On the interest of genetic diversity in domestic animal populations : Characterization, Conservation and Use for agroecological transition

Gwendal RESTOUX, INRAE, GABI, GiBBS

METABIO, Kfé Incubio'Breeding

18 décembre 2023

RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

INRAE

Introduction and context

Context

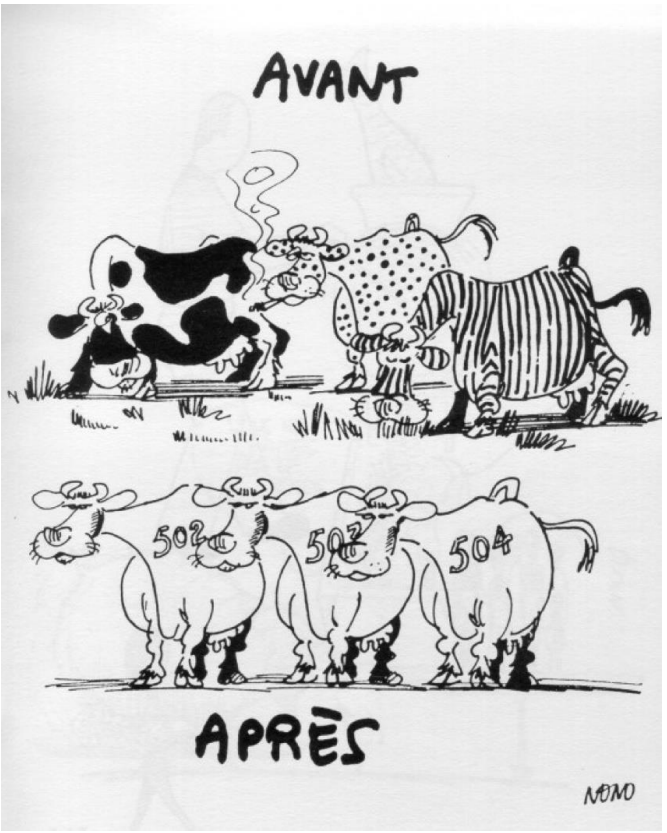
From the green revolution…

After World War II, large demand for food in Europe
Need for highly productive agriculture

It resulted in:

Standardization of the systems (dependency on inputs and feed)
Homogeneity at different levels

-> Use of highly productive breeds/varieties with large yields
-> Decrease in the number of breeds/varieties
-> Strong selection toward elite individuals (families)
-> Decrease of the within breed/variety genetic diversity

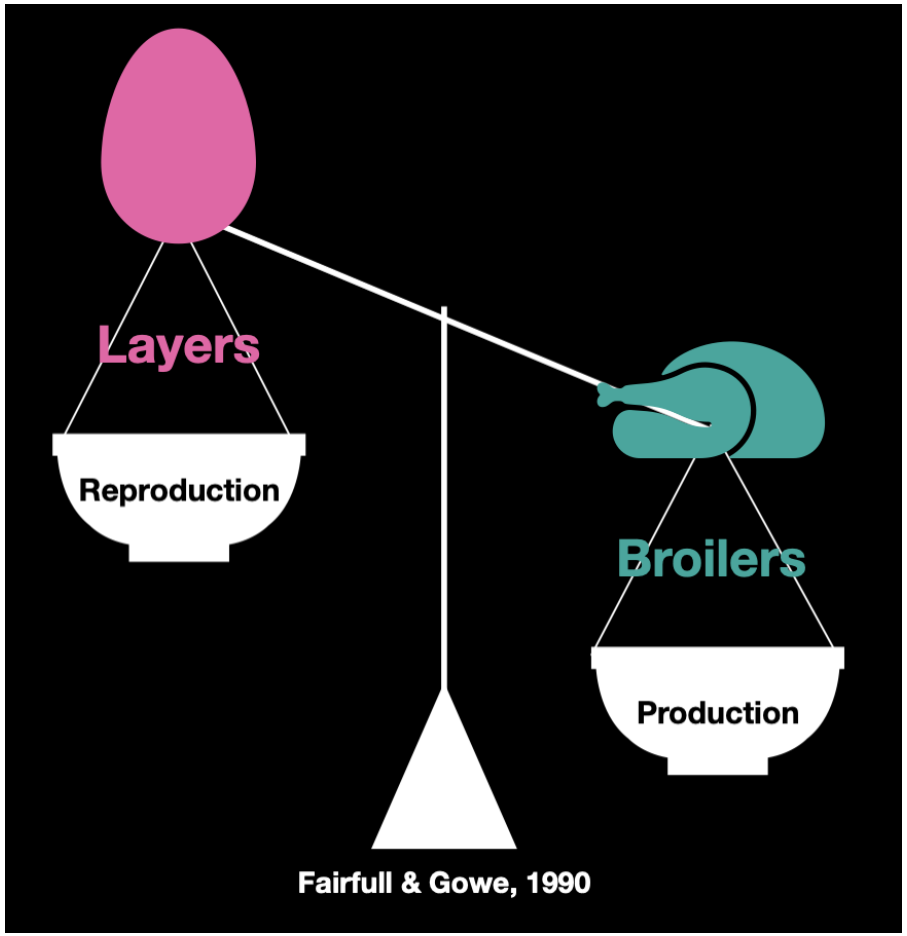


Animal breeding

Breeds often very specialized for a particular trait

Negative genetic correlations between those traits

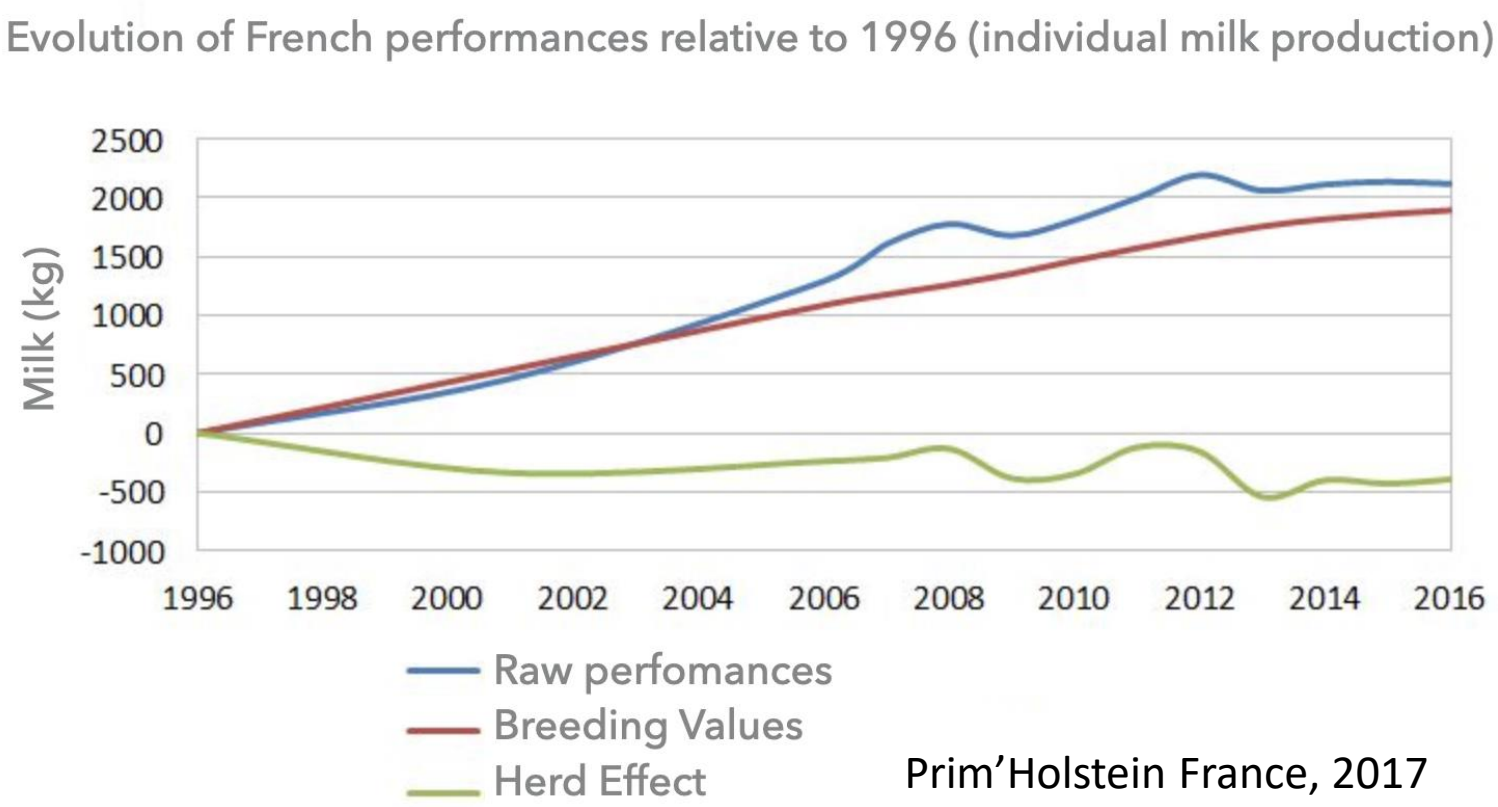
Cattle



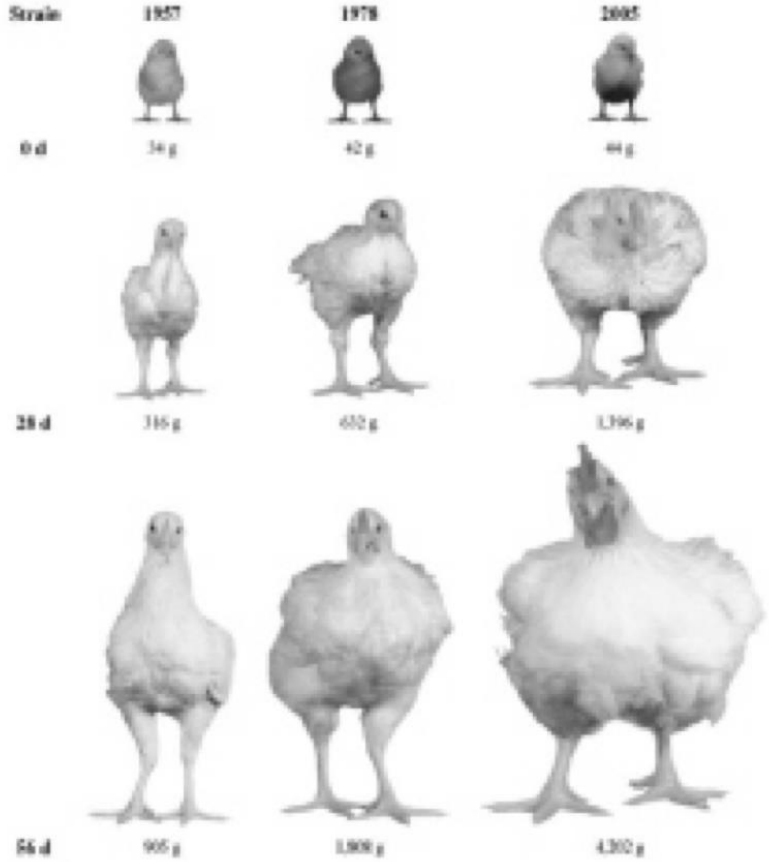
Poultry

Animal breeding

Lead to strong production increase



Prim'Holstein France, 2017



Context

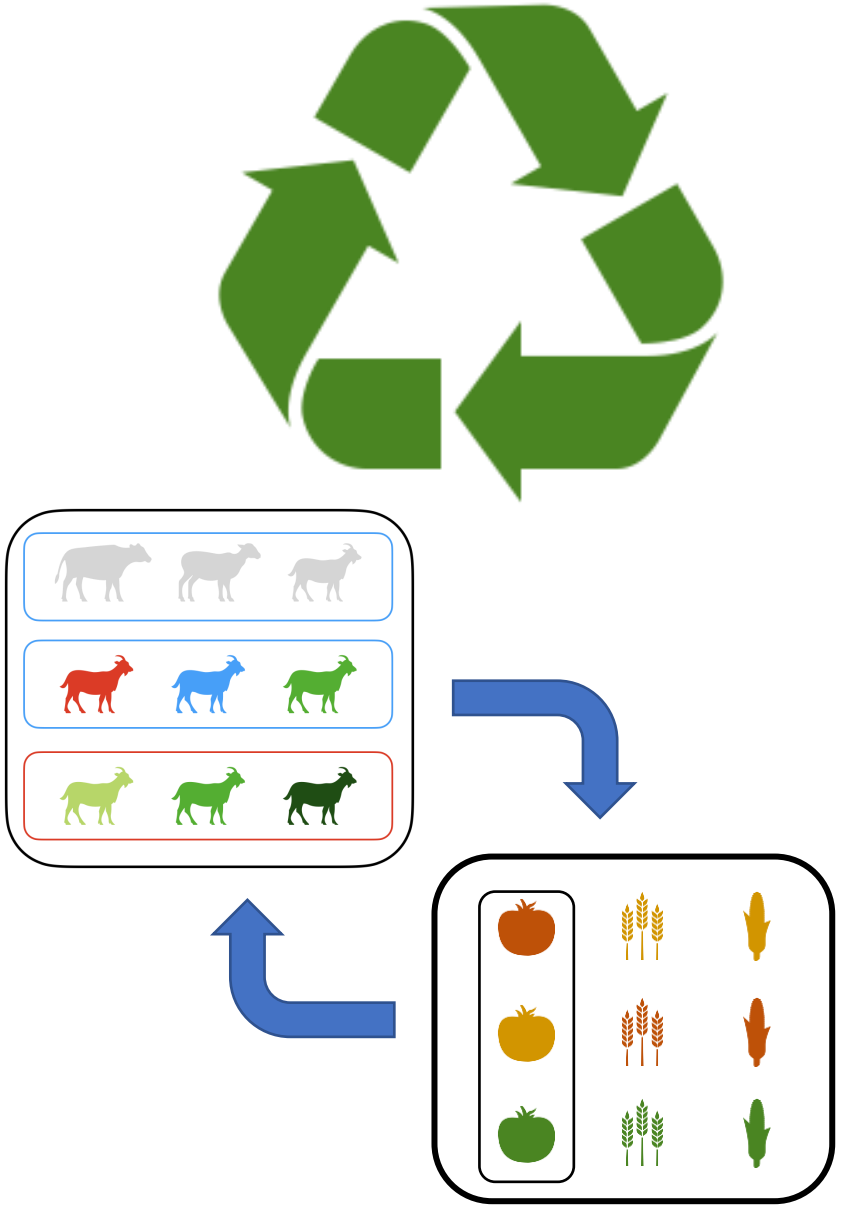
…to agroecology

Conceptualized in the 80's (Altieri, 1983)

Definition: *The application of ecological concepts and principles to the design and management of sustainable agroecosystems, or the science of sustainable agriculture* (Gliessman, 1990 ; Altieri, 1995)

Sustainability is expected from economic, ecological and social perspectives.

It mainly relies on conserving and benefiting from reciprocal services provided by wild and domestic species (plants and animals) as well as soil.



Agroecology principles

Source: AGROECOLOGY EUROPE

Climate change and ethics consideration

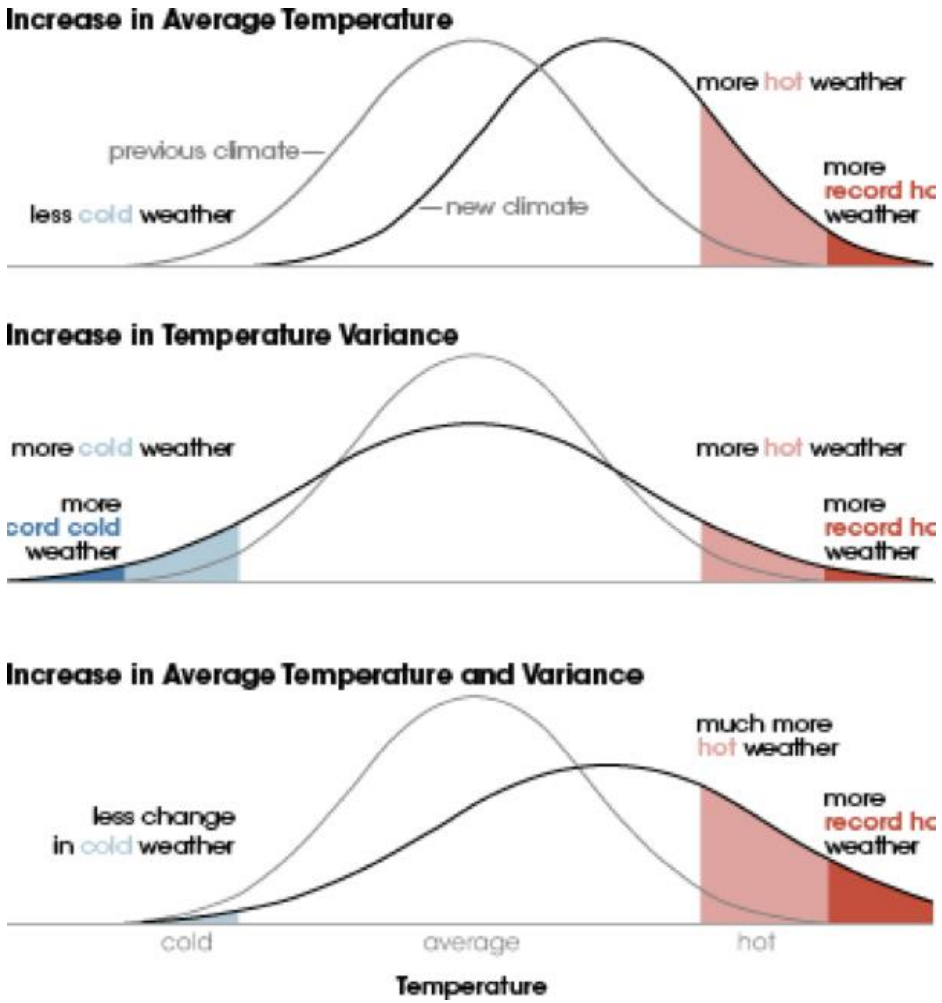
Livestock and domestic plant species

Climate change

- Increase in temperature
- Decrease in rainfalls
- More frequent extreme climatic events

-> Unpredictable environment

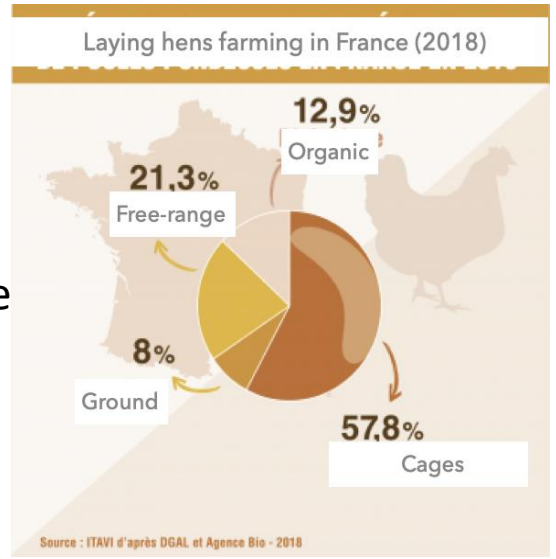
-> Feed, water availability



Source: IPCC

Climate change and ethics consideration

Livestock and domestic plant species



Twice more alternative breeding than in 2008

Source: CNPO

Change of the demand of consumers

- System: Free range, Organic farming
- Welfare
- Environmental considerations: GHG, antibiotics, artificial inputs, …

-> Reconnect agriculture and breeding to society and environment

Agroecological transition ?

Which levels ? Which levers ?

Adapted from Ducos et al., 2021

Diversity as a key for agroecology

- **System diversity:**
  - Locally adapted
  - Use of local breeds / varieties
- **Between individuals diversity:**
  - Keep adaptive potential / Genetic variance
  - Complementarity: Robustness / Resilience

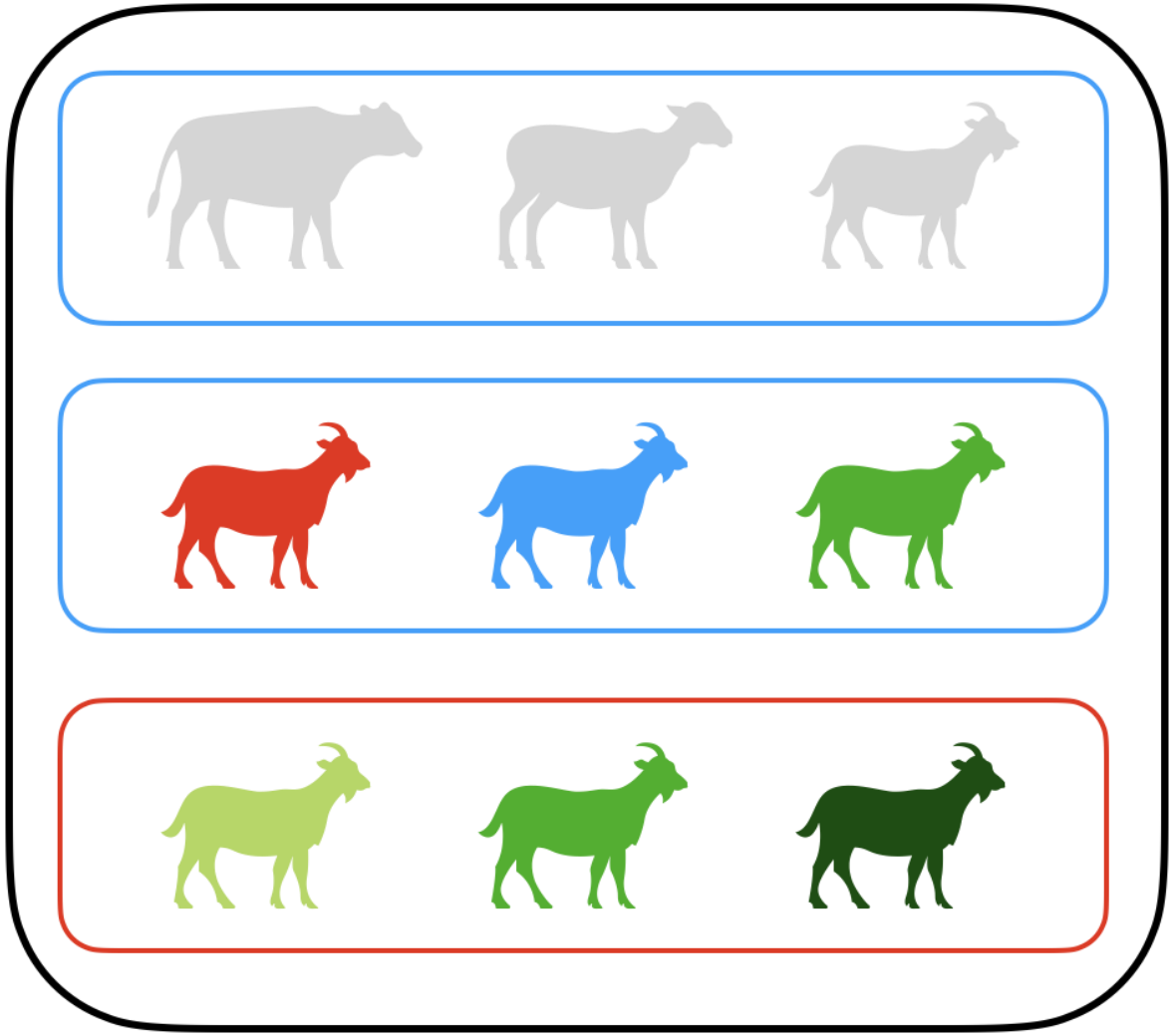
Diversity: The keystone of agroecology

On the role of diversity

Diversity is considered at numerous levels:

- Species
- Between Breeds / Varieties
- Within breeds / varieties

-> Need to characterize/conserve this diversity



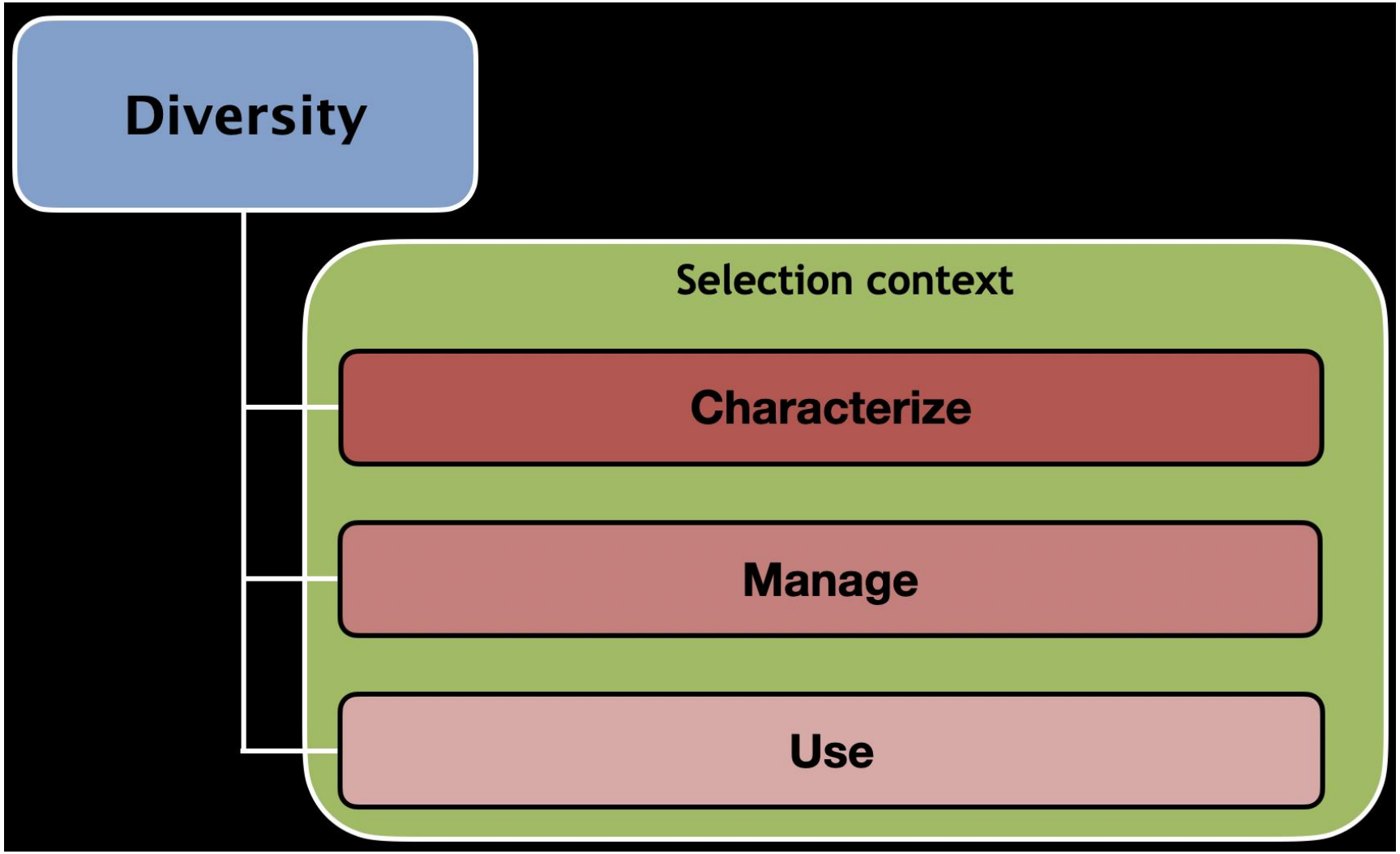
Global Diversity

Different uses / Different conditions

Restoux, 2022

Restoux, 2020

Genetic diversity: Three levels of action



Step 1: Characterization of genetic diversity

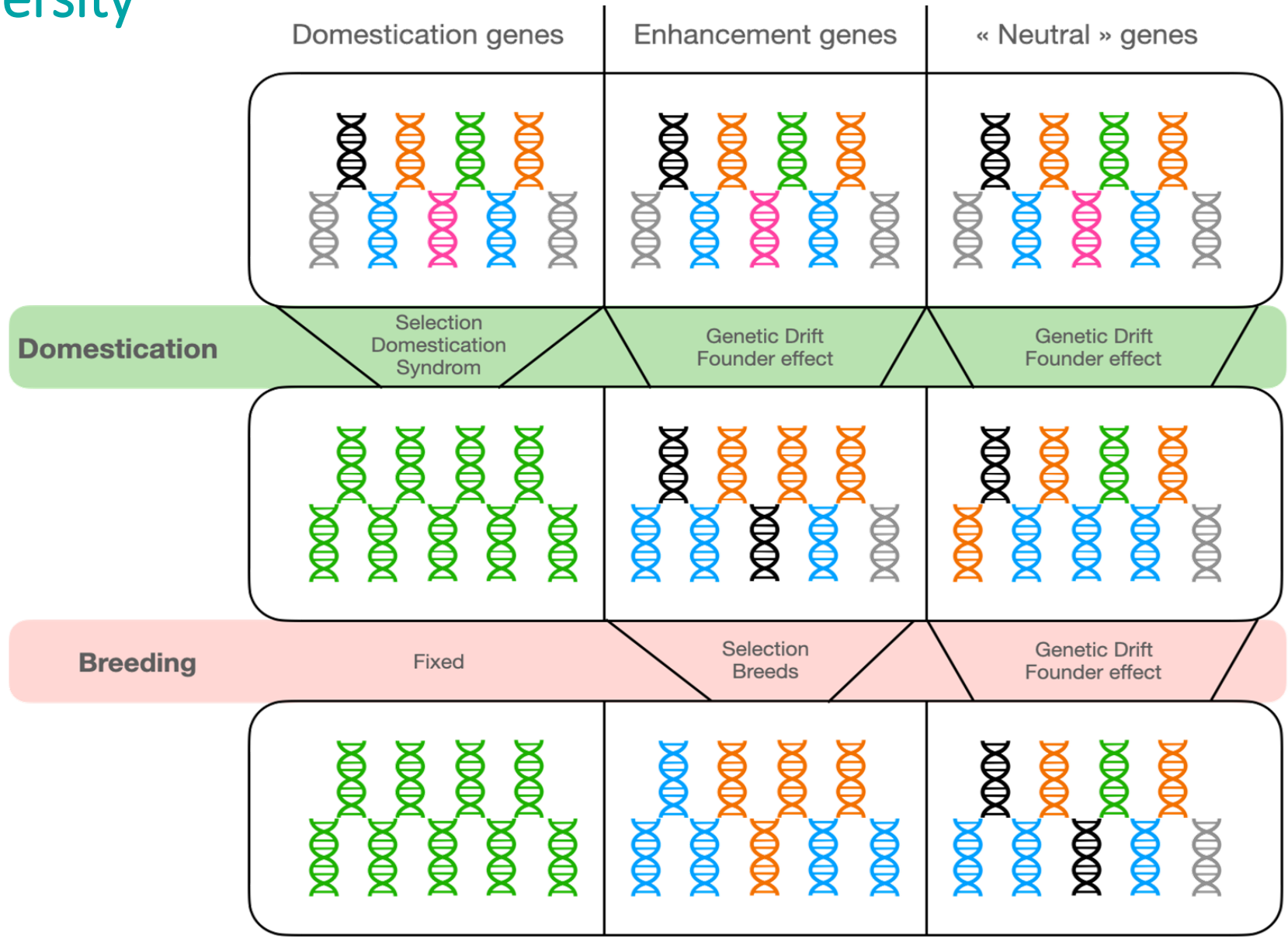
Structure of genetic diversity

Evolutionary forces:

- Selection
- Genetic drift
- Migration
- Mutation

Mating sytem:

Inbreeding



Animal breeding

A global overview

<u>Animal selection started early on :</u>

- Modern Selection / inbreeding / family management

(Bakewell, England, XVIII)

- First herd-books

(T. Eyton of Wellington, Hereford cattle breed, 1846, England)

- Quantitative inheritance and mechanisms

(mid XX, S. Wright, USDA “Husband-man” & R. A. Fisher)

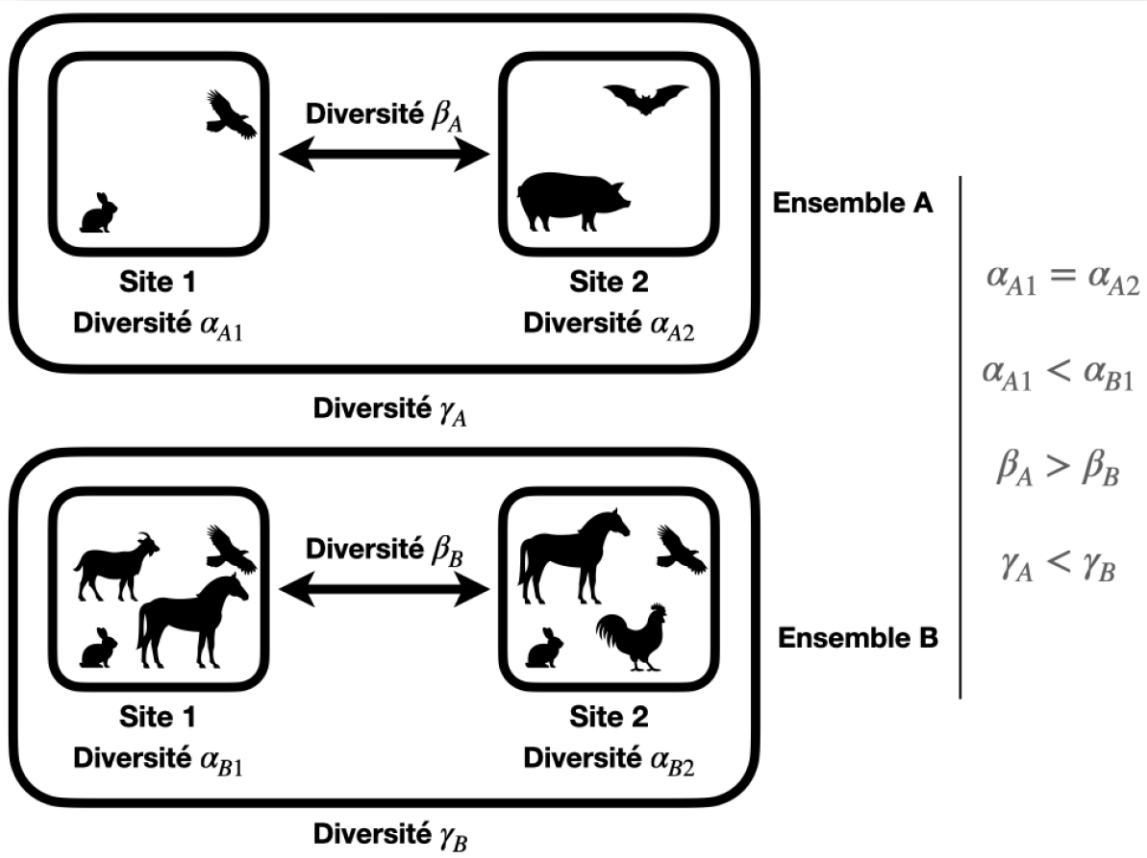
- BLUP animal model (Henderson, 1973)

Definition of breeds : Creation of genetic pools (~populations)

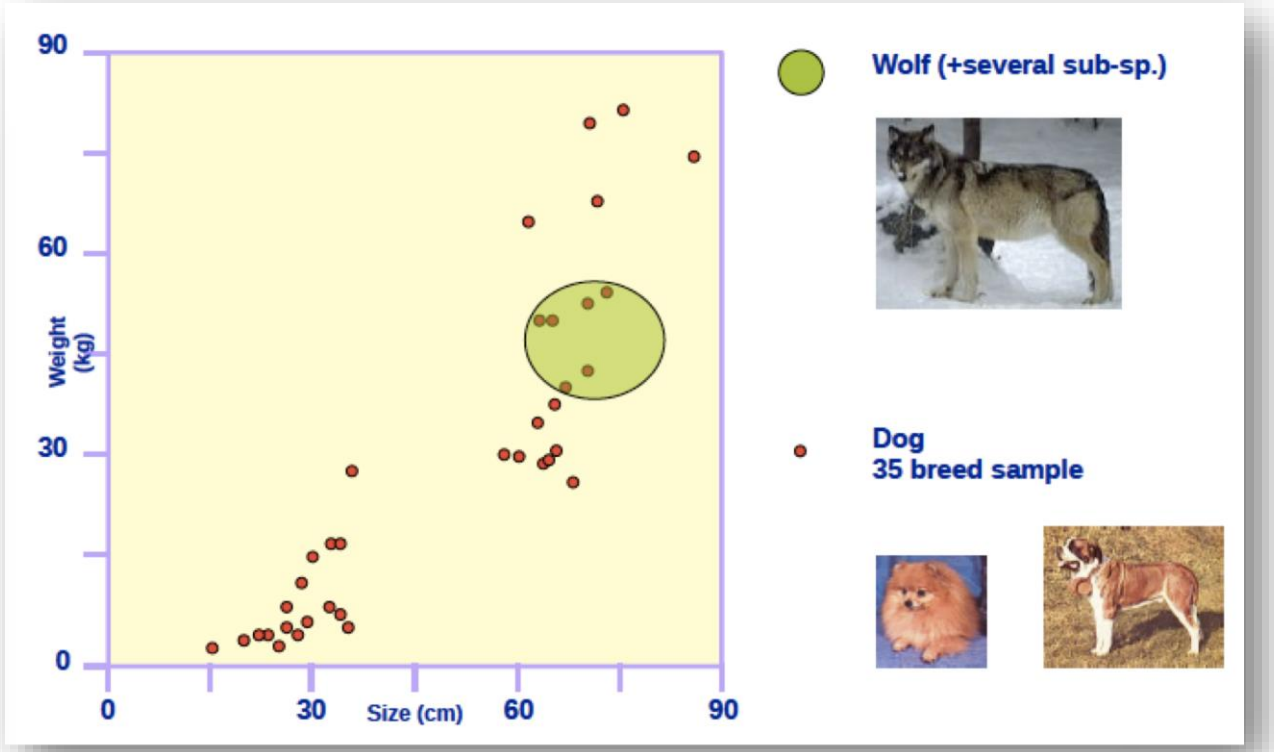
Different from the variety concept (~isogenic)

Animal breeding and genetic diversity

Hierarchical organization of diversity



Restoux, 2023

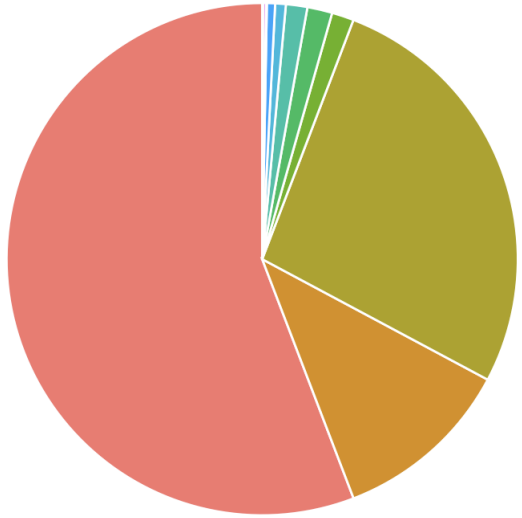


From Leroy

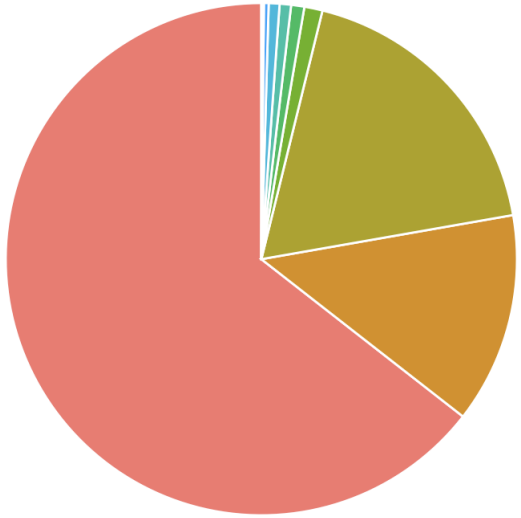
Breed diversity

Exemple of French breeds : Dairy cattle and goats

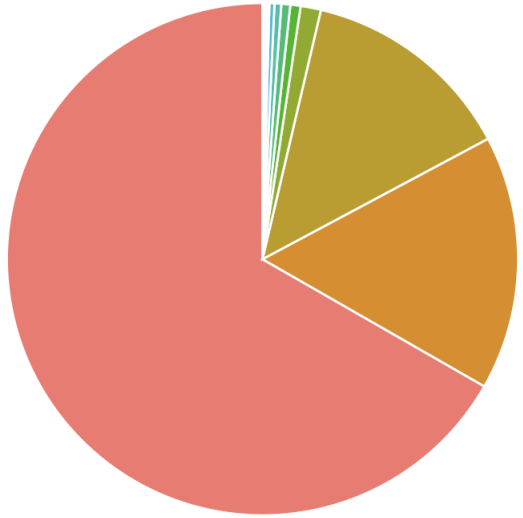
1979



1988



2008



From IDELE stats

3 main ones (Holstein, Montbéliarde, Normande) = 96.3 % of the total

2 main goat breeds (Saanen & Alpine) = 99% of the total

Assessing the risk status of livestock breeds: a multi-indicator method applied to 178 French local breeds belonging to ten species

Published online by Cambridge University Press: **08 September 2015**

E. Verrier, A. Audiot, C. Bertrand, H. Chapuis, E. Charvolin, C. Danchin-Burge, S. Danvy, J.L. Gourdine, P. Gaultier, D. Guémené ...Show all authors Show author details

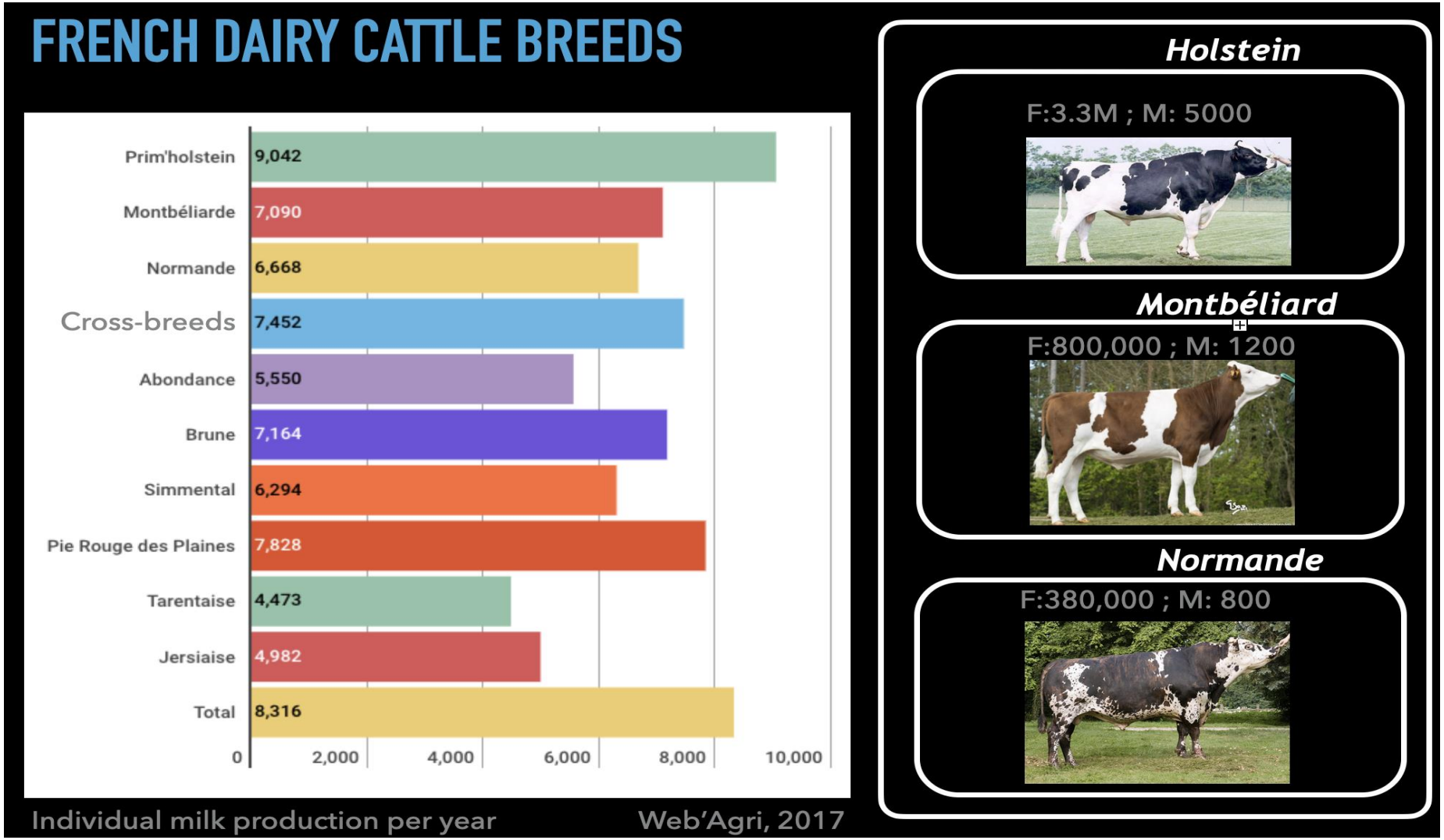
Les races caprines locales et à petits effectifs à la croisée des chemins

Si elles ne représentent que 1 % des effectifs caprins en France, le succès des races locales et à petits effectifs s'agrandit auprès des nouveaux installés. Les effectifs sont en croissance et les populations surveillées de près pour éviter les risques de consanguinité. Entretien avec Coralie Danchin et Louise Joly de l'Institut de l'élevage.

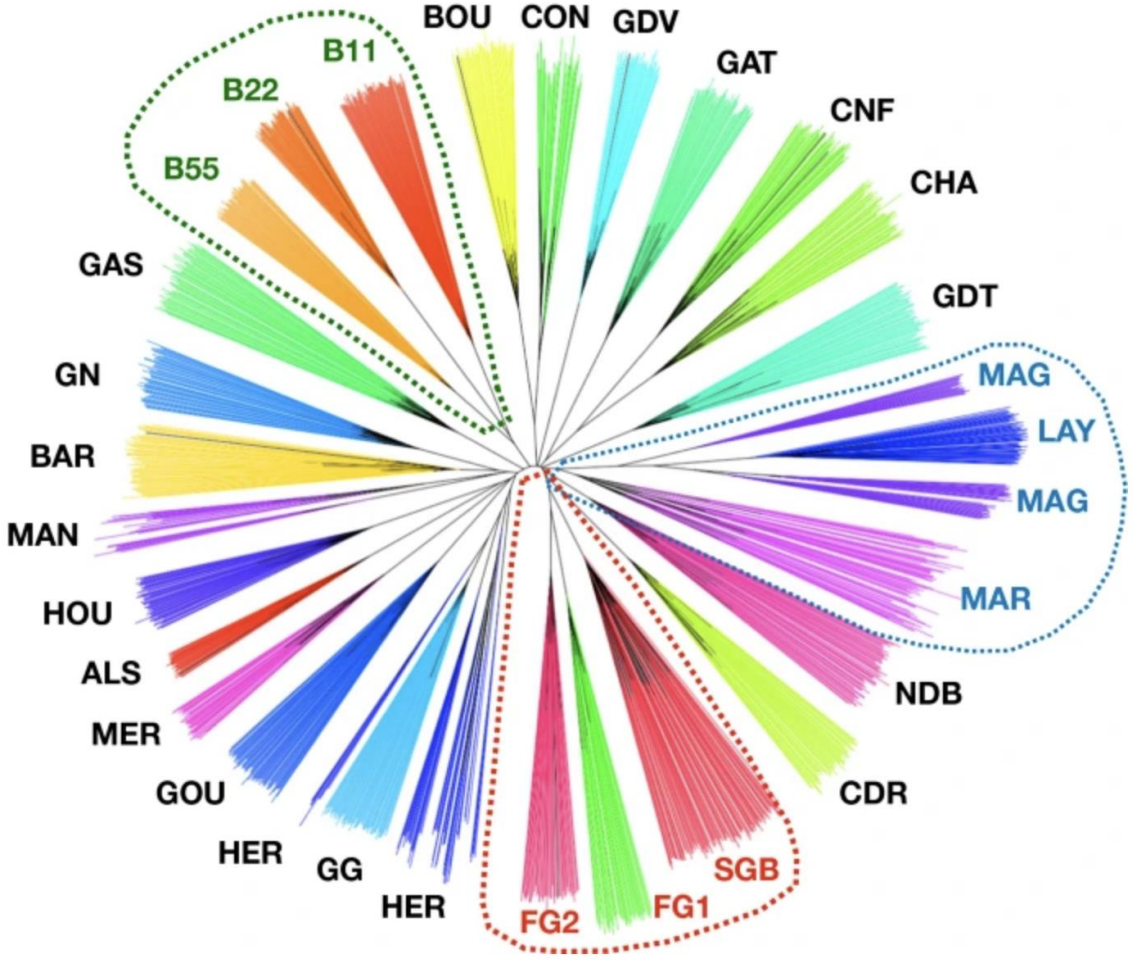
Publié le 18 avril 2022 - Par Virginie Hervé-Quartier

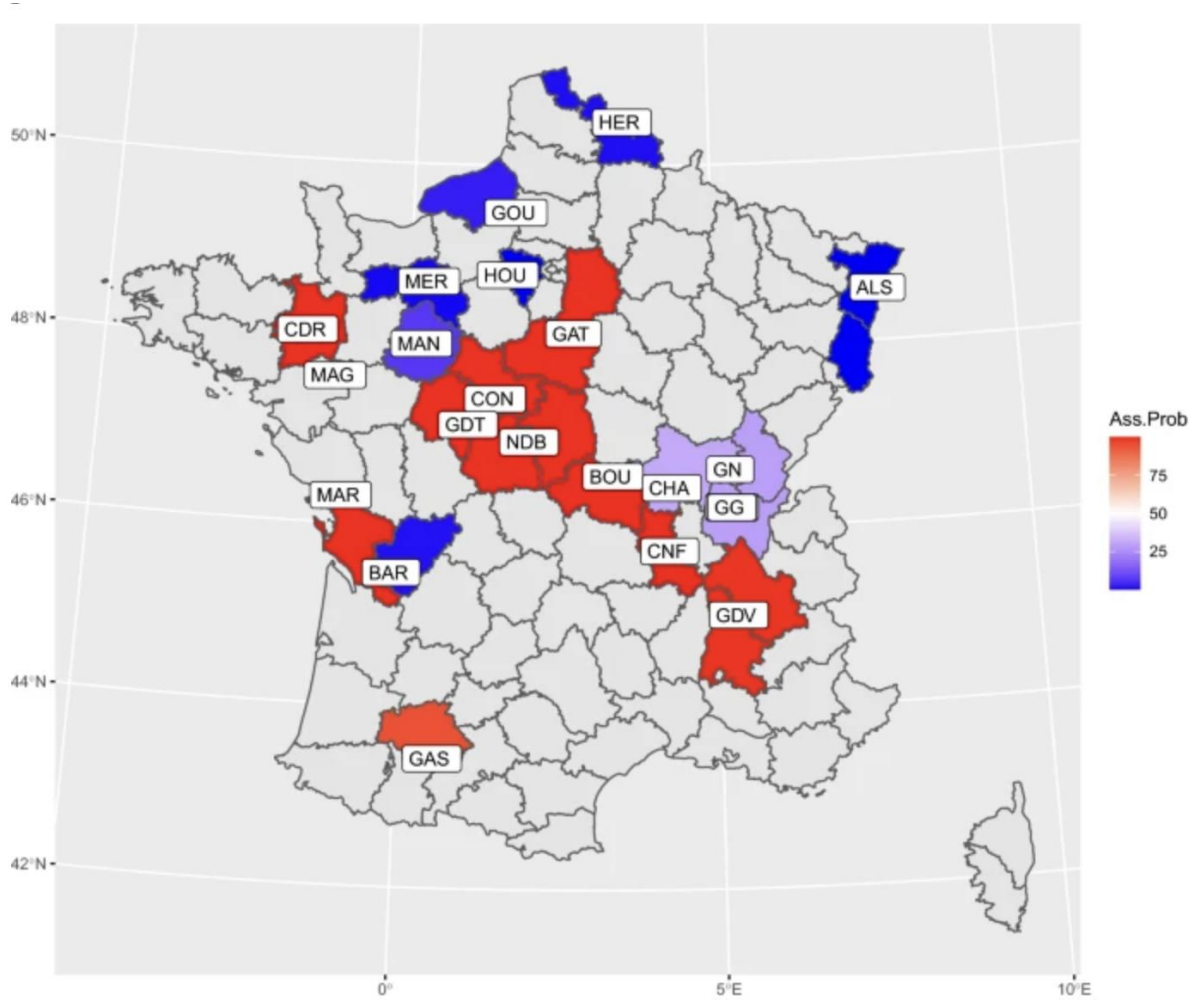
Animal breeding

Few breeds with very contrasted performances not only determinant of pop size



Diversity of French local chicken breeds : BioDivA





Restoux et al., 2022

Regulation / Policies

Heterogeneous over Europe

Innovations Agronomiques 63 (2018), 357-371

Quelle stratégie pour une politique de conservation des races locales avicoles ? (Biodiva)

Chiron G.[1], Chapuis H.[2], Tixier-Boichard M.[3], Restoux G.[3], Rognon X.[3], Lubac-Paye S.[1], Vieaud A.[3], Seigneurin F.[4], Petitjean F.[5], Guémené D.[4]

2023. Journées Recherche Porcine, 55, 291-296.

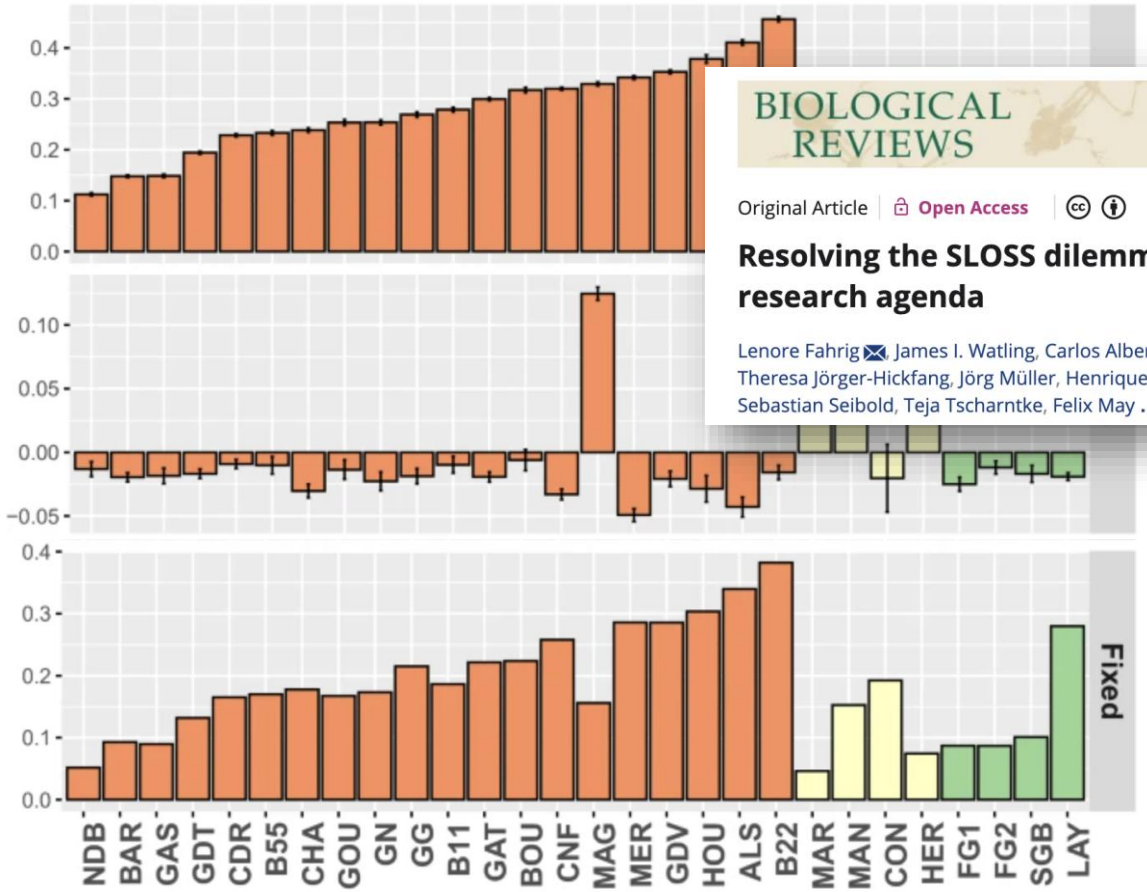
Perception des acteurs impliqués dans la préservation des races locales : une enquête du projet européen GEroNIMO

Marie-José MERCAT (1), Andreia AMARAL (2), Riccardo BOZZI (3), Marjeta ČANDEK-POTOKAR (4), Pedro FERNANDES (5), Jetsabell GUTIERREZ VALLEJOS (1), Danijel KAROLYI (6), Denis LALOË (7), Zoran LUKOVIC (6), Herveline LENOIR (1), Gwendal RESTOUX (7), António VICENTE (2), Virginia RIBEIRO (8), Tamara RODRIGUEZ SILVA (9), Romuald ROUGER (10), Dubravko ŠKORPUT (6), Martin ŠKRLEP (4)

Need for a local market and subsidies to keep it competitive

Diversity of French local chicken breeds : BioDivA

Structure of diversity



BIOLOGICAL REVIEWS
Cambridge Philosophical Society

Original Article | Open Access

Resolving the SLOSS dilemma for biodiversity conservation: a research agenda

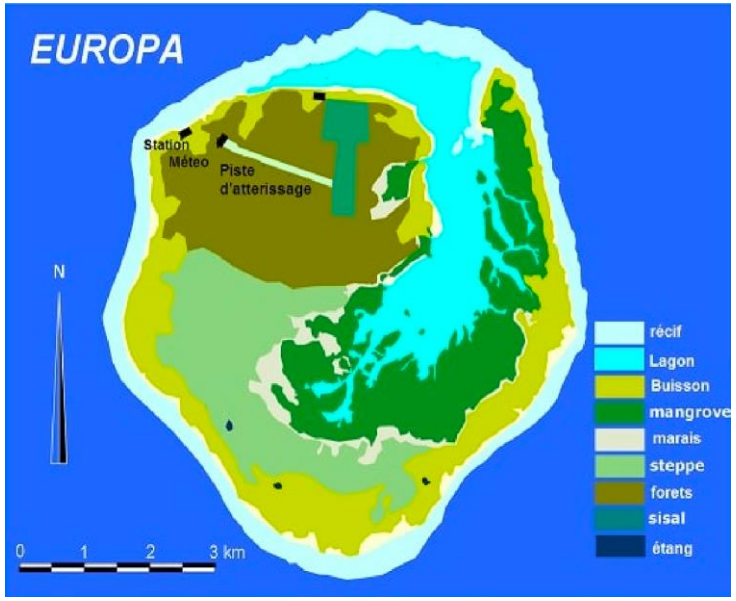
Lenore Fahrig, James I. Watling, Carlos Alberto Arnillas, Víctor Arroyo-Rodríguez, Theresa Jörger-Hickfang, Jörg Müller, Henrique M. Pereira, Federico Riva, Verena Rösch, Sebastian Seibold, Teja Tscharntke, Felix May ... See fewer authors

Within breed genetic diversity

Restoux et al., 2022

Identification of interesting populations

Goats in Europa island



A. Trouvilliez ©

Histoire

- Colonisée en 1860 par de Rosiers et sa famille
- Import d'animaux (poules, chèvres, lapins…)
- Seules les chèvres ont survécu
- Réserve naturelle de biodiversité (plus important site de ponte des tortues de l'océan Indien)
- Inhabitée (5-6 soldats max)

Chèvres de l'île

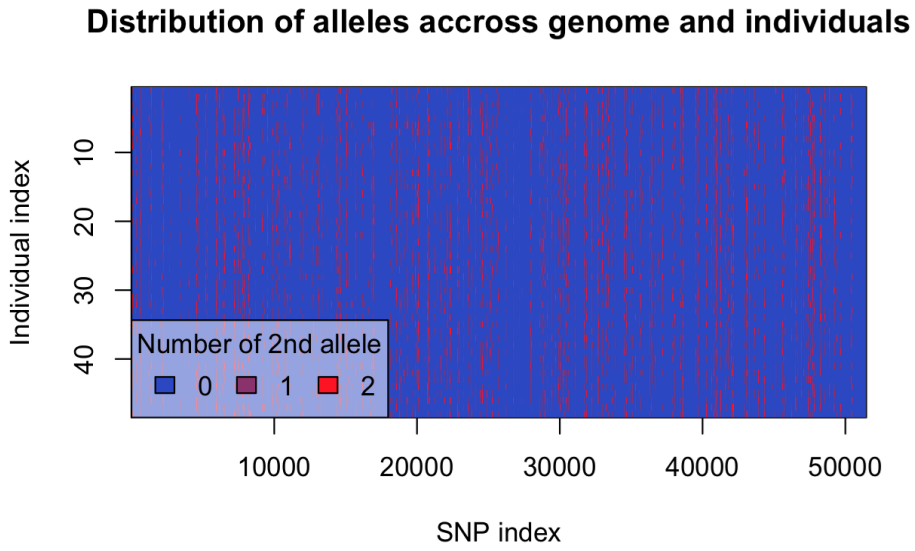
- Retournées à l'état sauvage : férales
- Surivivent au manque d'eau douce recurrent
- Environ 600 individus
- Origine inconnue
- Prélèvement de sang, photos et mesures (TAAF)

Les chèvres de l'île Europa

Histoire et diversité

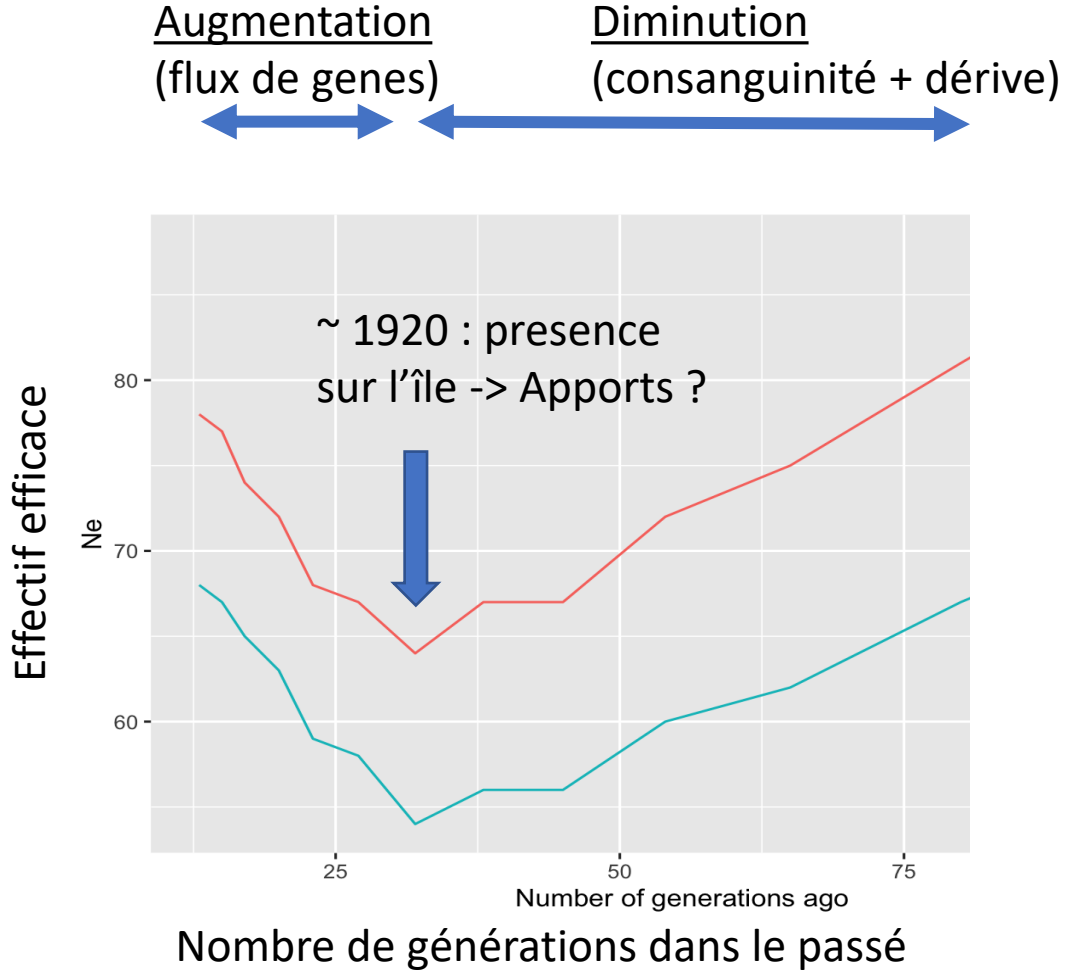
Données génétique

- Sang de 48 individus
- Extraction AND
- Génotypage (54K SNP)



Peu de diversité, forte consanguinité

-> pool génétique homogène



Nombre de générations dans le passé

Une origine principale et unique ou peu variée.

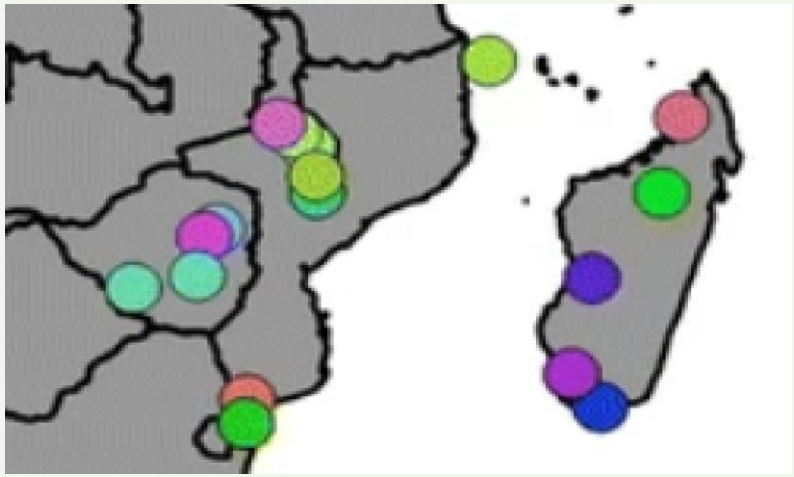
Restoux et al., *in prep.*

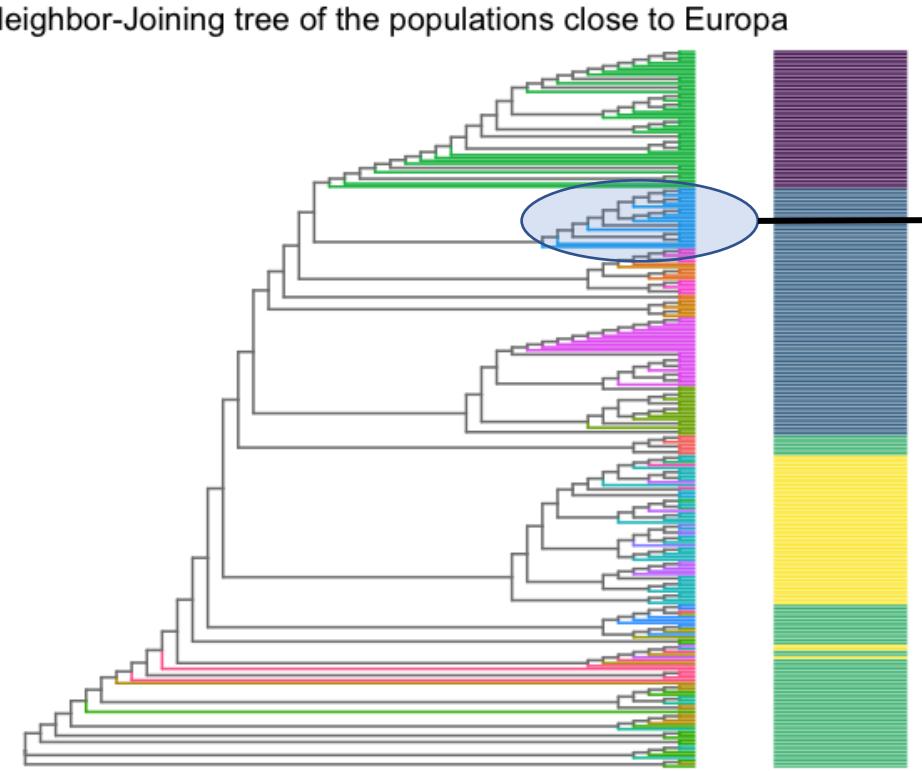
Les chèvres de l'île Europa

Identification des origines et diversité

Base de données externe

- Données externes projet AdaptMap (Stella et al., 2012)
- Génotypes de milliers de chèvres à travers le monde
- Metadonnées associées (localization, race…)





Race Malgache : Morphologie très variable.

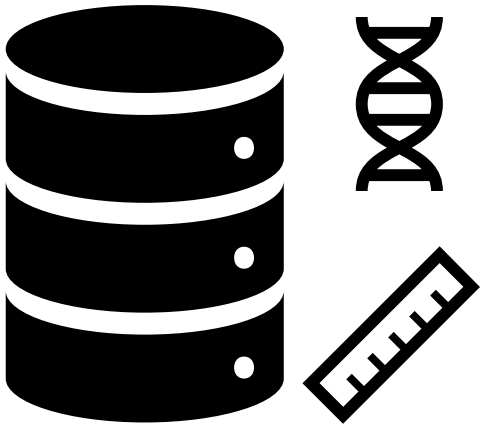
Restoux et al., *in prep.* p. 25

Les chèvres de l'île Europa

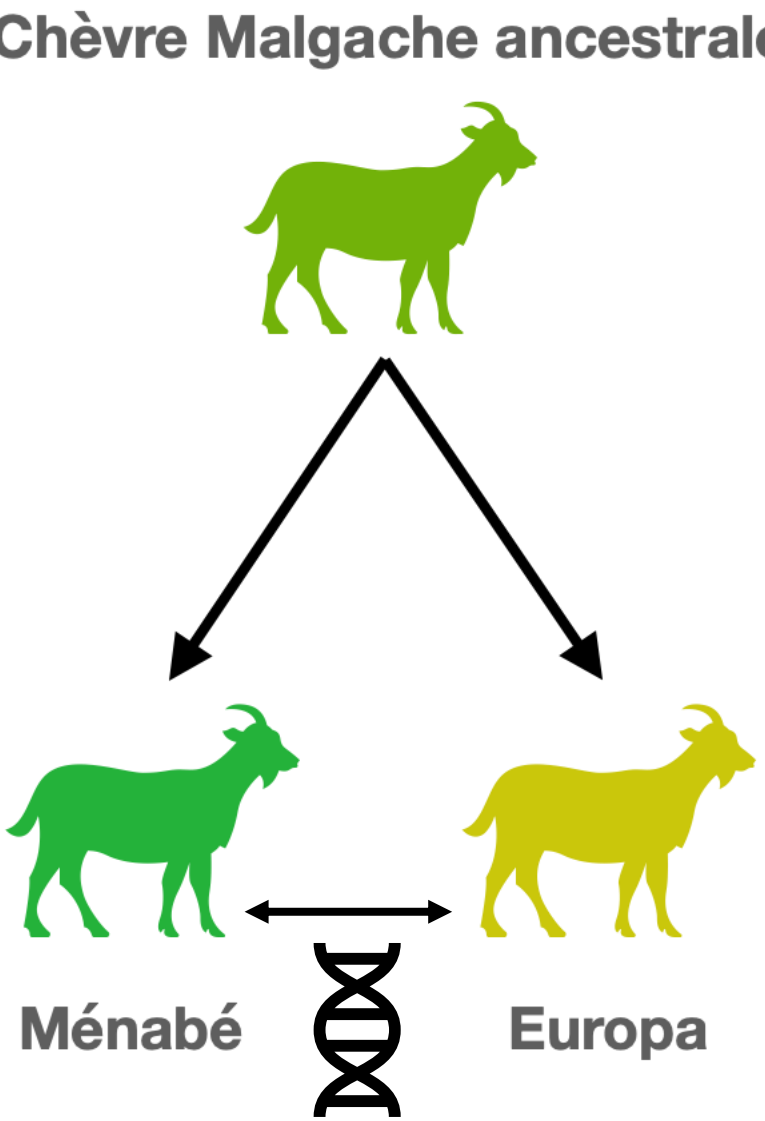
La suite…

Analyse comparative avec les races affiliées

- Quelle difference avec la race ancestrale ?
- Présence de gènes candidats d'intérêt agroécologique (resistance sécheresse) ?
- Présence de ces genes dans d'autres populations ?
- Sélection / Introduction dans d'autres populations
- Intérêt du projet AgroDiv (sequences, données, méthodes + phénotypage)



Exploration de bases de données



Step 2: Conservation of genetic diversity

Impact of population management on genetic diversity

Consequences of genomic selection

RESEARCH ARTICLE Open Access

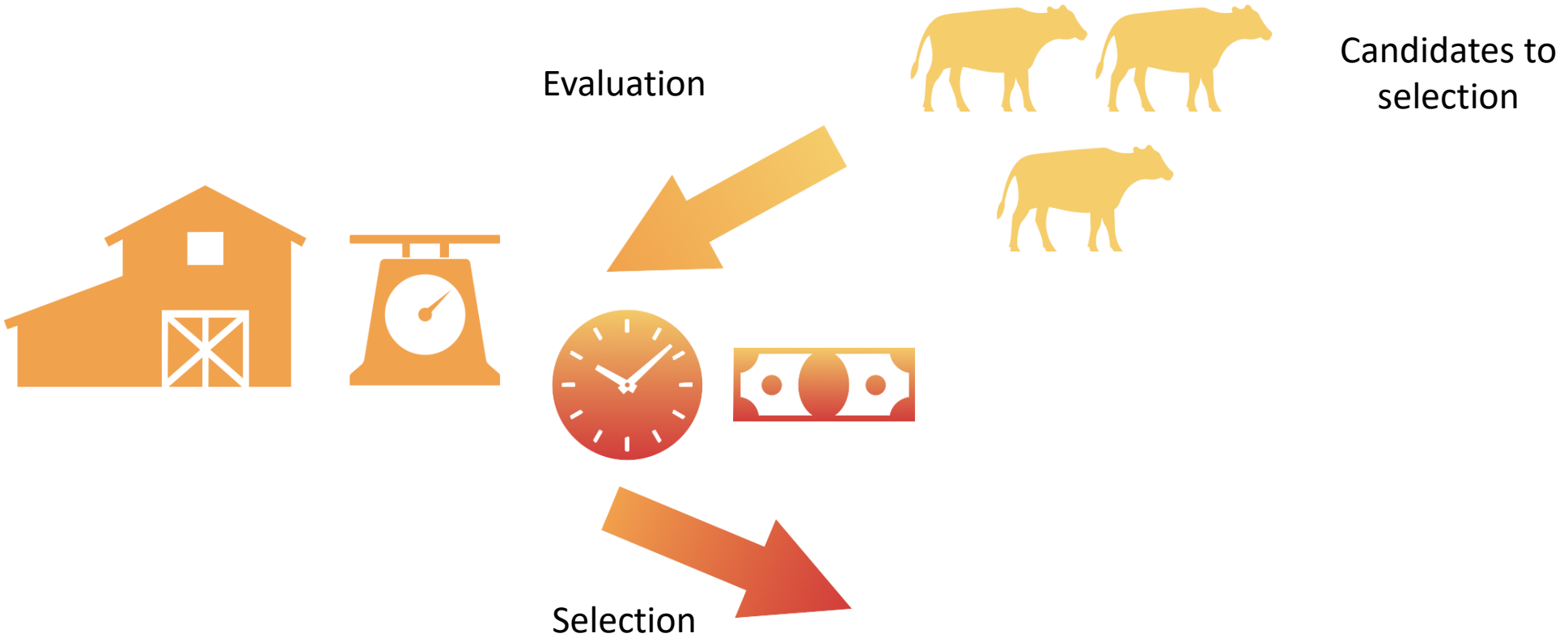
The impact of genomic selection on genetic diversity and genetic gain in three French dairy cattle breeds

Anna-Charlotte Doublet[1,2*], Pascal Croiseau[1], Sébastien Fritz[1,2], Alexis Michenet[1,2], Chris Hozé[1,2], Coralie Danchin-Burge[3], Denis Laloë[1] and Gwendal Restoux[1]

GSE Genetics Selection Evolution

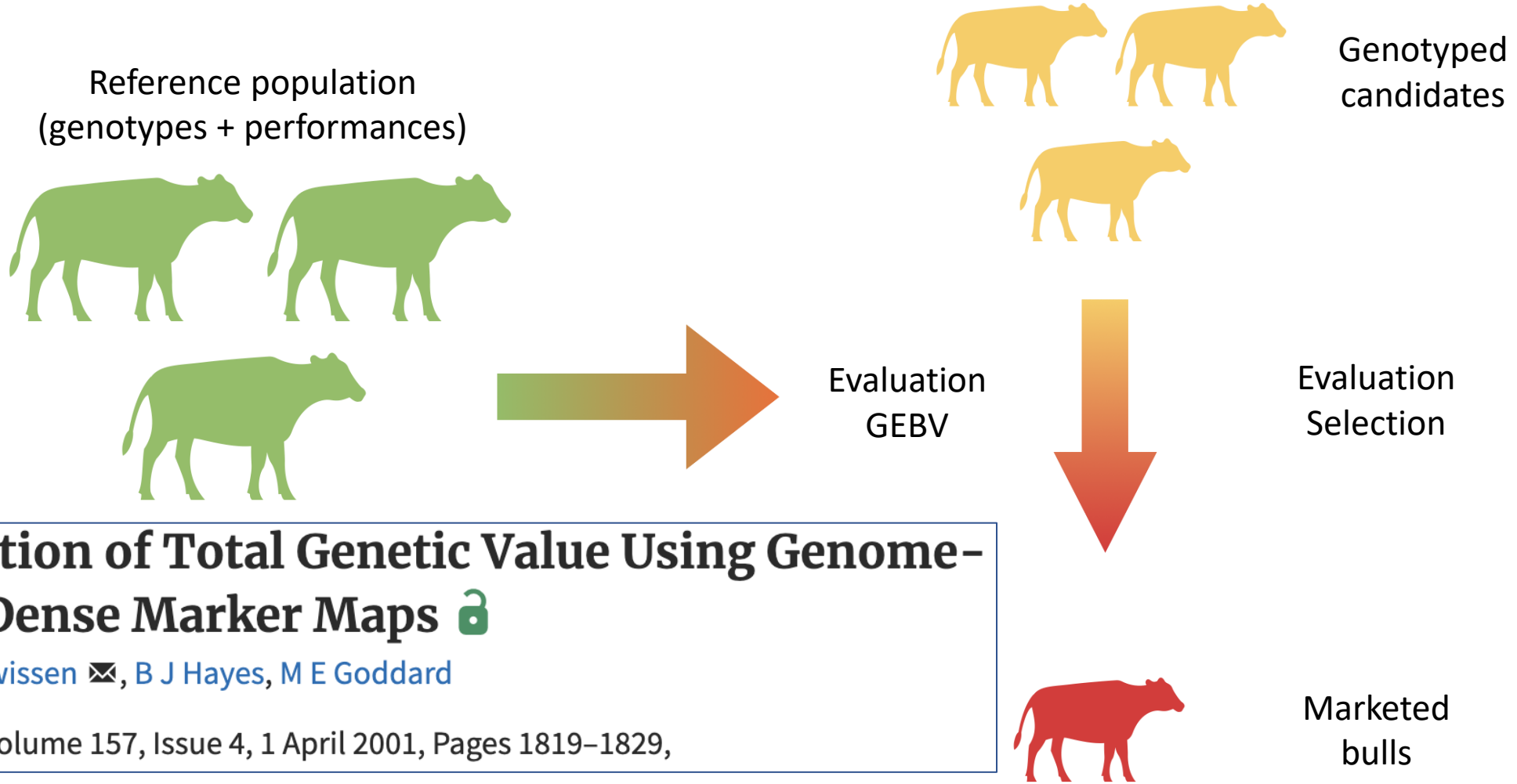
Impact of population management on genetic diversity

Progeny testing



Impact of population management on genetic diversity

Genomic selection



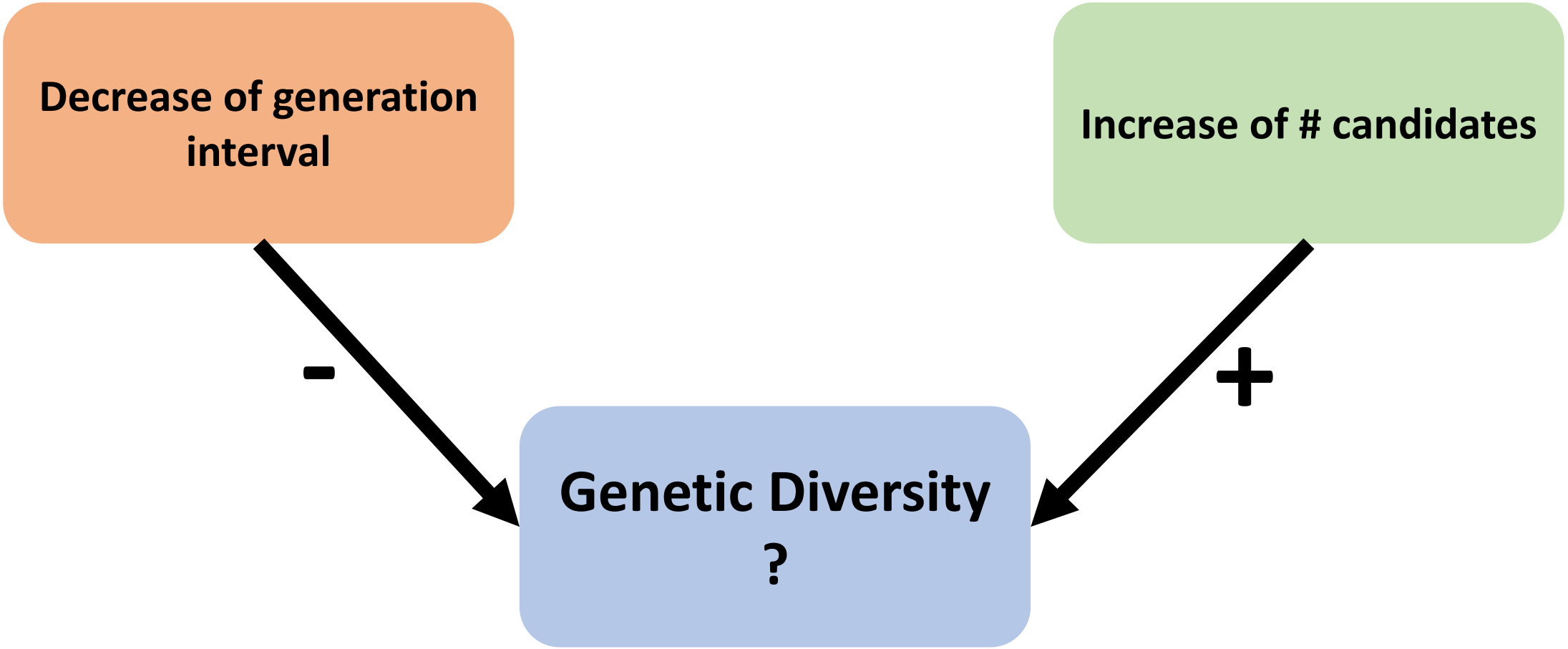
Prediction of Total Genetic Value Using Genome-Wide Dense Marker Maps

T H E Meuwissen ✉, B J Hayes, M E Goddard

Genetics, Volume 157, Issue 4, 1 April 2001, Pages 1819–1829,

Impact of population management on genetic diversity

Consequences of genomic selection



Impact of population management on genetic diversity

Consequences of genomic selection

All marketed bulls in France, genotyped (50K)

Montbéliarde
National breed

Normande
National breed

Holstein
International breed

Evolution of genetic diversity: Inbreeding

Pedigrees :
Inbreeding
Kinship

Genotypes 50K :
Inbreeding
Length of ROH

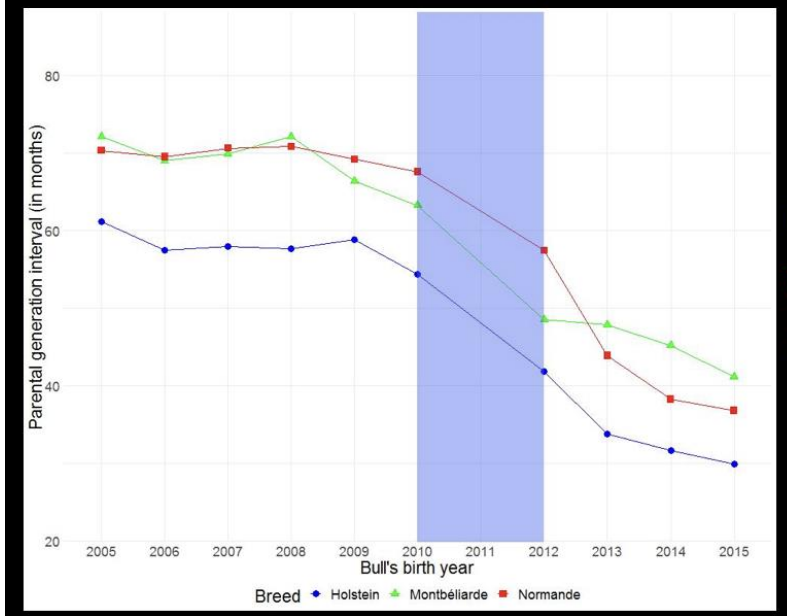
EVOLUTION OF GENETIC GIN ISU (FRENCH TOTAL MERIT INDEX)

Doublet et al., 2019

Impact of population management on genetic diversity

Consequences of genomic selection

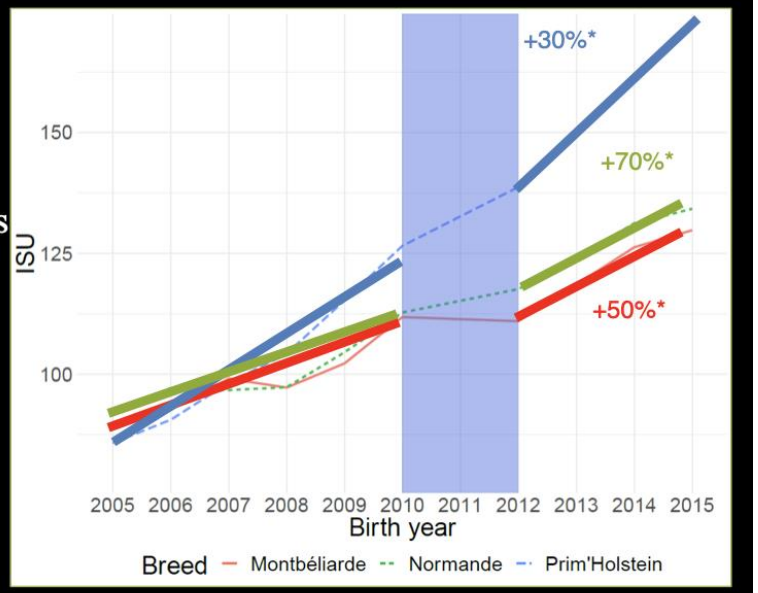
Before 2010: Progeny testing	2010-2012:Transition period	Since 2012: Genomic selection
Fathers of bulls ≈ 6 years old Mothers of bulls ≈ 3 years old on farm	Intermediate situation	Fathers of bulls ≈ 2 years old Mothers of bulls ≈ 2 years old in testing station



Montbéliarde 5,76 → 3,85 years

Normande 5,81 → 3,74 years

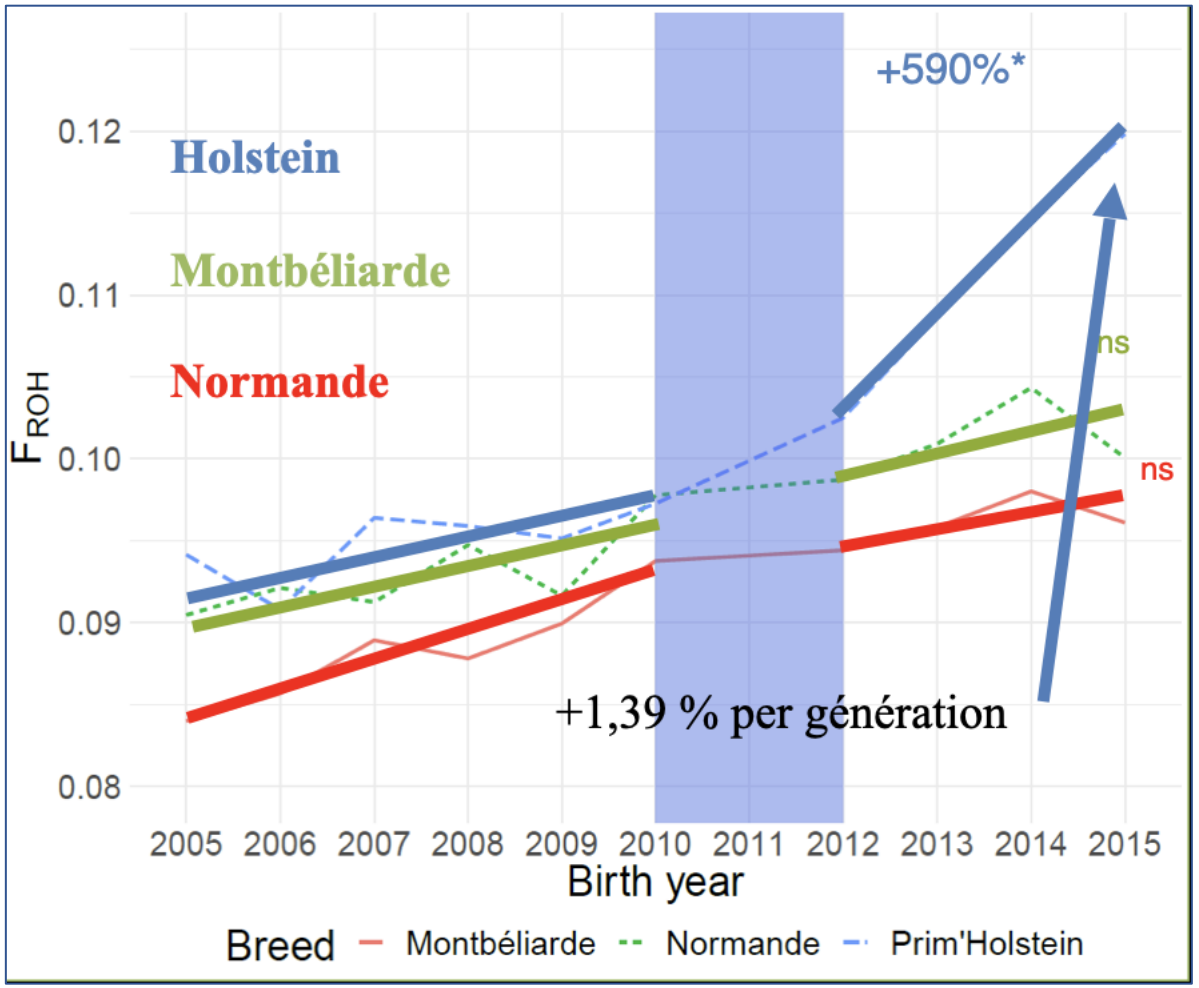
Holstein 4,84 → 2,86 years

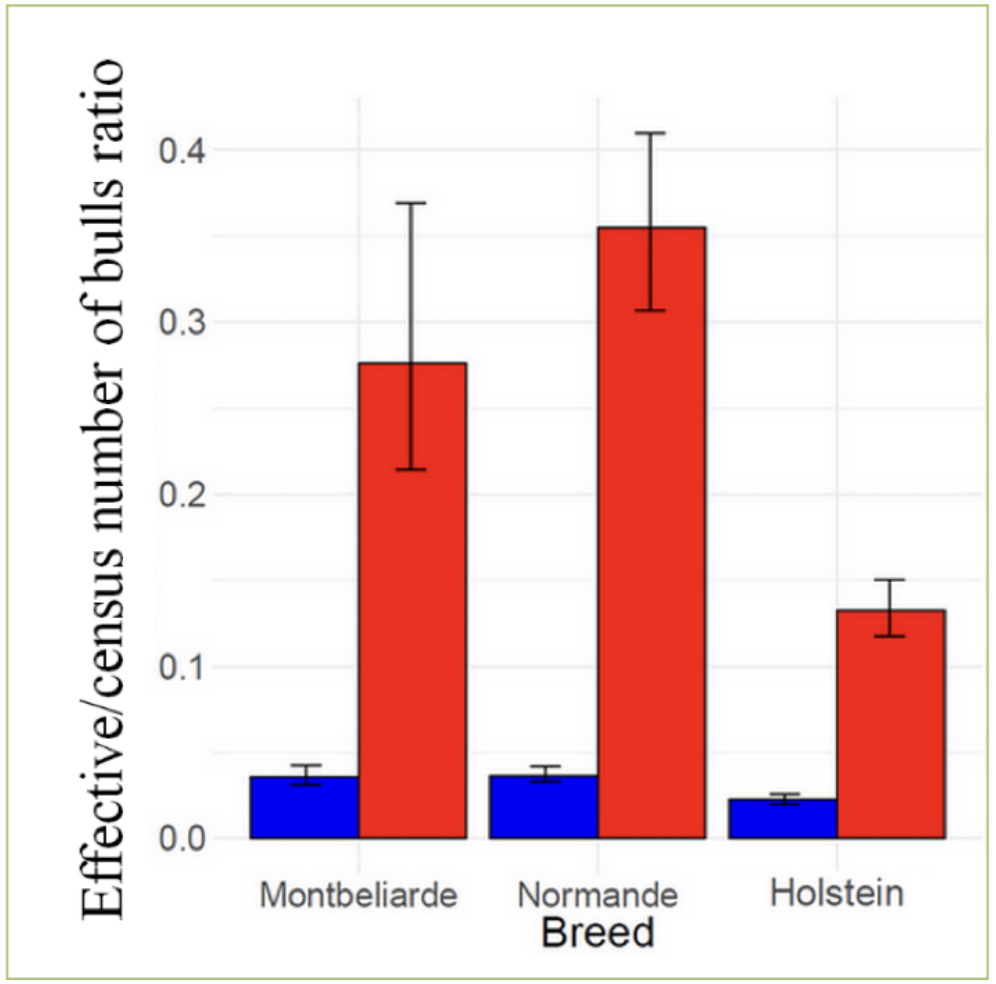


Doublet et al., 2019

Impact of population management on genetic diversity

Consequences of genomic selection





Impact of population management on genetic diversity

Consequences of genomic selection

Breed	Montbéliarde	Normande	Holstein
Genetic gain	+	+	+
Inbreeding rate	=	=	+
# of bulls	-	-	- -

Consequences depend on the market size :

National vs International breeds

Gain less important for Holstein and most costly in terms of F

Step 3: Use genetic diversity

Use of genetic resources in current breeding schemes

A case study in a local dairy cattle

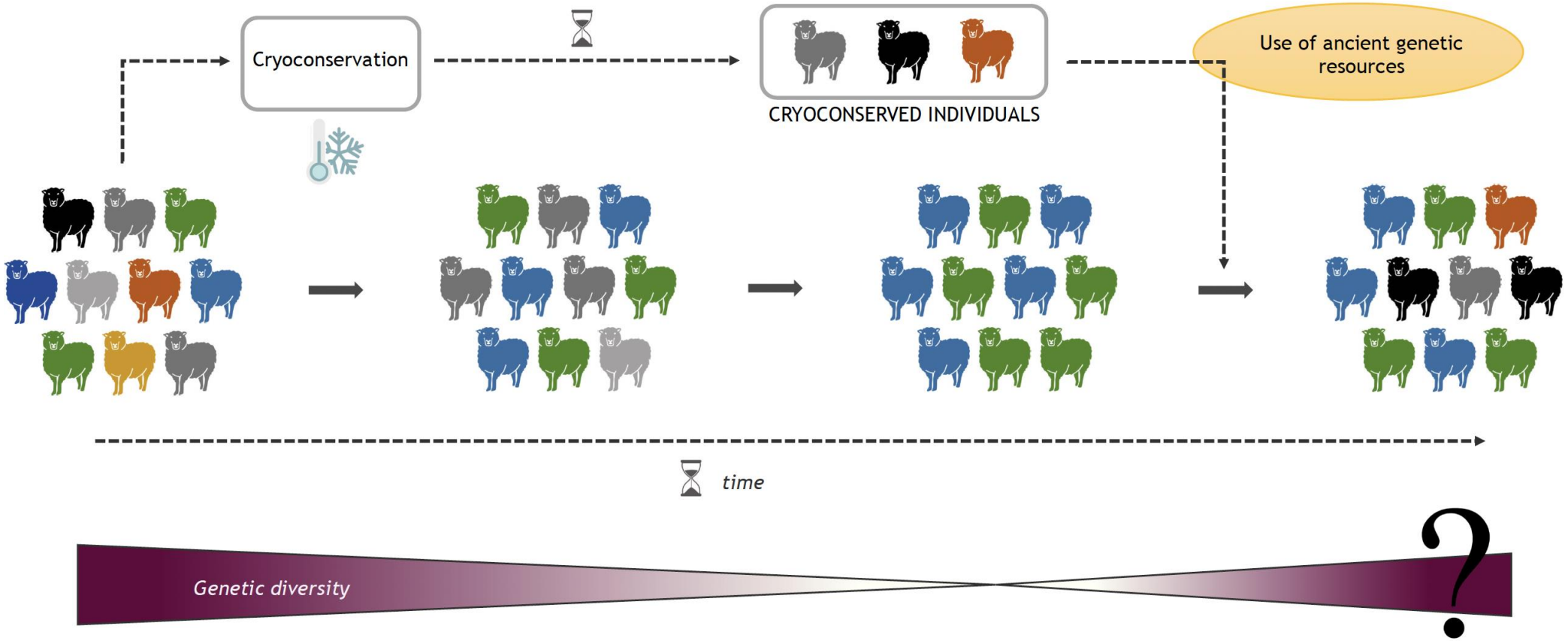
RESEARCH ARTICLE Open Access

Reintroducing genetic diversity in populations from cryopreserved material: the case of Abondance, a French local dairy cattle breed

Alicia Jacques[1], Grégoire Leroy[2], Xavier Rognon[1], Etienne Verrier[1], Michèle Tixier-Boichard[1] and Gwendal Restoux[1*]

Use of genetic resources in current breeding schemes

A case study



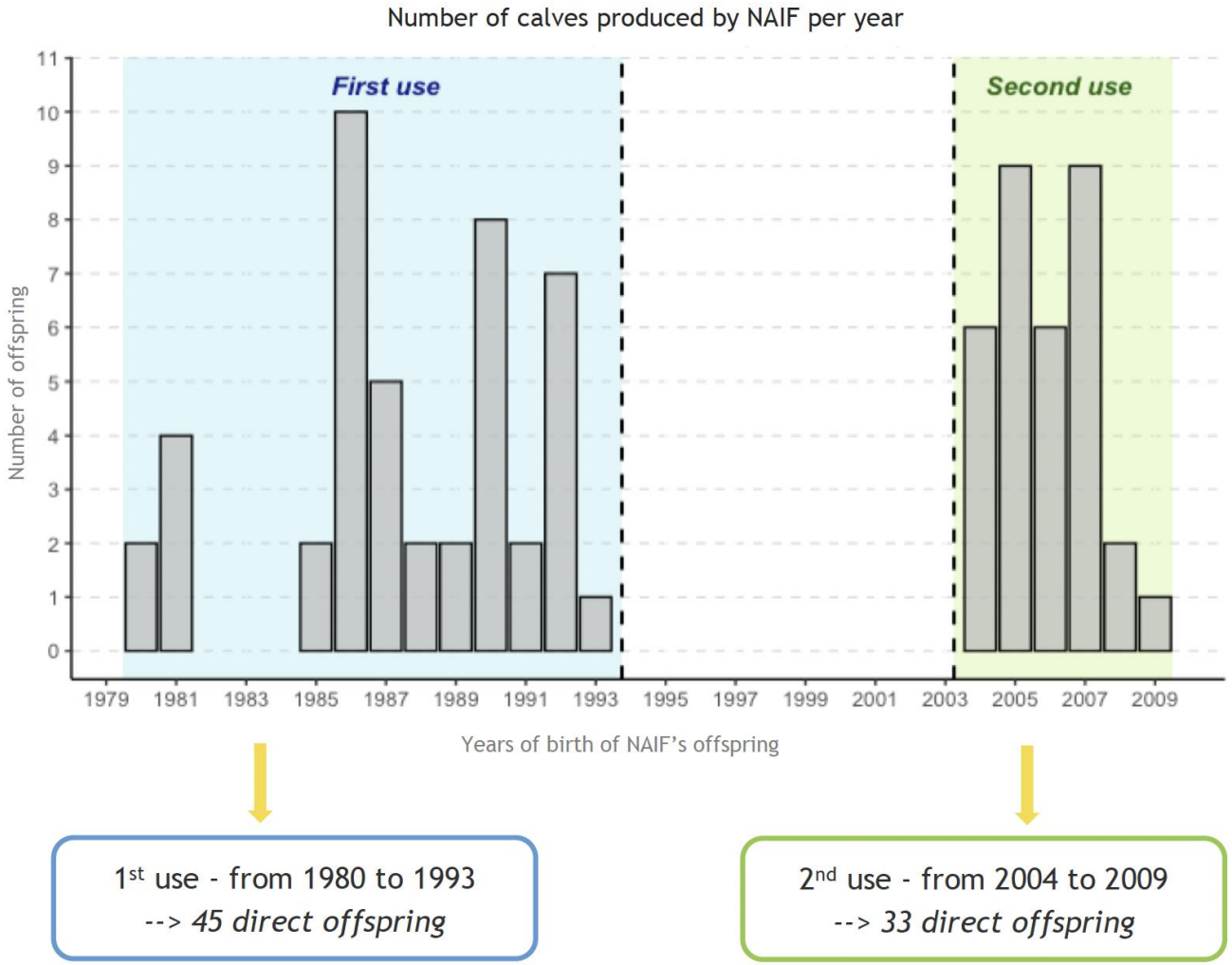
Use of genetic resources in current breeding schemes

A case study

Disappeared male lineage

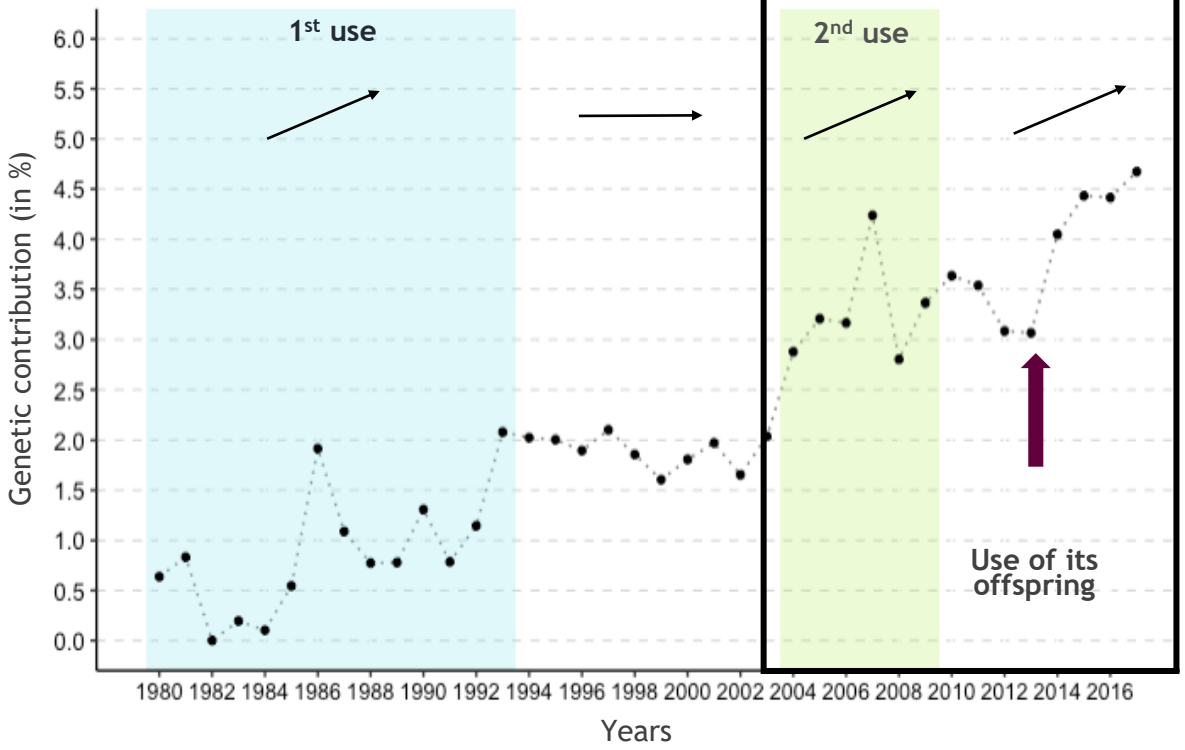
NAIF
A bull born in 1977
With cryopreserved semen

HOW HAS NAIF BEEN USED?

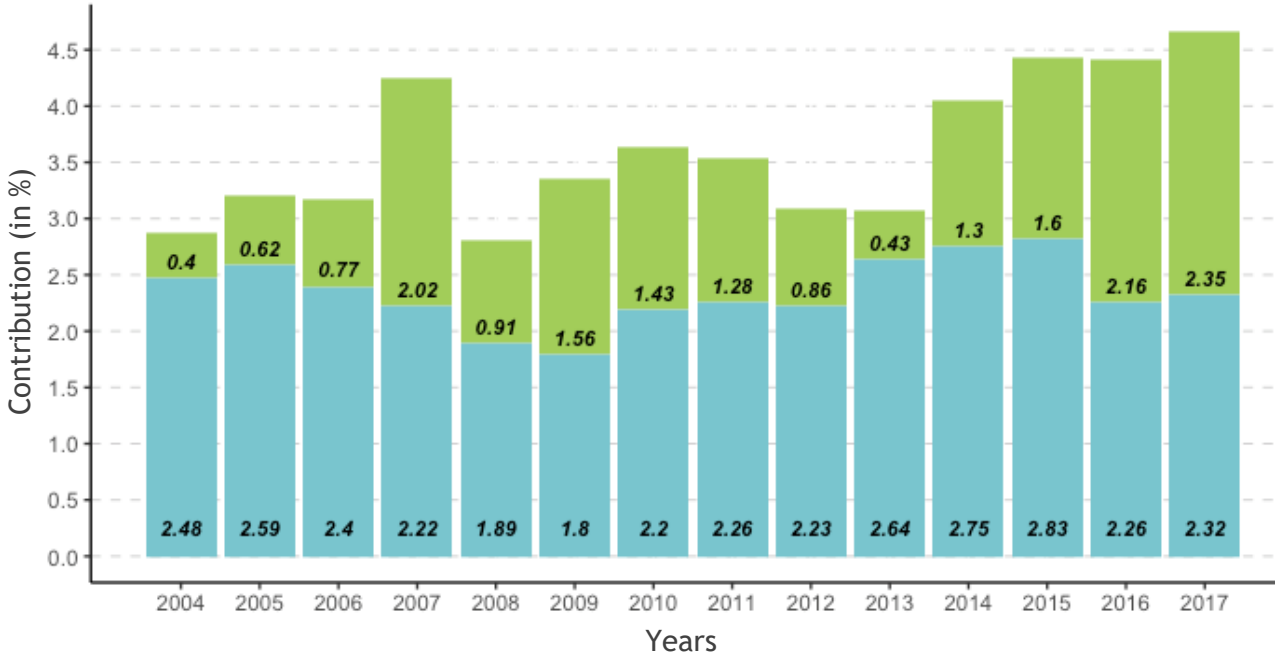


Use of genetic resources in current breeding schemes

Global genetic contribution of NAIF to the breed



Old and recent genetic contributions of NAIF



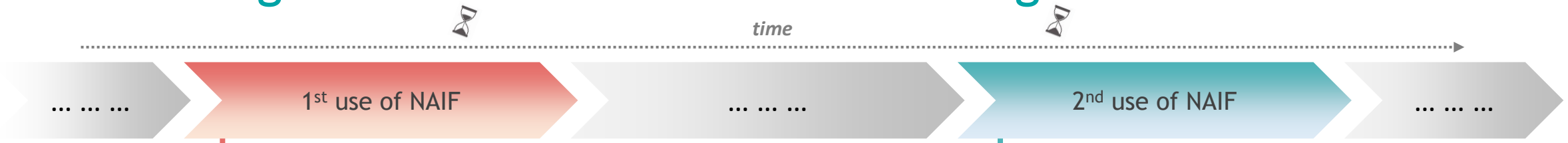
TYPE OF CONTRIBUTIONS

Old contribution
(from the use of NAIF between 1980 and 1993)

Recent contribution
(from the use of NAIF between 2004 and 2009)

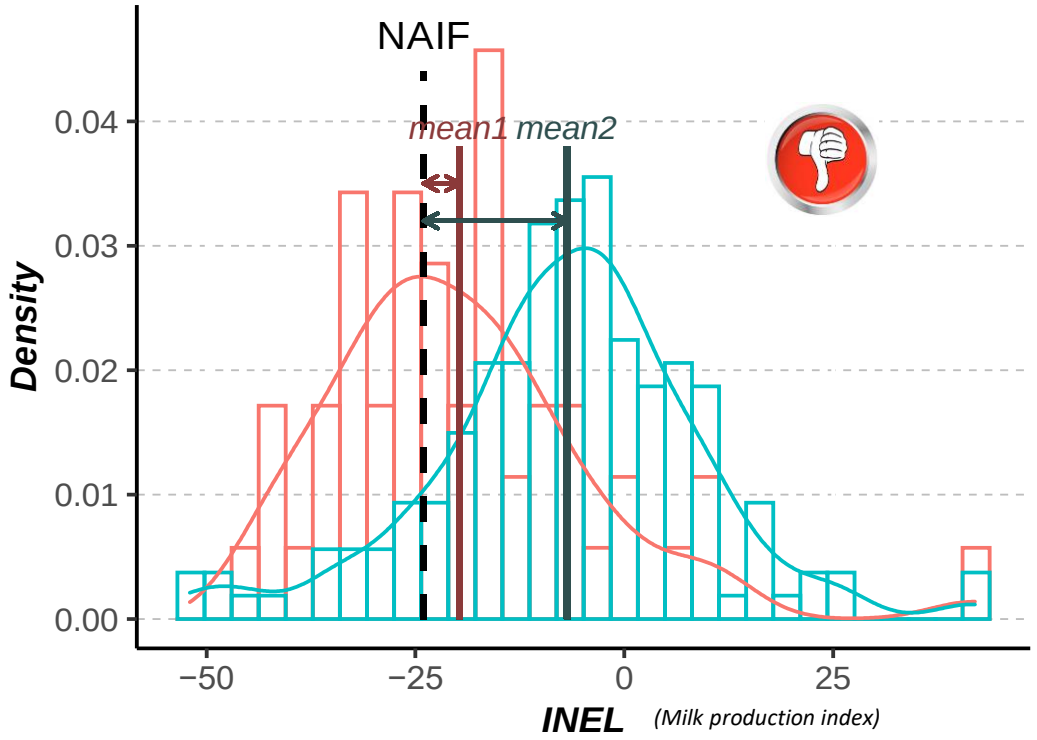
An important use, in particular via its descendants from 2014

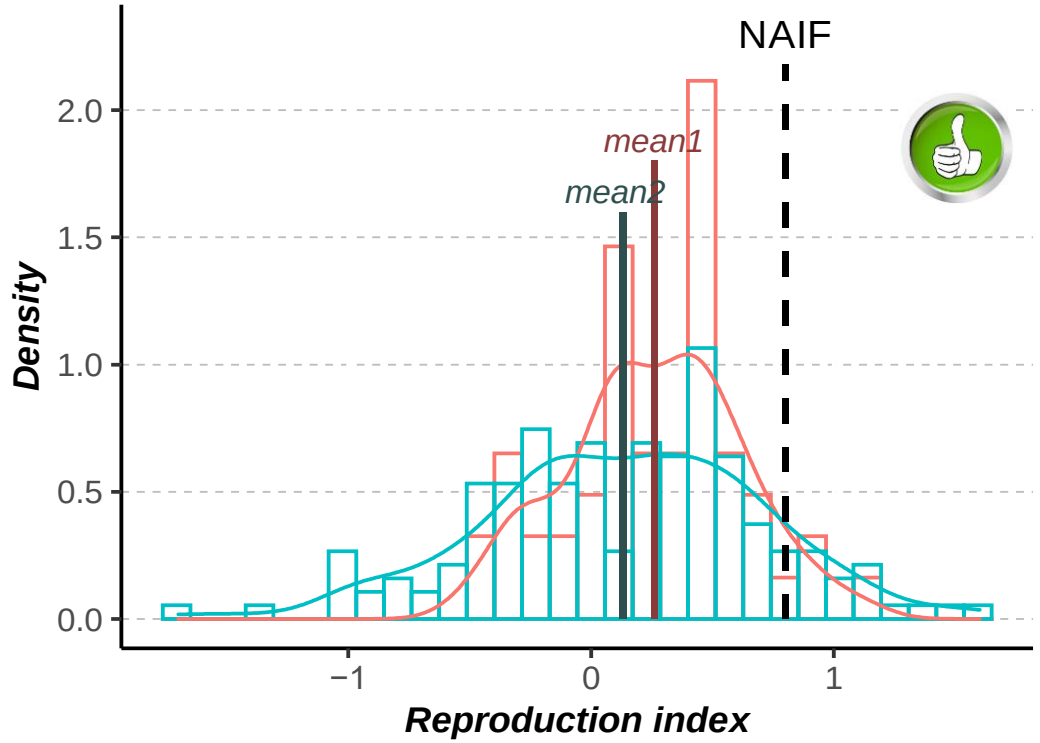
Use of genetic resources in current breeding schemes



COHORT 1
62 genotyped sires
(born between 1970 and 1991)

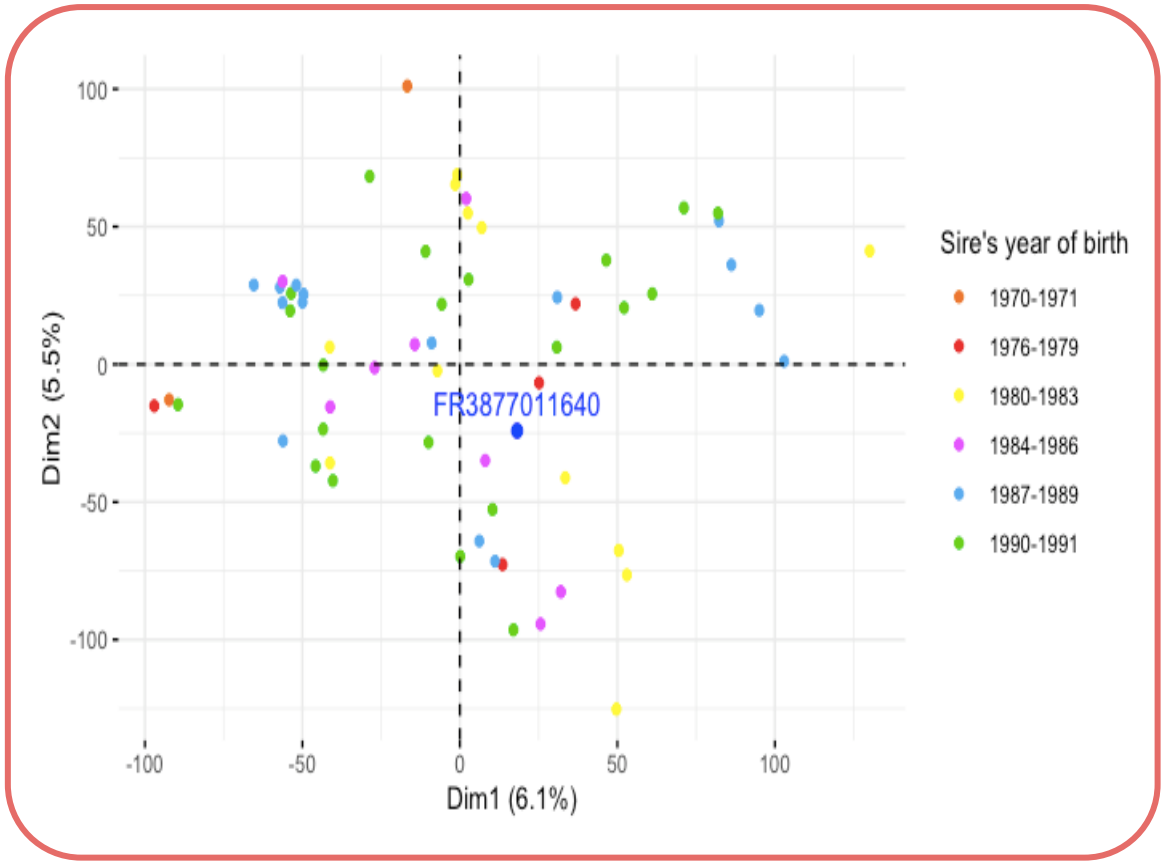
COHORT 2
165 genotyped sires
(born between 1982 and 2007)



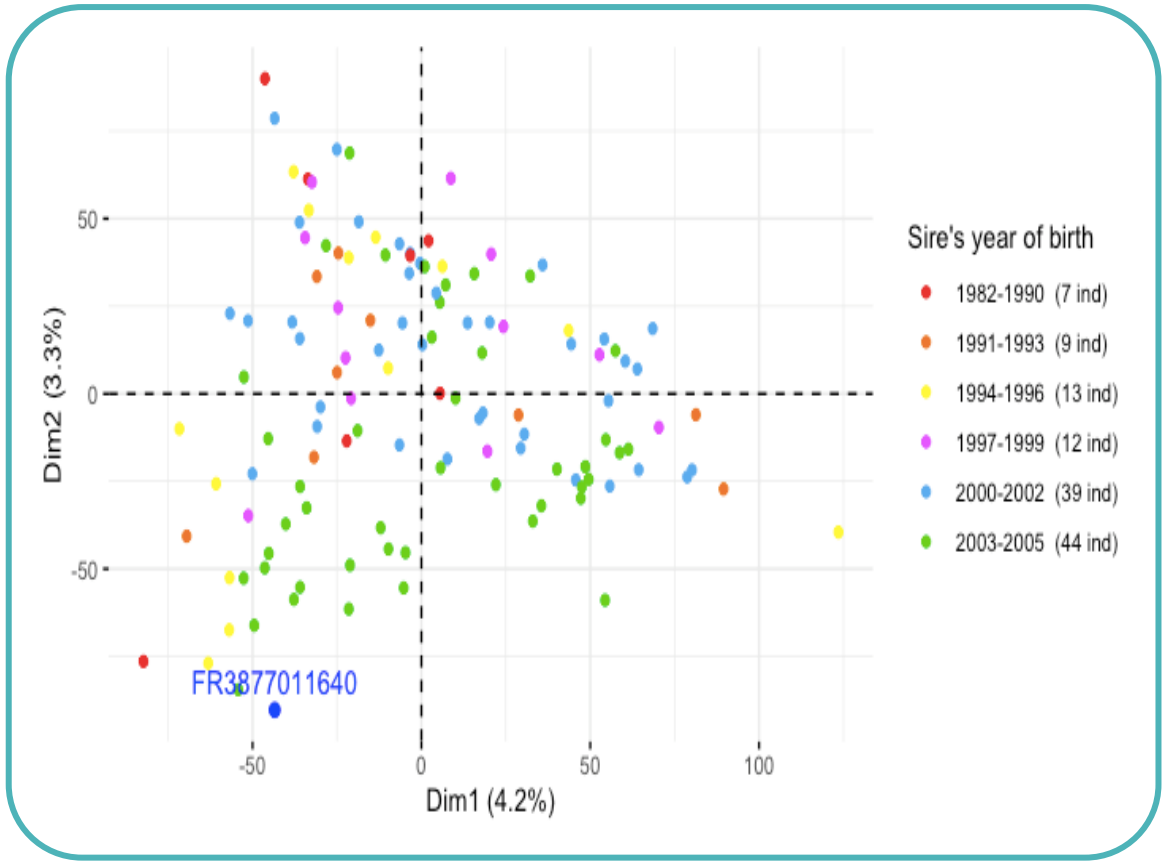


→ *Judicious choice of females to quickly fill the performance gap brought by NAIF*

Use of genetic resources in current breeding schemes



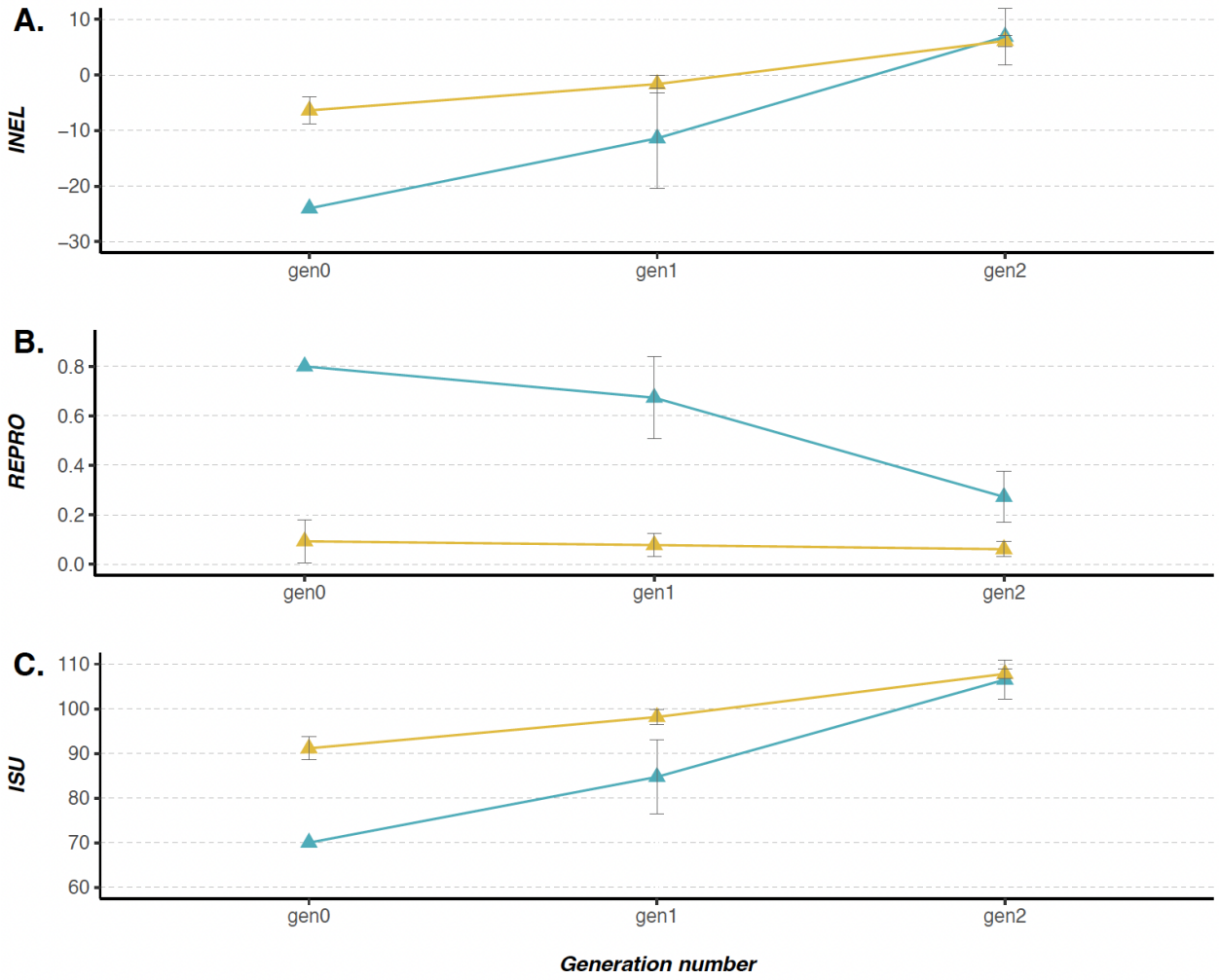
1st use



2nd use

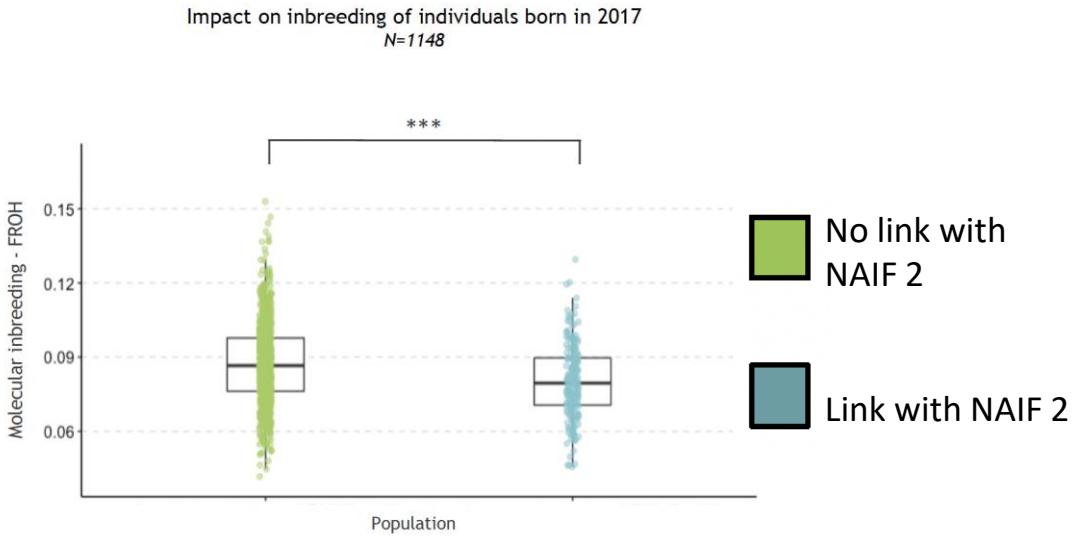
NAIF quite common during its 1st use BUT very original during the use of its frozen semen

Use of genetic resources in current breeding schemes



GEBV empirical within-family standard deviations

Famille	INEL	REPRO	ISU
NAIF	17.86	0.33	16.48
Others	13.81	0.45	13.96



Increase in genetic variance (cf. inbreeding)

Conclusion and perspectives

Need for better characterization of genetic resources

A multiple levels task

- Genetic Diversity
  - Neutral
  - Functional

- Multi-criteria evaluation of genetic resources
  - Experiments at the system level are needed
  - Rely on both Experimental units and On-farm measurement

- Need to develop tools
  - For data integration (accounting for various sources of data)
  - To predict and optimize the impact on populations

- Need policies and subsidies to make this market sustainable