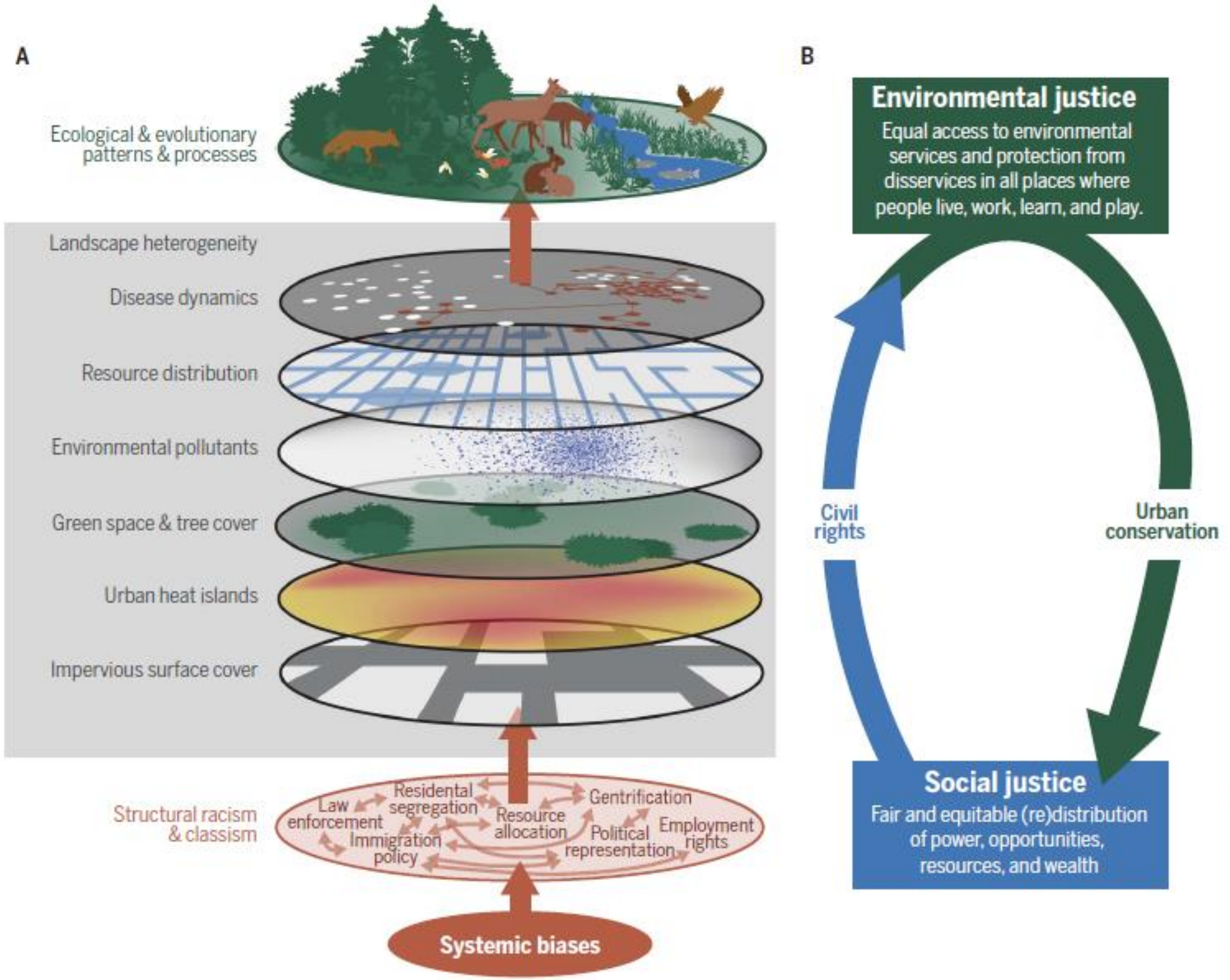
Séparation 11000 ans
2 gènes sous sélection :

COL11A1
AMY2A // chien, dingo

Signatures of human-commensalism in the house sparrow genome *Passer domesticus*
Ravinet et al 2018

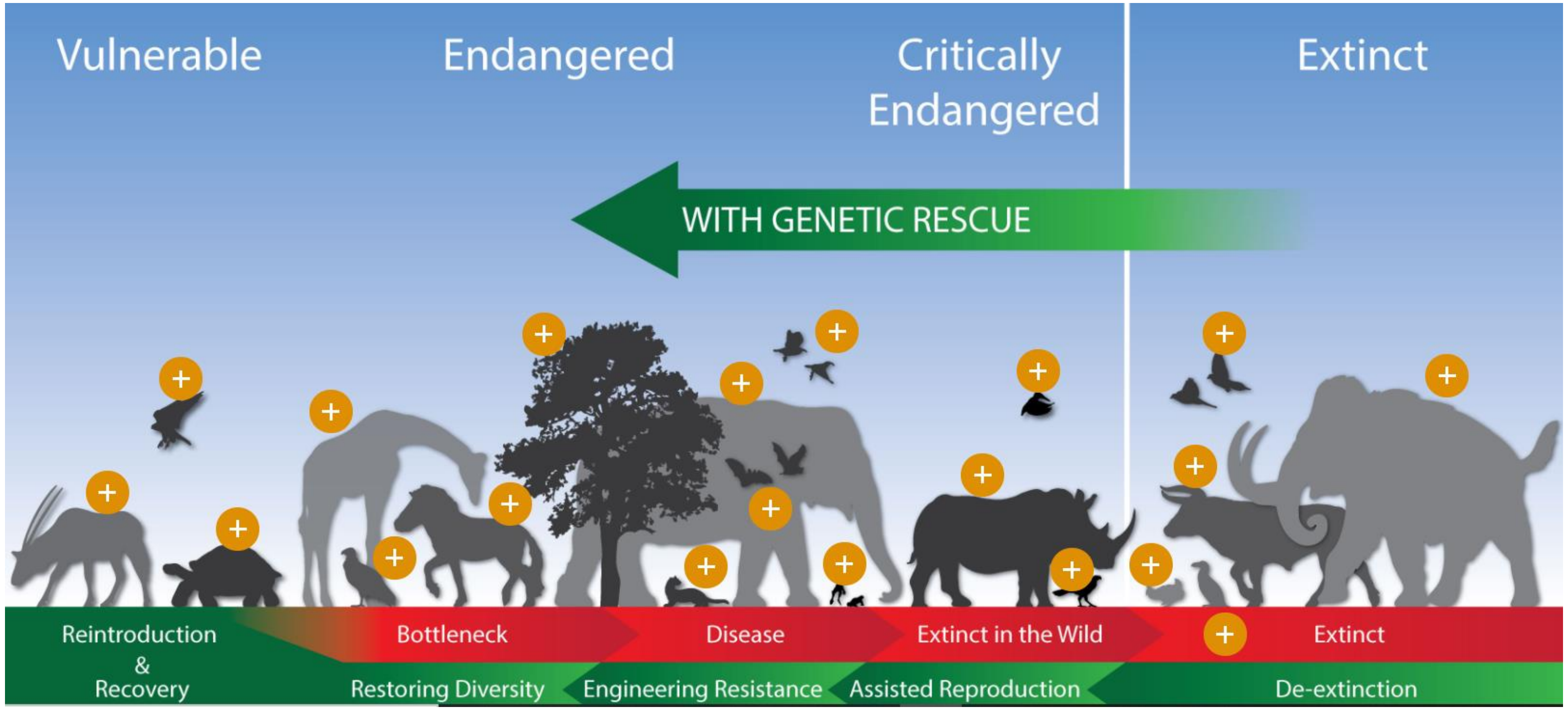


Desroches et al 2020



Schell et al 2020

7. Resusciter les espèces disparues?



Cryotechnology for wildlife

San Diego Zoo Wildlife Alliance

https://science.sandiegozoo.org/resources/frozen-zoo%C2%AE

THE FROZEN ARK

https://www.frozenark.org/

revive & restore

https://reviverestore.org/

revive&restore

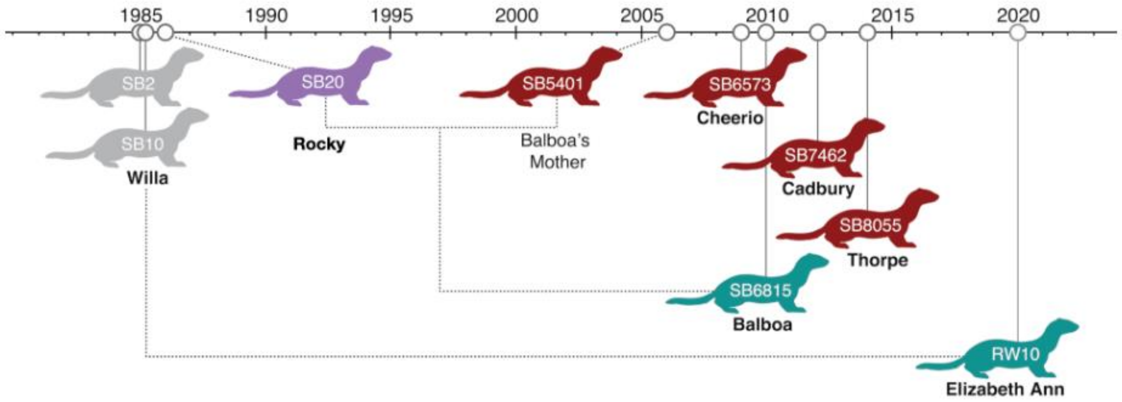
In the 1980's, conservationists captured the last 18 wild individuals from a population that was on the brink of extinction => captive breeding program

Willa lived until 1988. When she died, they sent the tissue to the Frozen Zoo at San Diego Zoo Wildlife Alliance (SDZWA).

A cell line was established and cryopreserved three days after she died

Revive & Restore in 2014 determined that Willa's genome had high genetic Diversity (more than the current population)

Elizabeth Ann born on december 10,2020 from Willa's cell!! And is now the Most genetically valuable Black-footed ferret alive.



https://reviverestore.org/projects/black-footed-ferret/

THE PRZEWALSKI’S HORSE

THE HEATH HEN

THE WOOLLY MAMMOTH