A general introduction to animal adaptation

Environmental Genetics Doctoral Course
Paris 23/05/2016

Tatiana Zerjal

Adaptation

From the Latin words *Adaptare* " to adjust " and *Aptus* "fitted"

Become adjusted to new conditions

Oxford dictionary

Adaptation

Is the process by which genetic changes occur to enhance the fitness and survival of individuals in a changing environment

Adaptive trait

Is a trait that promotes reproductive success

Adaptation is important

Because

- Allows the organisms to adjust themselves and survive in their environment

- Maximizes their survival in their environment

- Allows organisms that are successfully adapted to live and reproduce

Adaptation is "Universal"

Life occurs essentially everywhere on Earth






Adaptation to a given environment is the result of natural selection

The study of Adaptation ⟷ **The study of Evolution**

Selective pressures are the driving forces of evolution

Natural Selection is the process where, as a result of a number of factors (climatic, population size, etc) in a given population, individuals with a particular genotype has greater reproductive success than other individuals with different genotypes

Artificial Selection is the process of selection conducted under human direction to promote a desired character (color, size, capacity to produce etc.)

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Natural Selection and The Theory of Evolution

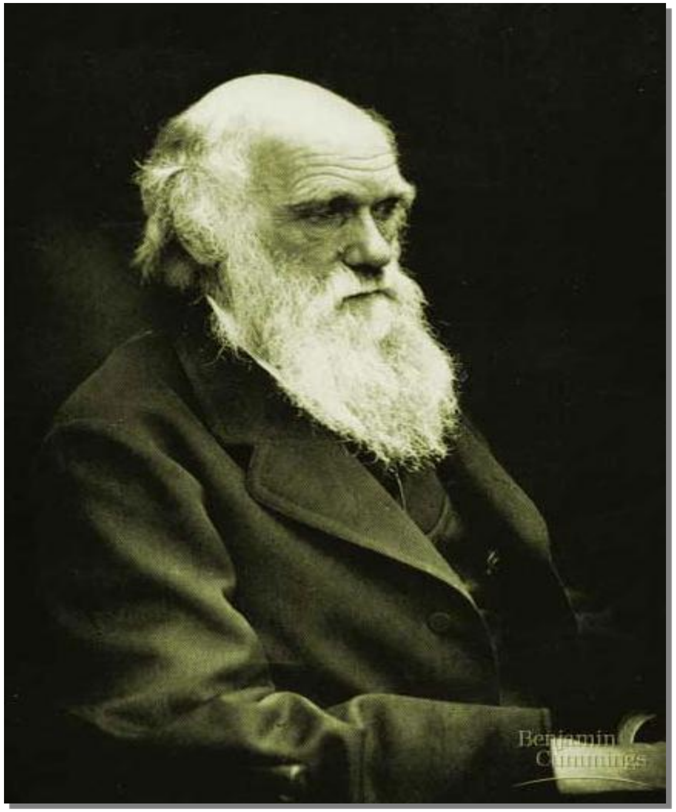
Charles Darwin (1802-1882)

He put together a number of ideas from different disciplines and relied upon the findings of other scientists to come up with the Theory of Natural Selection

"I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection."

(The Origin of Species)

http://www.interaktv.com/Darwin/Darwin.html



Natural Selection and The Theory of Evolution

Three conditions for Natural Selection:

1) Variation in traits
2) Heritability
3) Survivorship/Competition

1) Variation in traits: variation exists between individuals

➢CONTINUOUS: having a multitude of variants (e.g., colour bands in the snail)

➢DISCRETE: limited number of types (e.g. Blood types, A, B , 0)

Natural Selection and The Theory of Evolution

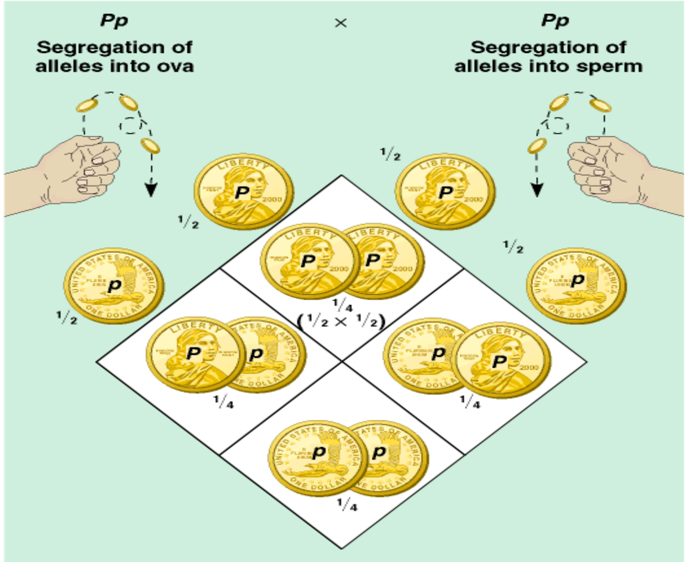
Three conditions for Natural Selection:

1) Variation in traits

2) Heritability

3) Survivorship/Competition

2) Heritability: Offsprings inherit the majority of their traits from their parents.



- In Diploids there are 2 copies of each gene
- The pass on of a certain copy of a gene is an independent event for each offspring

Natural Selection and The Theory of Evolution

Three conditions for Natural Selection:

1) Variation in traits

2) Heritability

3) Survivorship/Competition

3) Survivorship/Competition

More offspring are produced than there are resources to support them (*Essay on the Principle of Population"* by Thomas Malthus 1798)

Struggle to survive

Some individuals will be better at surviving and reproducing than others (i.e., have higher *fitness*)

Environmental conditions affect selection

The environment determines the pressures natural selection exerts

These pressures determine:

- **who survives and reproduces**
- **what traits will evolve to improve success in the environment**

Examples of natural selection

The peppered moth and the industrial melanism: genetic darkening of species in response to pollutants

Early in the 19th century, the melanistic (dark) form of the moth was rare.

Polluted woods

Unpolluted woods

Over the next hundred years, this dark form became increasing common in forests near heavily industrialized regions

Since the 70s the melanistic form is decreasing in frequent due to the implementation of the pollution control policy

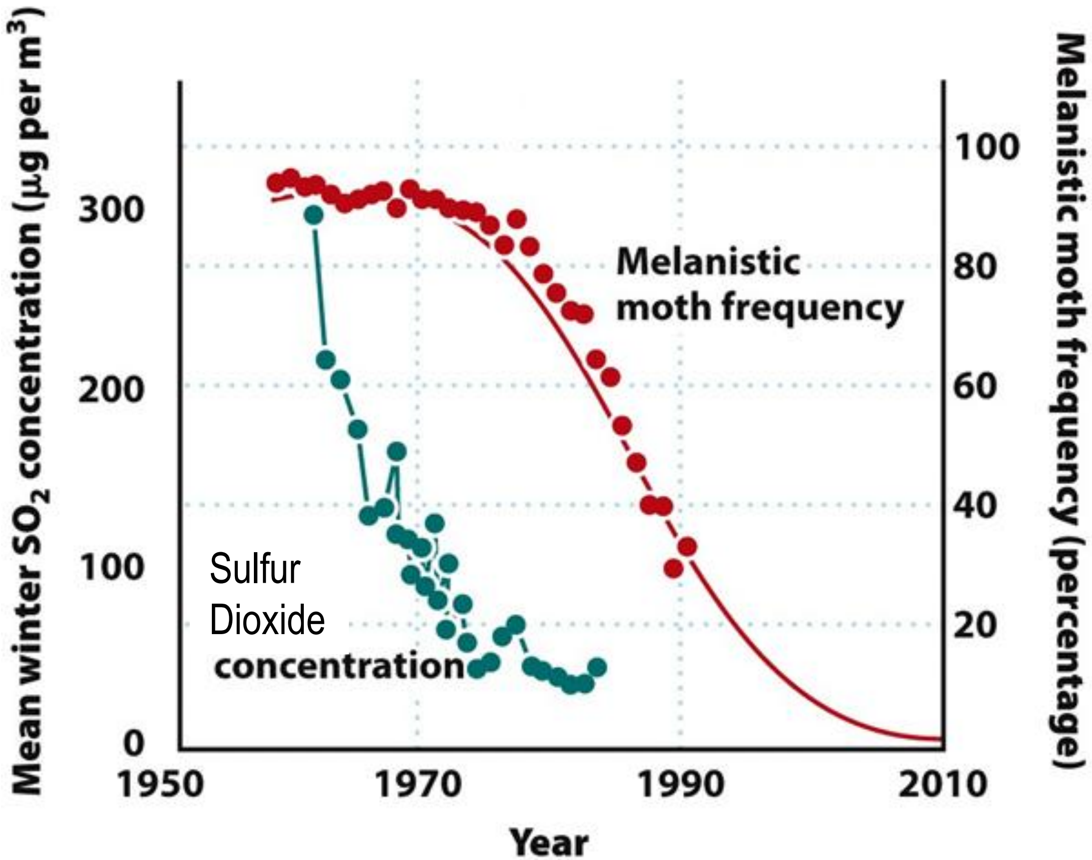
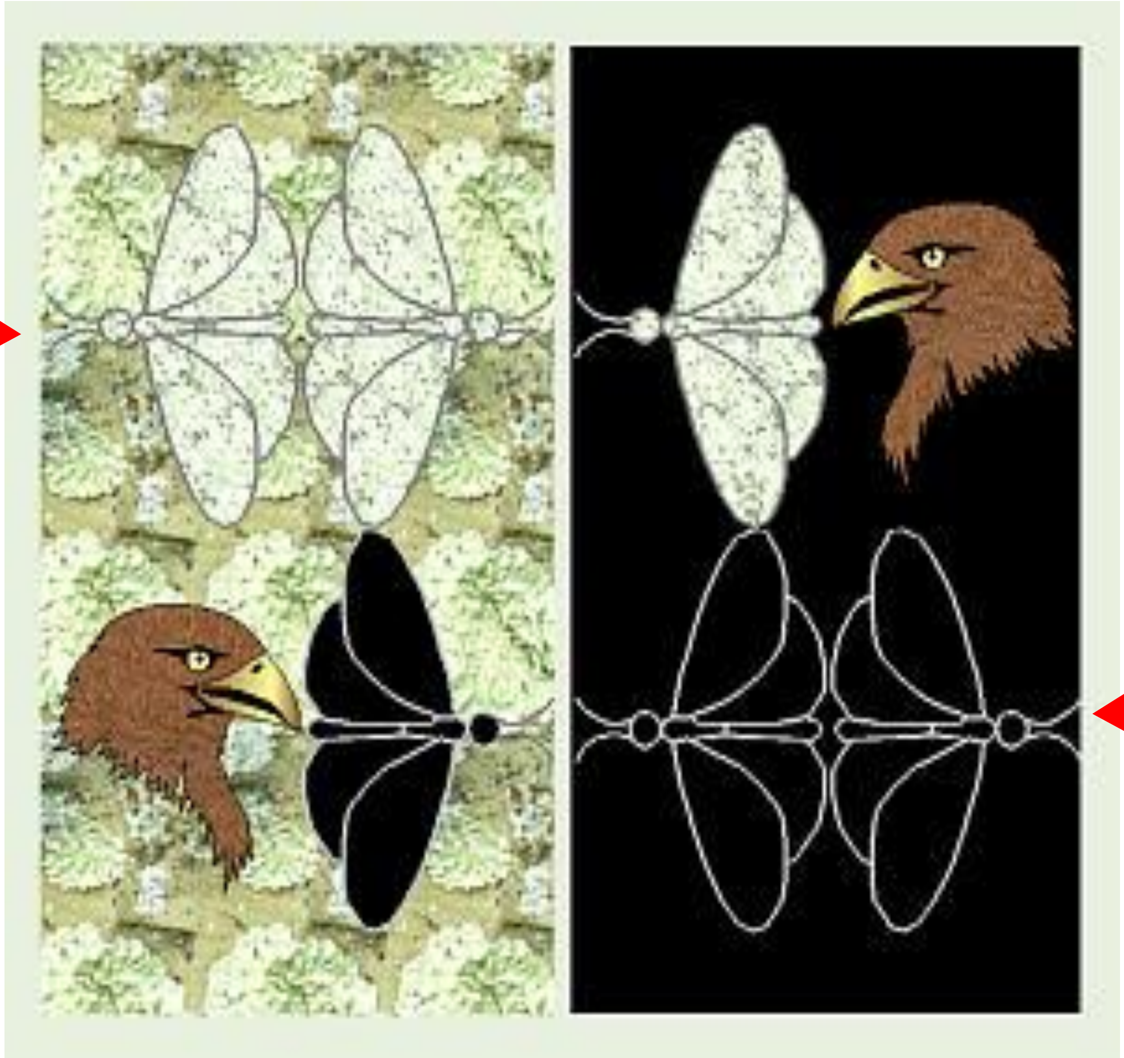


Figure 6.9
The Economy of Nature, Sixth Edition

Traits that promote success in a specific environment may not do so if the environment changes

Selected by natural selection



Selected by natural selection

Example from the work of Peter and Rosemary Grant on Darwin's finches

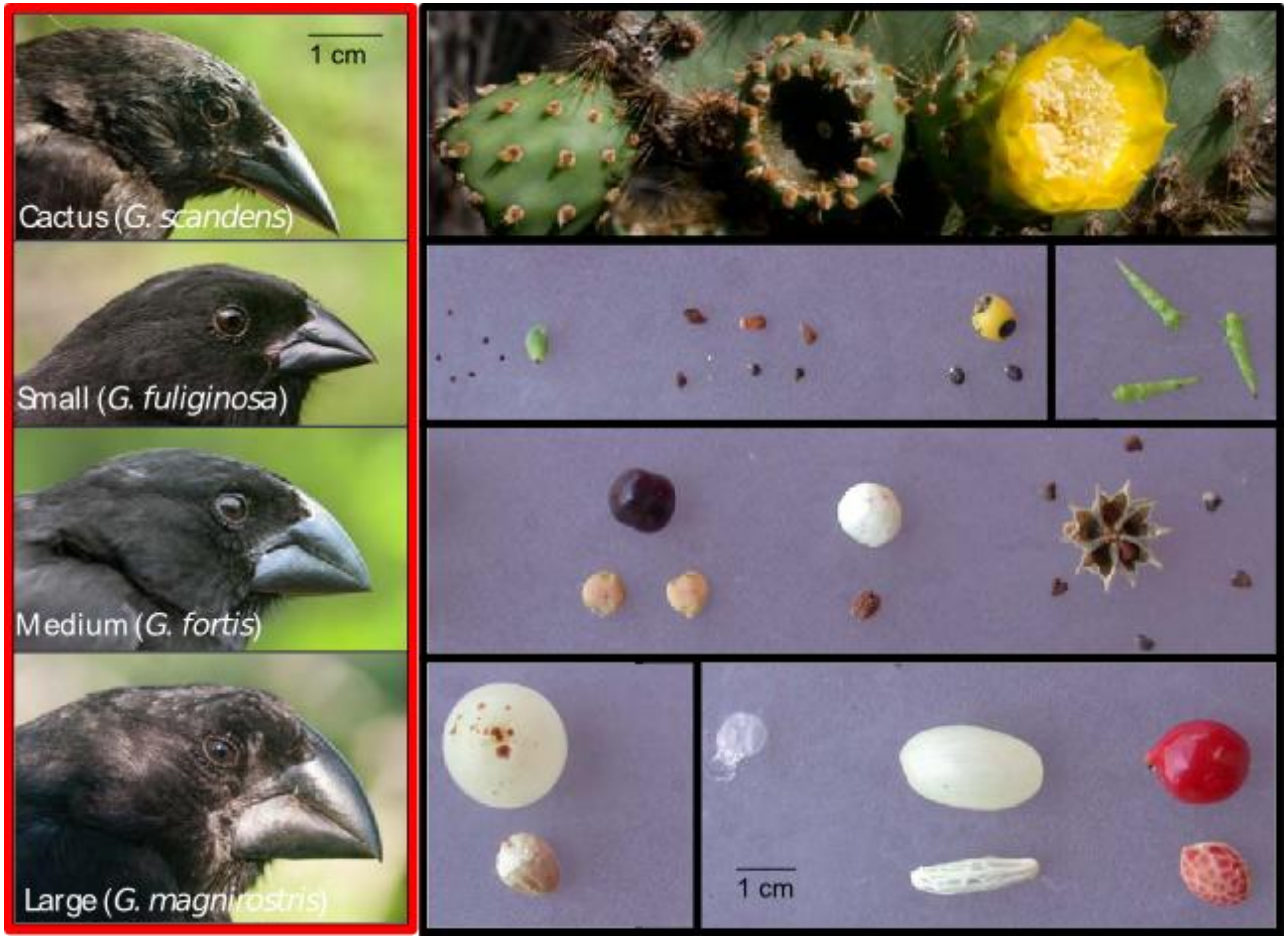
From http://www.pbs.org/wgbh/evolution/library/01/6/l_016_01.html

The Grant are evolutionary biologists at Princeton University. Since1973 they spent several months each year on Daphne Major island in the Galapagos to measure and identify hundreds of finches and record their diets every year.

Fig. P.4 Phenotypic variation in the *G. fortis* population on Daphne.

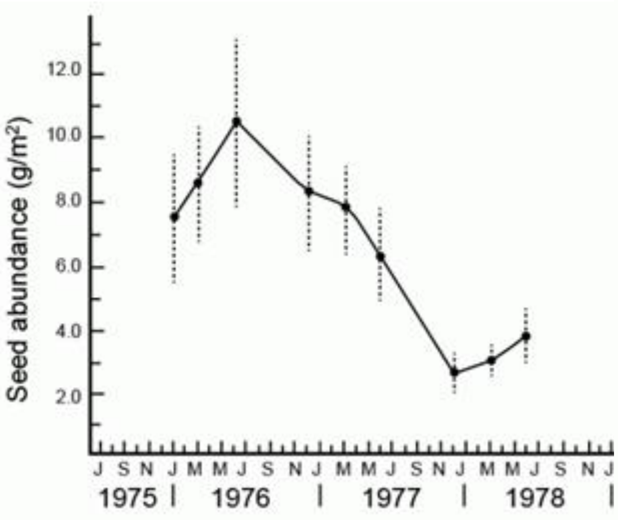
They wanted to find out whether they could see the force of natural selection at work judging by which birds survived the changing environment of the island

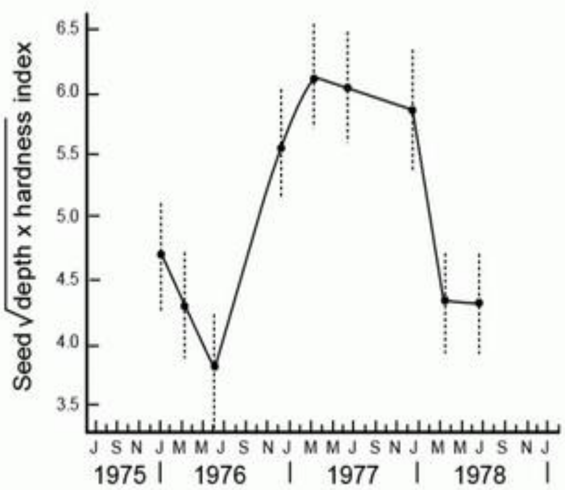
For the finches, body size and the size and shape of their beaks are traits that vary in adapting to environmental niches or changes in those niches.

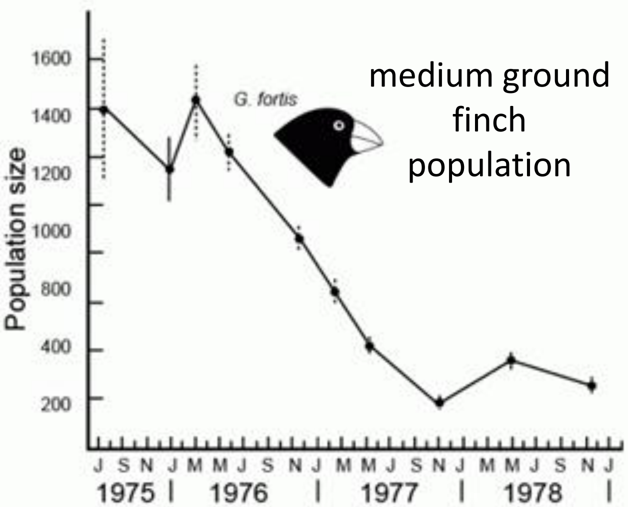


Year to year weather changes on Daphne Major island caused

Variation in the number and types of seeds available

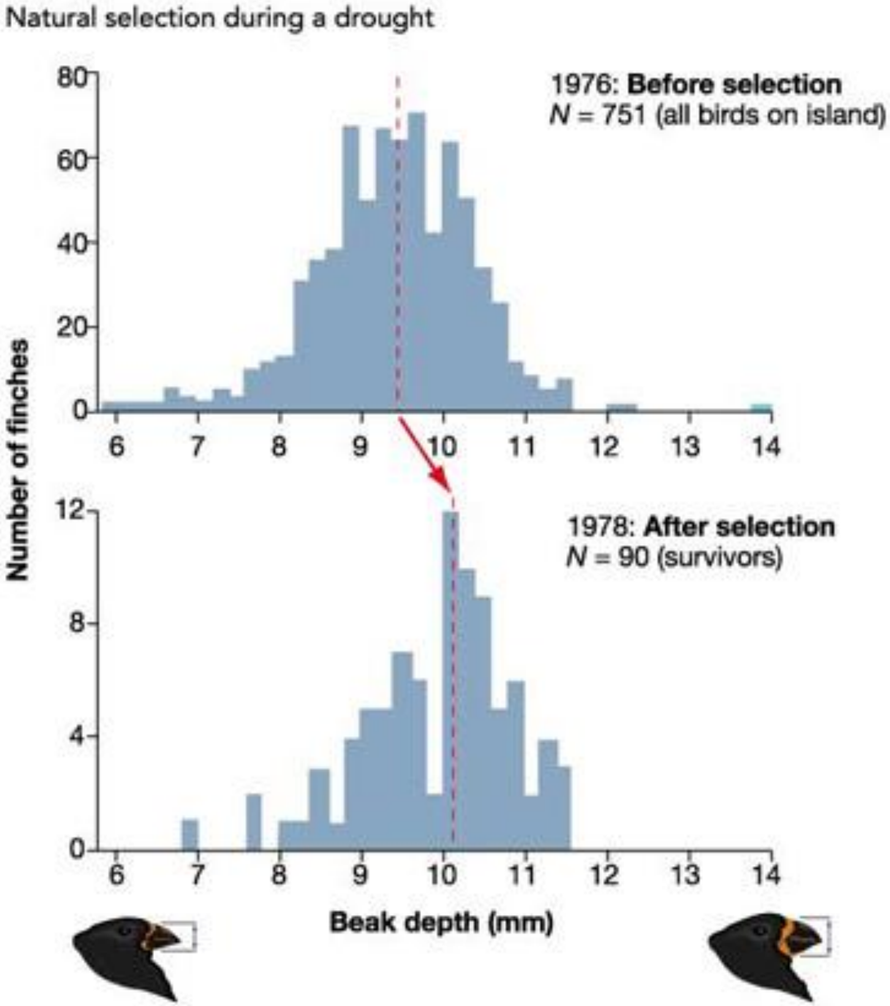






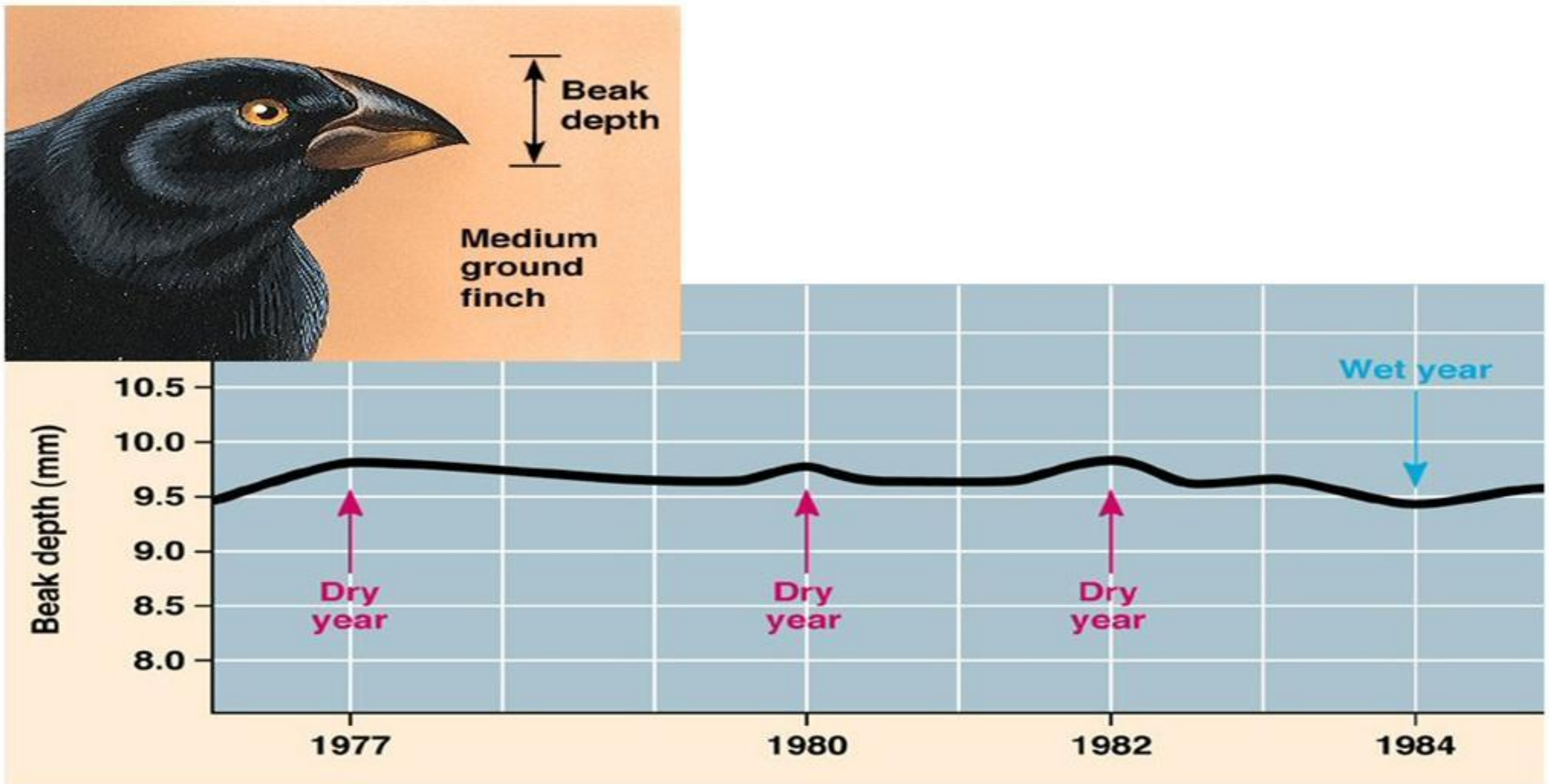
medium ground finch population

A severe drought occurred in 1977 on Daphne Major island



The offspring of the birds that survived the 1977 drought tended to be larger, with bigger beaks.

Weather changes on Daphne Major island caused changes in beak depth in the medium ground finch population



Very rapid changes in body and beak size in response to changes in the food supply are driven by natural selection

Output of the study

The drought favored the larger birds with deep, strong beaks for opening the hard seeds.

Unusually rainy weather favored smaller beaked birds more adapted for opening small, soft seeds

Traits that promote success may not do so over time if the environmental conditions change

Hendry et al. 2006 DOI: 10.1098/rspb.2006.3534

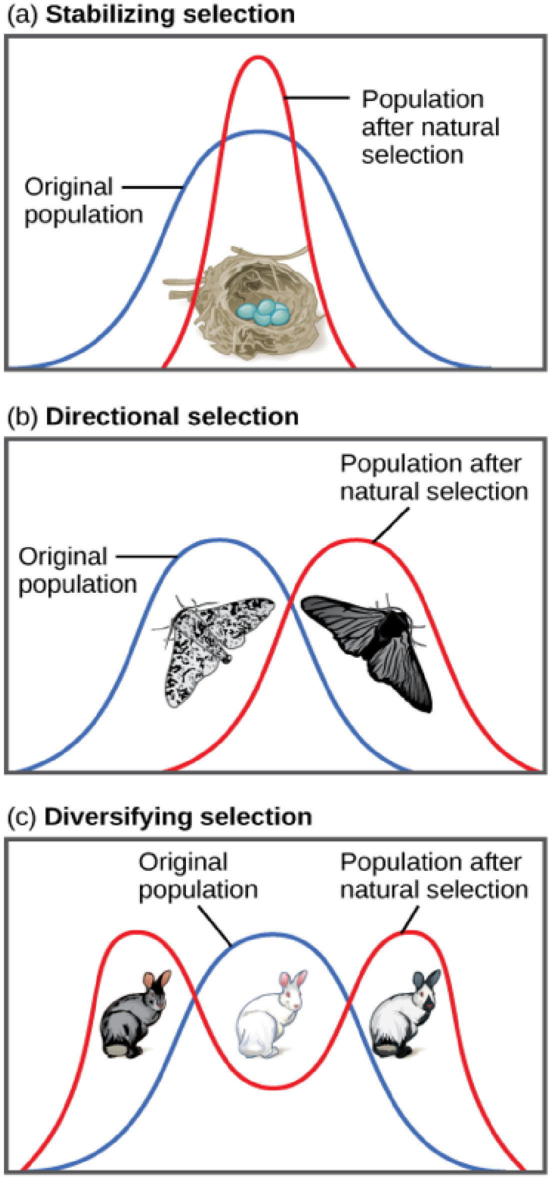
Types of natural selection

Three types of Natural selection

- *Stabilizing selection* =
  Favors intermediate traits

- *Directional selection* =
  Favors one extreme

- *Diversifying selection* =
  Favors both extremes



https://www.boundless.com

Characteristics of natural selection

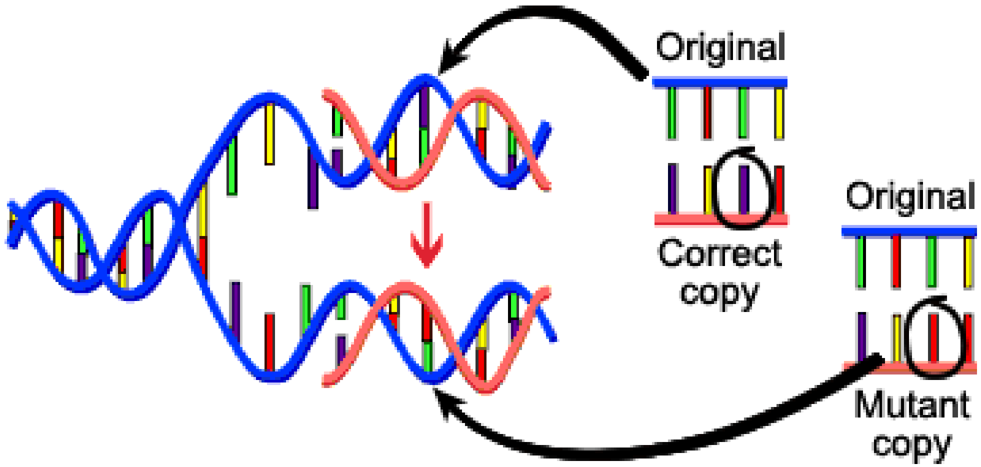
- Natural Selection acts only if genetic variation is present in the population

- Natural Selection acts only if present selection pressures

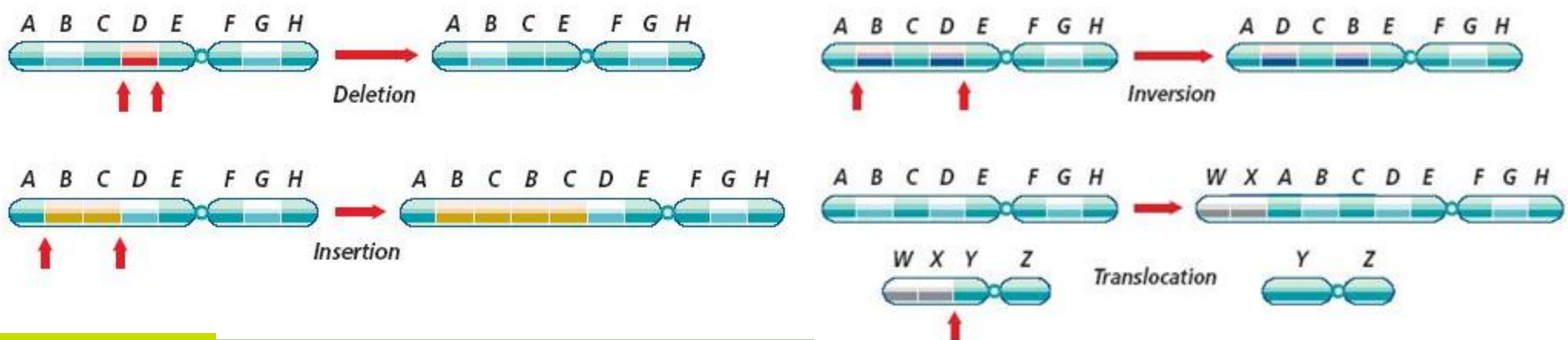
Sources of variation

- Mutation
- Recombination
- Gene flow: migration

Mutation: inheritable changes in the DNA sequence

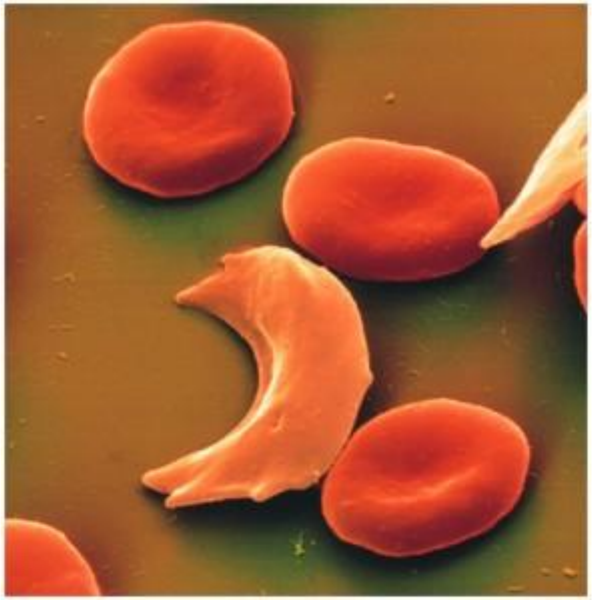


Chromosome mutation: Deletion, Insertion, Inversion and Translocation



Mutation at the Phenotype Level

- Mutations can be:
  - beneficial
  - detrimental
  - neutral

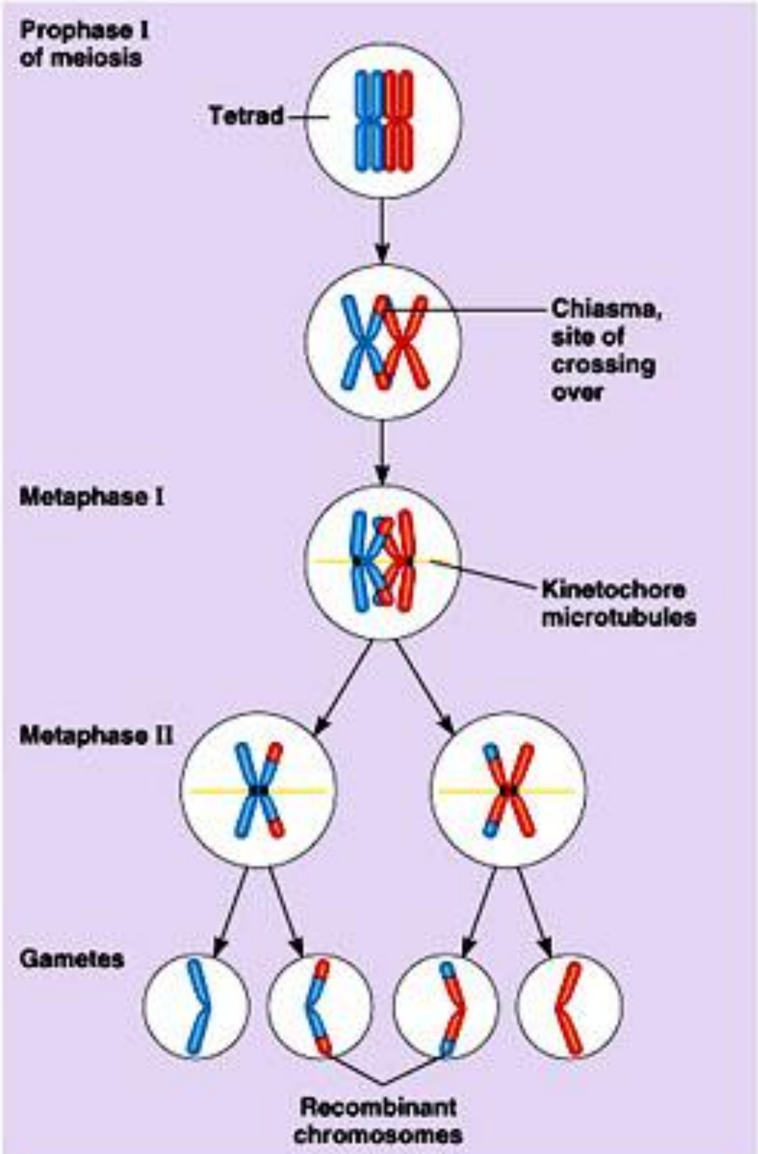


Detrimental mutation can be under specific circumstances beneficial (e. g. sickle cell anemia and malaria)

Recombination creates variation in offspring

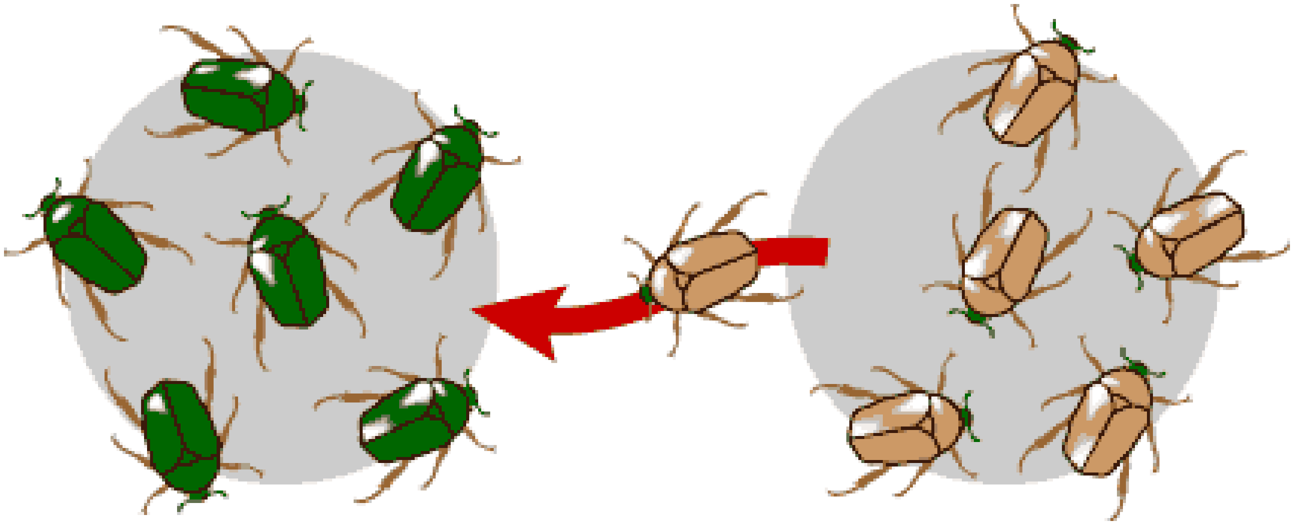
Sexual reproduction increases dramatically the variation within a population by creating new combinations of existing genes.

In asexual organisms mutations are the only way in which a change in gene variation can be achieved



Migration

➢The migration of individuals allows the spread of alleles to other populations.



The randomness of Variation

- When a new mutant genotype appears in a population, there is no tendency for it to arise in the direction of improved adaptation

- Natural selection imposes direction on evolution, using undirected variation

The study of Adaptation ⟷ **The study of Evolution**

Selective pressures are the driving forces of evolution

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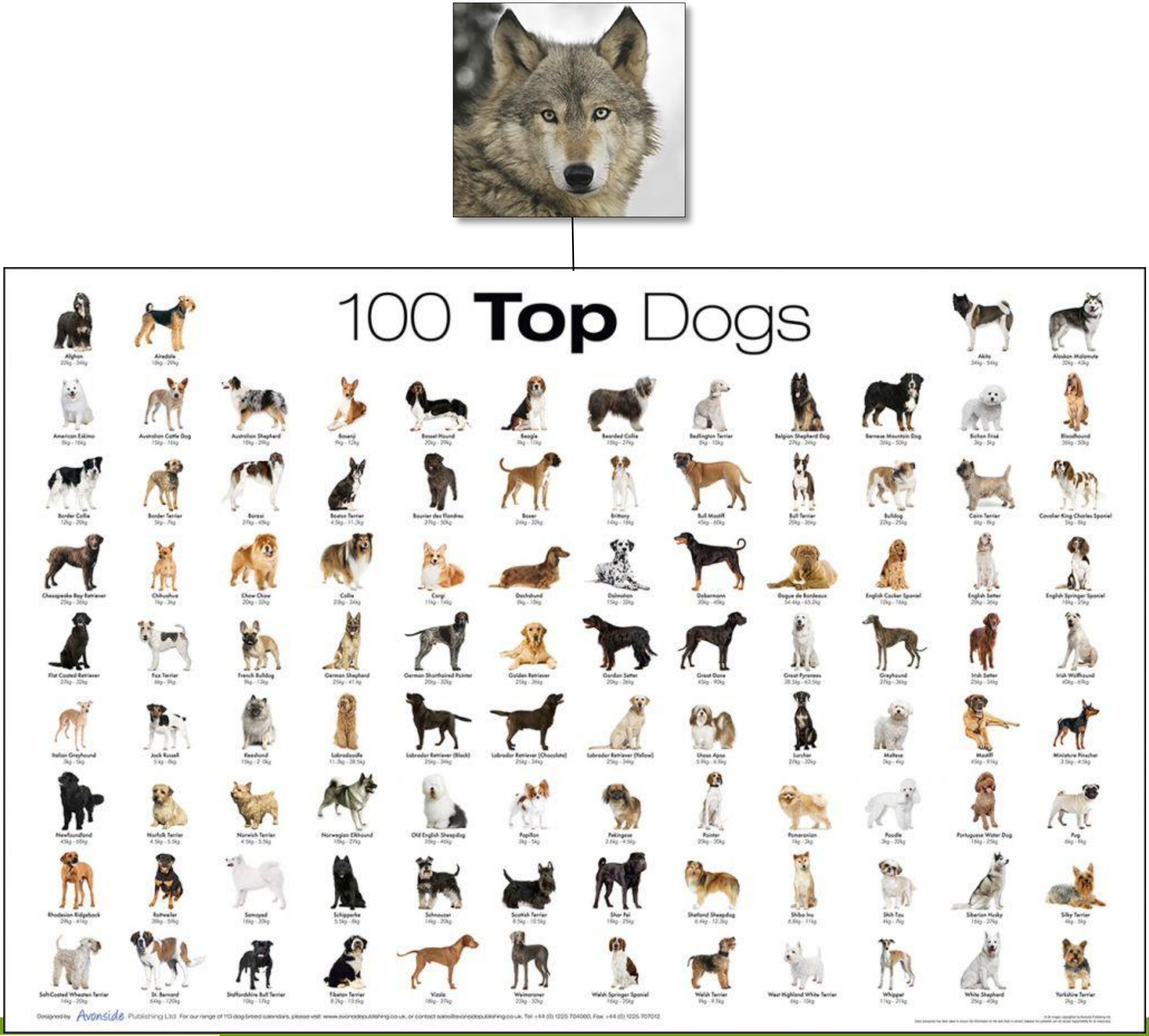
Artificial Selection is the process of selection conducted under human direction to promote a desired character (color, size, capacity to produce etc.)

Examples of Artificial Selection

Dog breeding



Livestock breeding to improve performance

Livestock breeding to improve performance

Belgian blue : double muscling phenotype due to mutation of the myostatin gene

By Gwendal Restoux 2016

Livestock breeding to eradicate diseases

Scrapie disease (goat & sheep)

- Prion induced
- Lethal and incurable
- Affect nervous system (TSE)
- Transmission through contaminated soil (grazing...)

Genetic resistance exists → selective breeding to minimize the effects of the disease.

From Gwendal Restoux 2016

Farm Animal Adaptation

Many terms in the scientific literature, although there is considerable confusion about their meanings *(Ellen et al. 2009)*

Definition: Robustness

different definitions for different species

In pig:
“Is the ability to combine a **high production** potential with resilience to stressors, allowing for high production **in a wide variety of environmental conditions** “ (Knap ,2005)

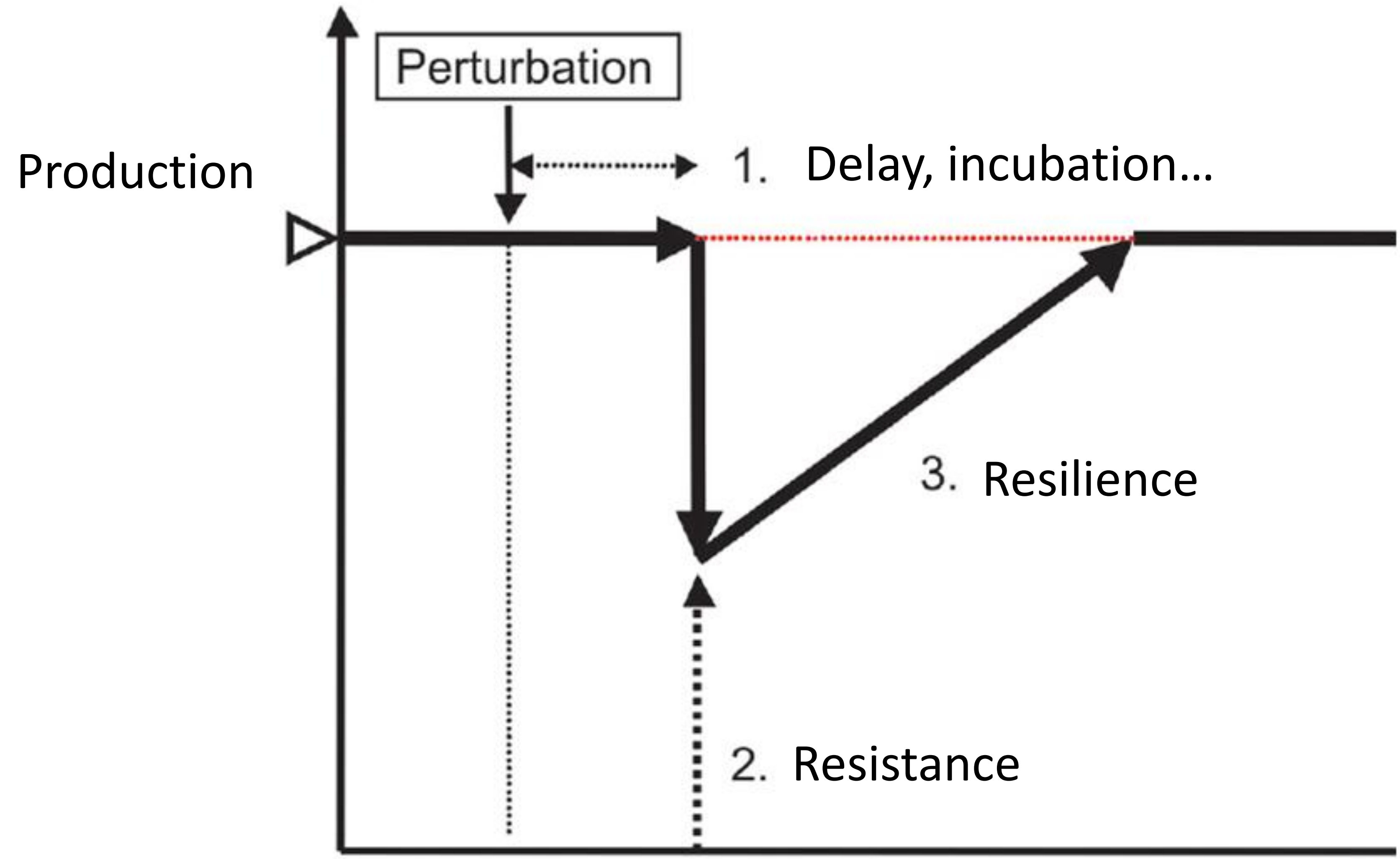
In dairy cattle:
“The ability to maintain homeostasis in commonly accepted and sustainable dairy herds” (Ten Napel et al., 2006)

In laying hens:
“An animal under a normal physical condition that has the potential to **keep functioning** and **take short periods to recover** under **varying environmental conditions**” (Star et al., 2008)

The Robust Animal

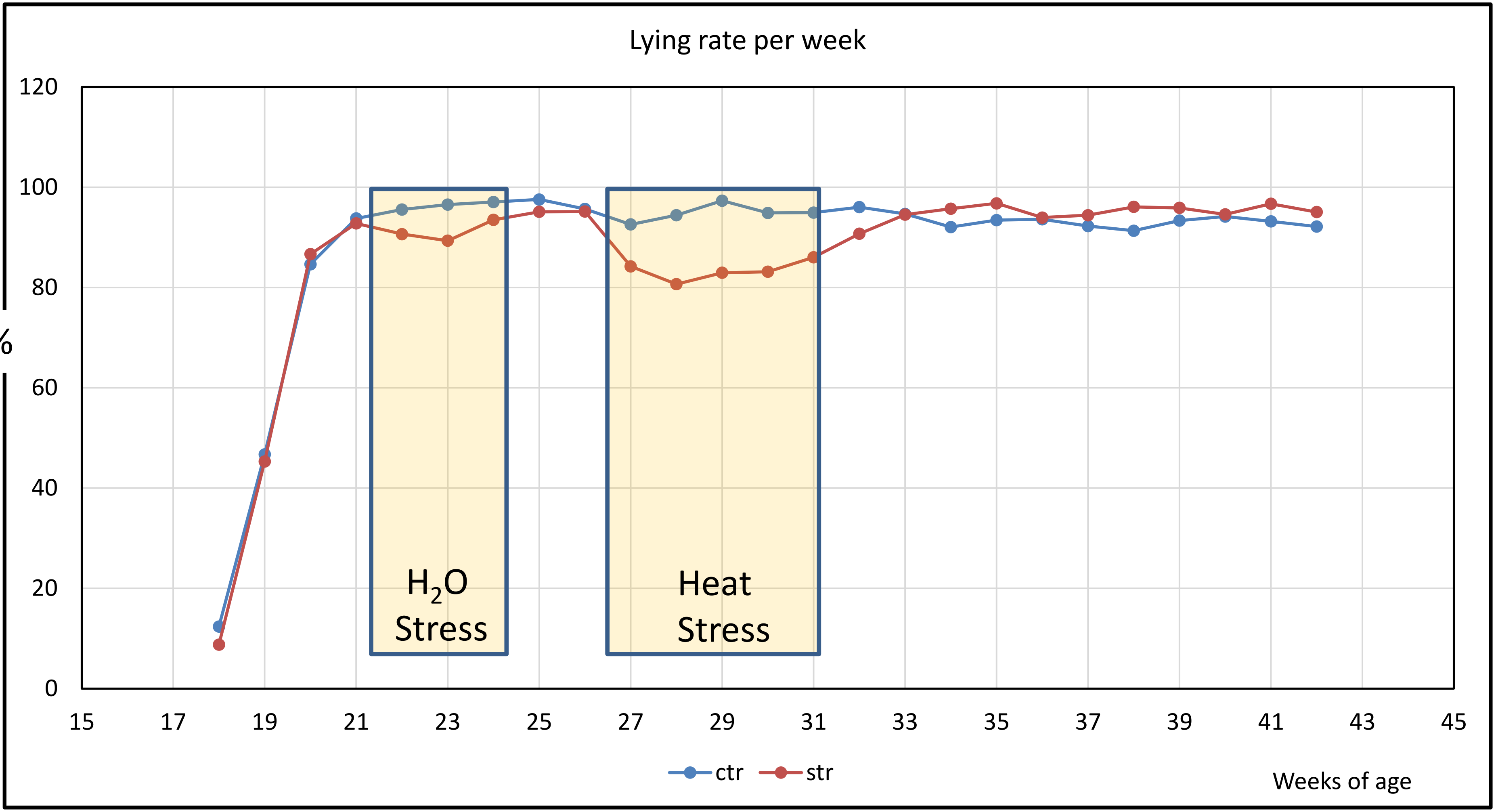
- High Production potential
- Takes short periods of recovery
- Good health
- Adapts to every environment
- ……….

Resilience: is the capacity to respond to a perturbation by **resisting damage** and **recovering quickly**



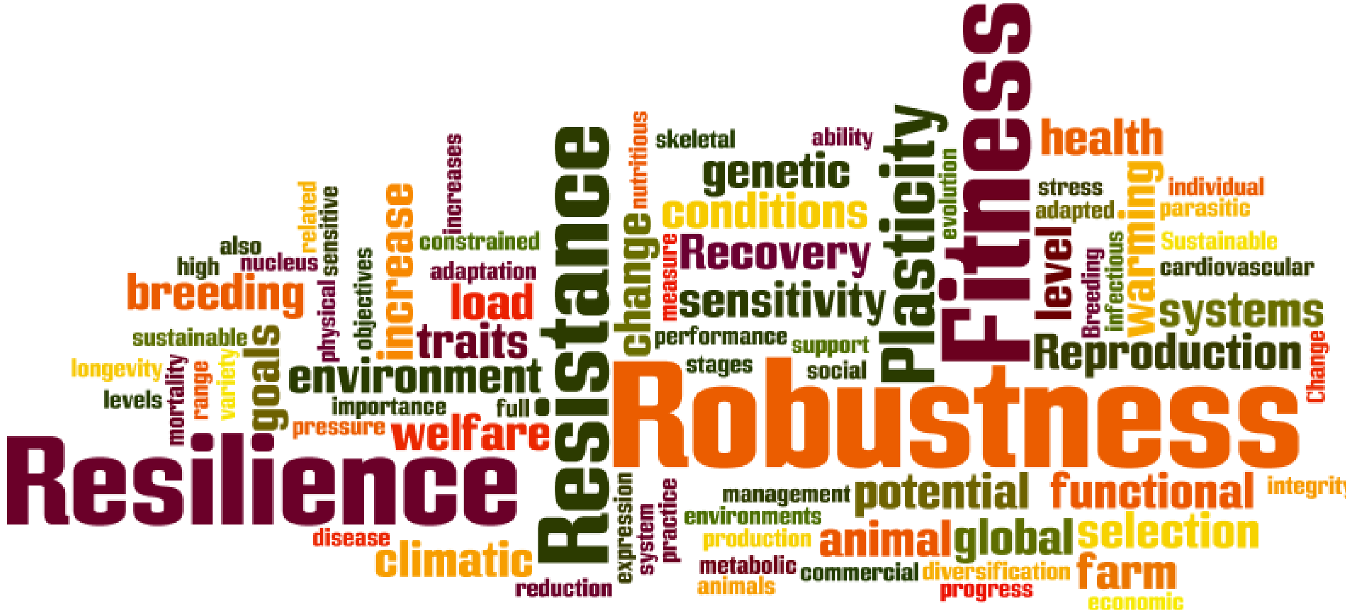
Modified from Sauvant and Martin INRA Prod Anim 2010

Egg production during water scarcity and heat stress



A robust animal … has the potential to **keep functioning** and **take short periods to recover** under **varying environmental conditions**" (Star et al., 2008)

Fitness: the capacity to maintain general health, wellbeing and reproductive ability



Phenotypic Plasticity: the ability of an organism to **change its phenotype in response to changes in the environment**

It involves all phenotypic responses to environmental change: morphological, physiological, behavioral, phonological etc.

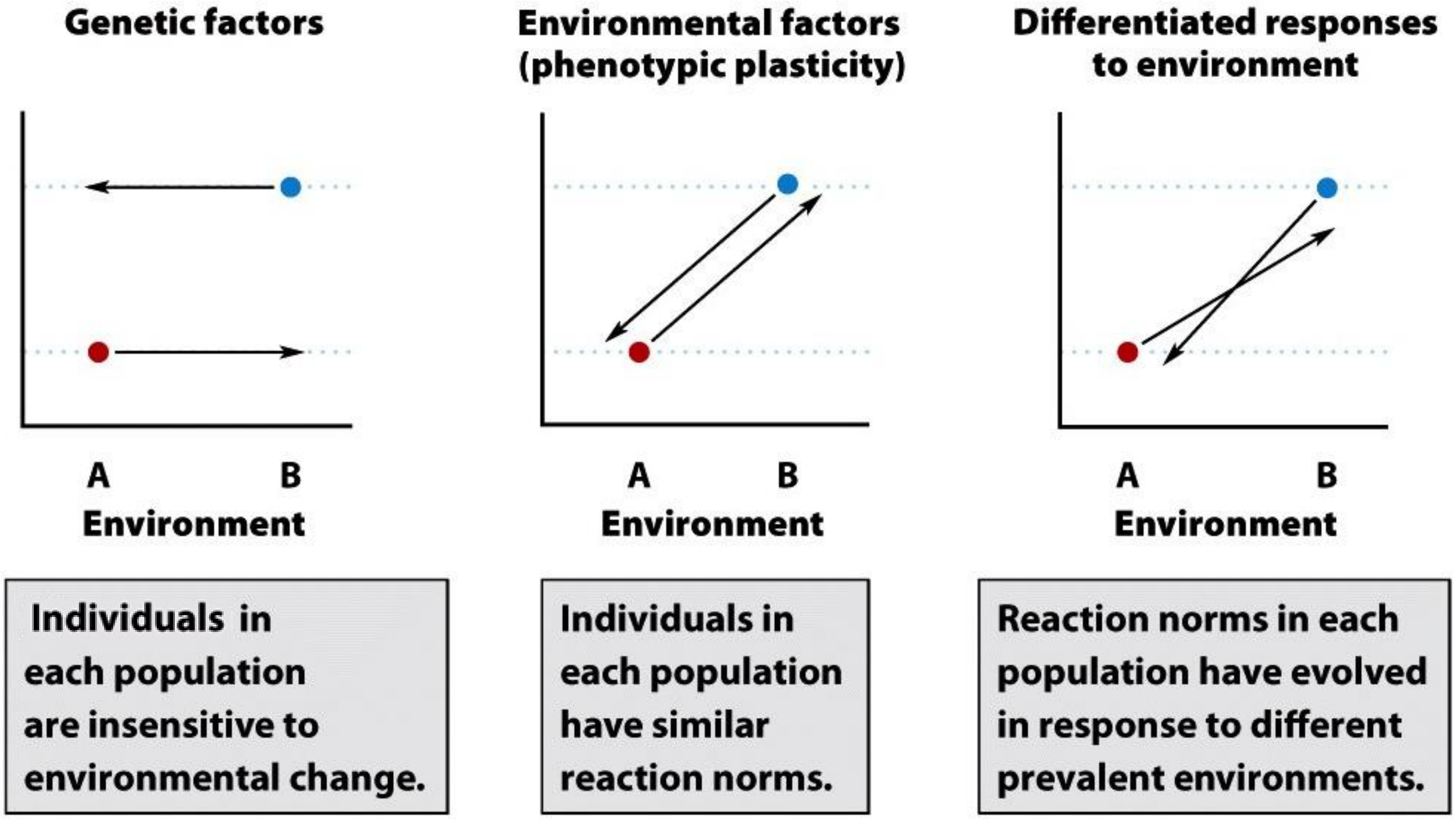
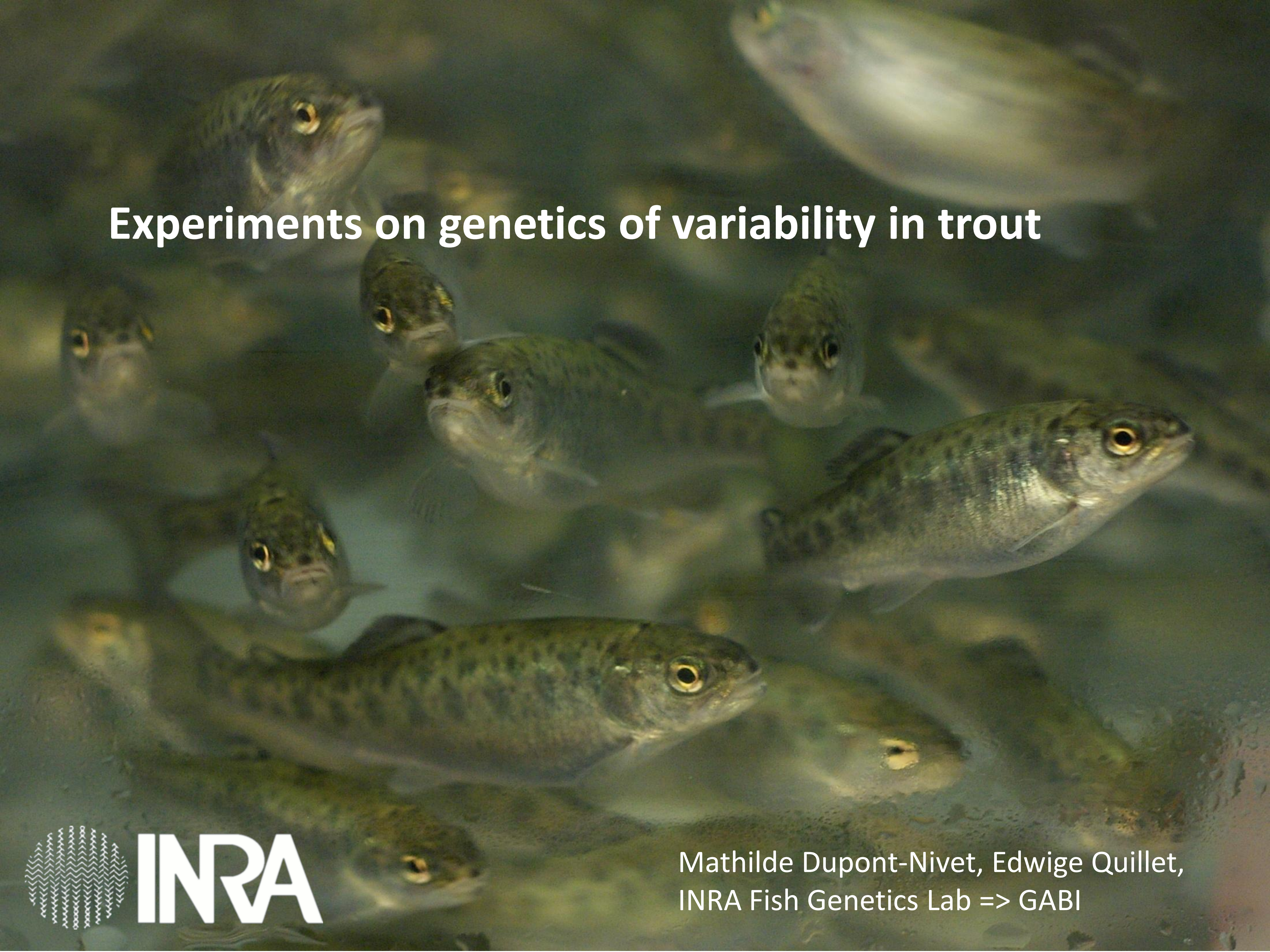


Figure 6.19
The Economy of Nature, Sixth Edition

Let’s look at an example



Experiments on genetics of variability in trout

Mathilde Dupont-Nivet, Edwige Quillet,
INRA Fish Genetics Lab => GABI

Even in the same fish farm, fish can experience large variations of environment

Environment

vary also

from one

fish farm

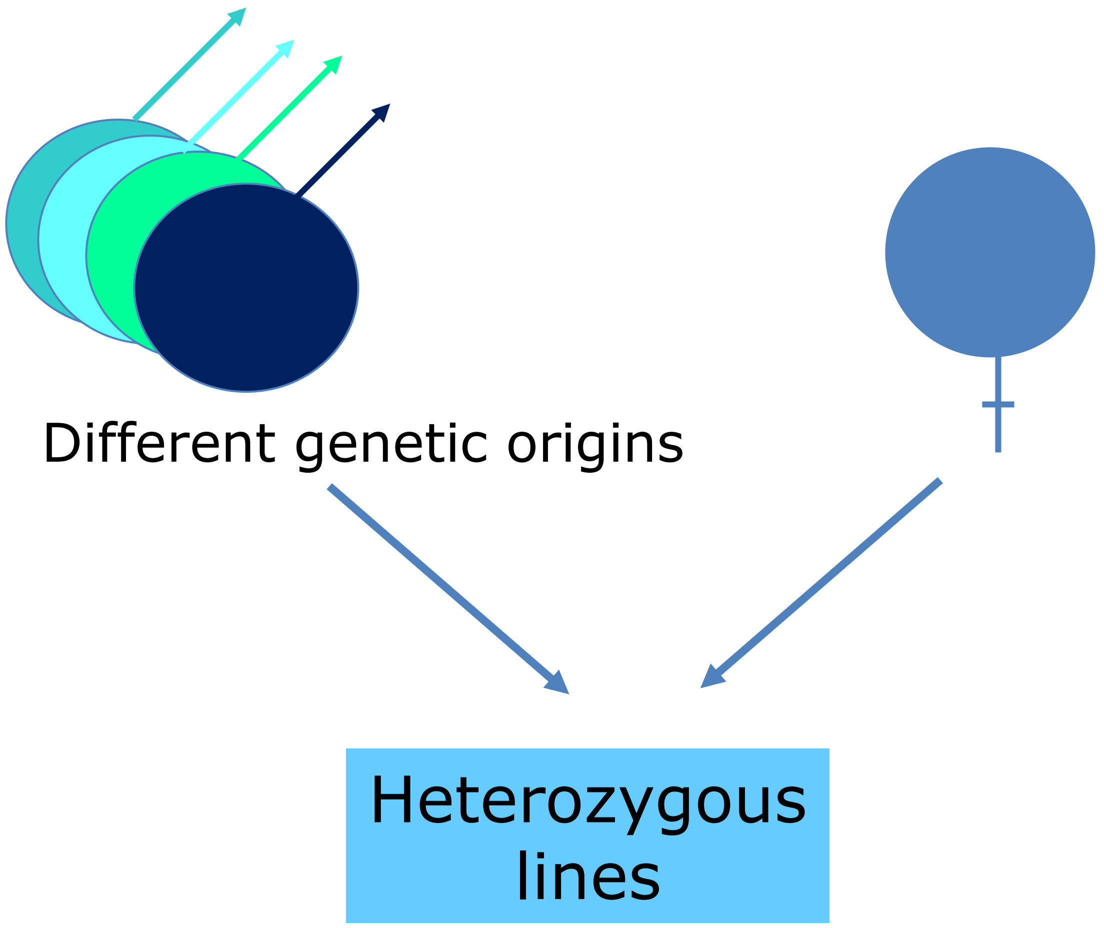
to another

Dupont-Nivet et al, Aquaculture, 2008

Phenotypic plasticity in Rainbow trout :

- Is there a genetic determinism of sensibility to the environment in Rainbow trout ?

Isogenic lines: Within each line, all fish are homozygous and genetically identical, i.e. constitute replicates of the same genotype.



The phenotypic value (P) of an individual is the combined result of its genotype (G) and the effects of the environment (E)

$$P = G + E + GxE$$

The total phenotypic variance (Vp) of a population is the sum of the genetic variance , of the environmental variance and of the gene-environment interaction

$$\mathbf{V_P = V_G + V_E + V_{(G,E)}}$$

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$$P = G + E$$

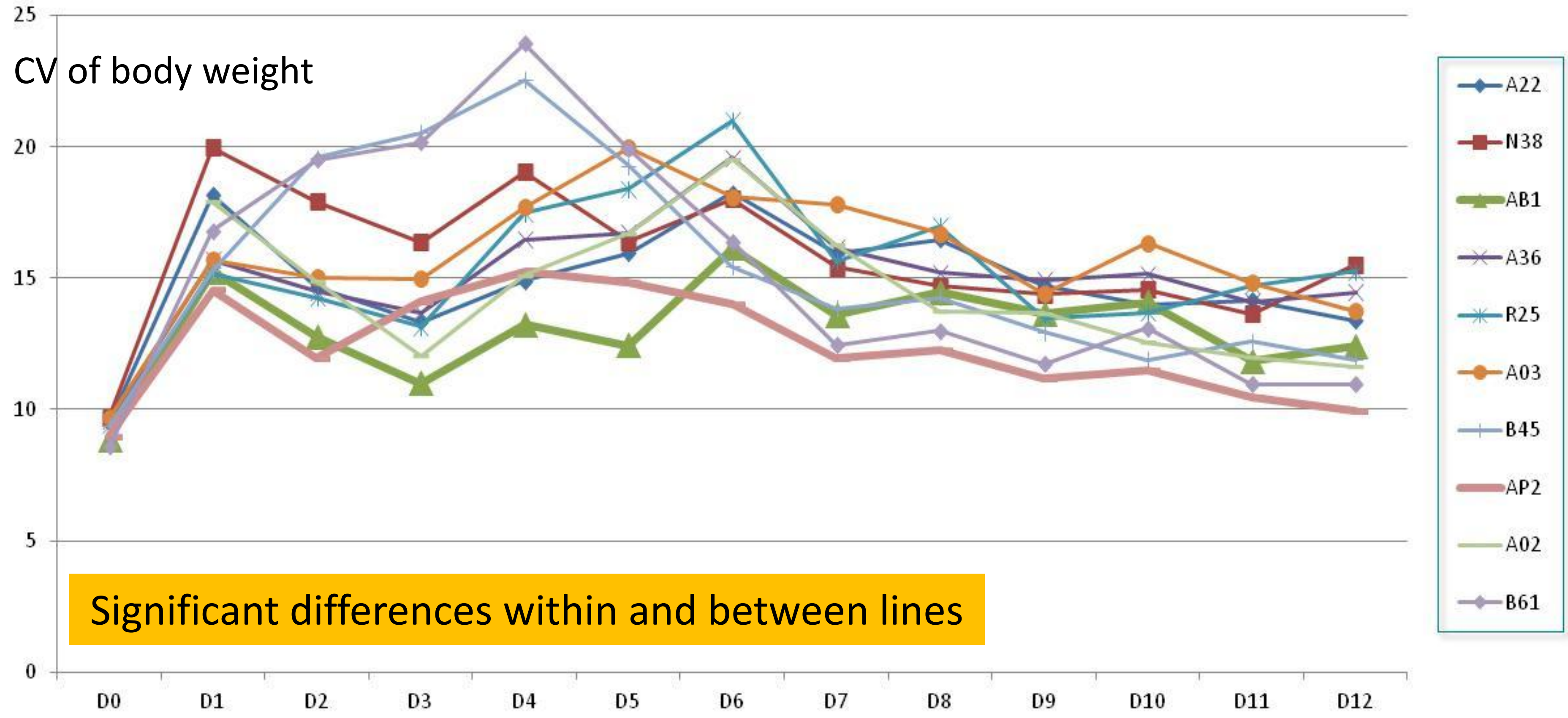
The total phenotypic variance (Vp) of a population is the sum of the genetic variance , of the environmental variance and of the gene-environment interaction

$$V_P = \cancel{V_G} + V_E + 2\cancel{Cov}(G,E)$$

Phenotypic variability of isogenic lines is a direct measure of its sensitivity to the environment (i.e. phenotypic plasticity)

Coefficient of variation (CV): defined as the ratio of the standard deviation (sigma) to the mean (mu)→ It allows to compare the degree of variation from one sample to another, even if the means are different.

In less environmental sensitive animals we would expect a lower coefficient of variation



Improving animal adaptation

Adaptation…. to what?

Heat stress

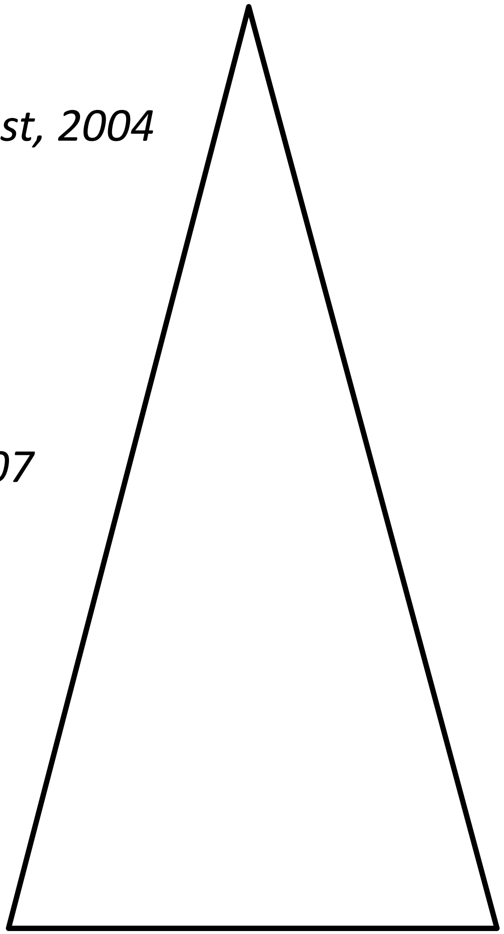
Lamont et al., 2014; West, 2004

Differences in housing conditions

Star et al., 2007

Global Climate Change

Misra and Dei, 2014



Adapted animal.... to what?

Global Climate Change

Housing conditions

Heat stress

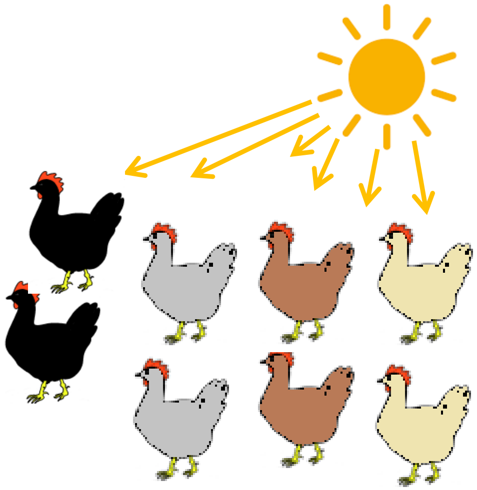
We need to decide for what we want to improve animal adaptation

The "super animal" does not exist yet

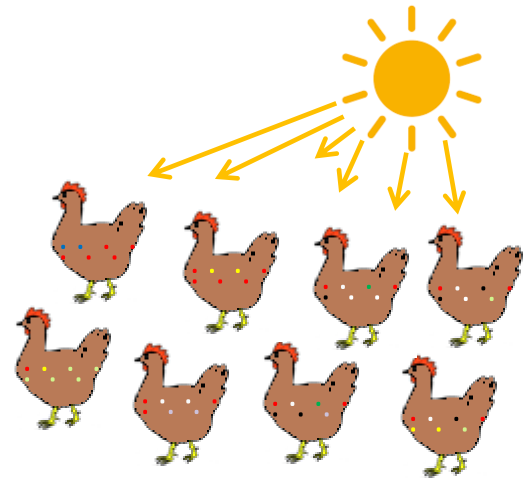
The genetic approaches to improve adaptation

Different adaptive capacities exist because genetic diversity exists

Among breeds



Within breed

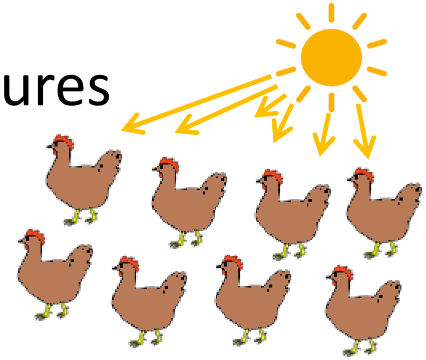


An example from fish

Different adaptability for vegetable based feed

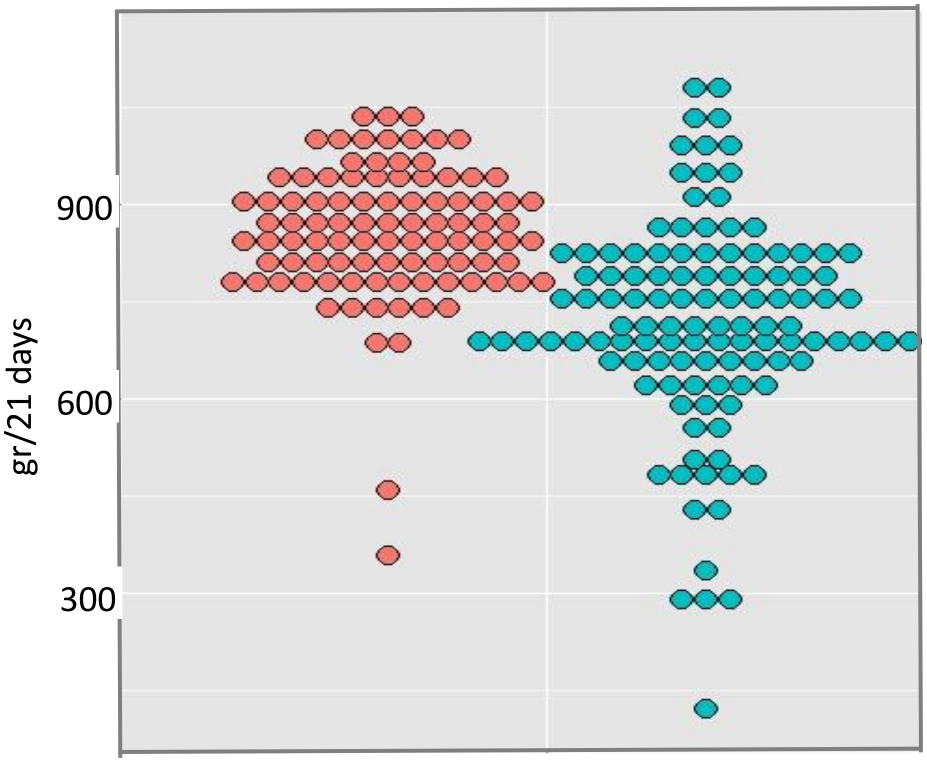
An example from chicken

Within breed diversity



Different adaptability to high ambient temperatures

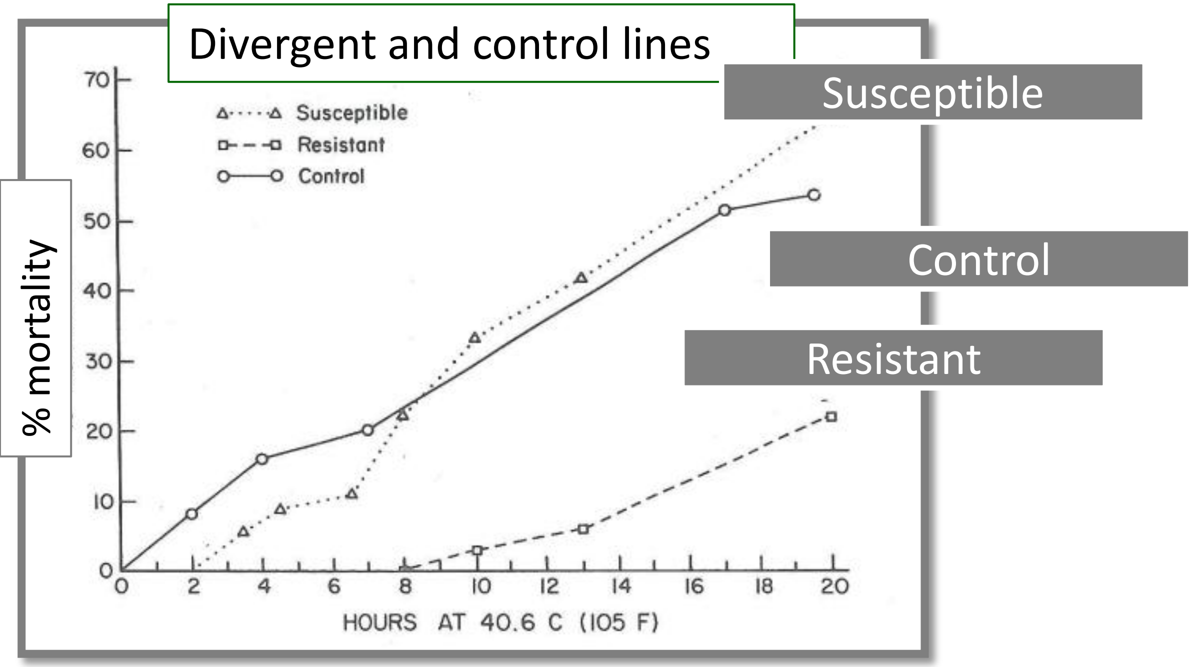
Feed intake records



Zerjal et al. unpublished data

Examples from chickens

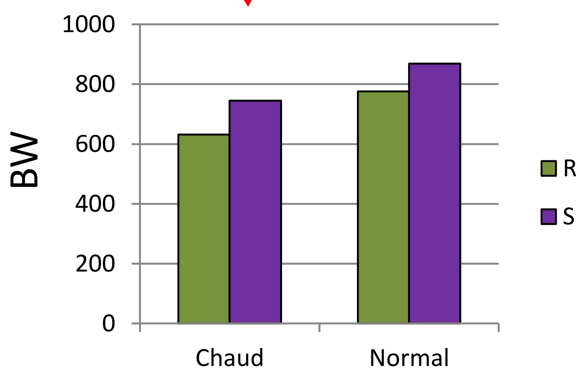
Young White Leghorn selected on time of survival at 41°C
Heritability : 0.31



Wilson et al., 1975

Tolerance to heat stress (resistance) can be genetically selected but...

Attention!!!



The most resistant is not the most productive under warm environment

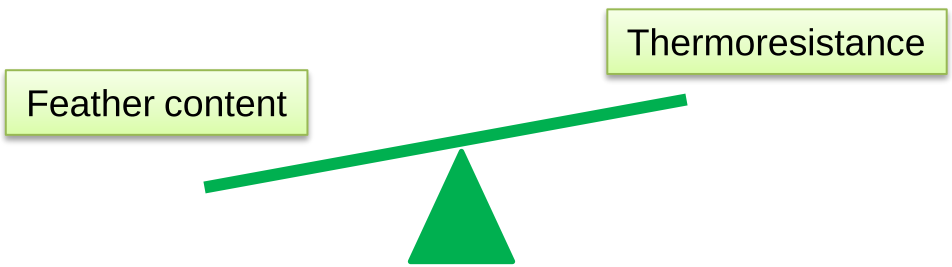
Animal genetic improvement for heat tollerance

Effect of major genes

Frizzle

Naked neck

Scaleless *(Cahaner et al. 2008)*



The capacity of thermoregulation is increased thanks to a more efficient dissipation of body heat

Several studies have shown an increased resistance to heat

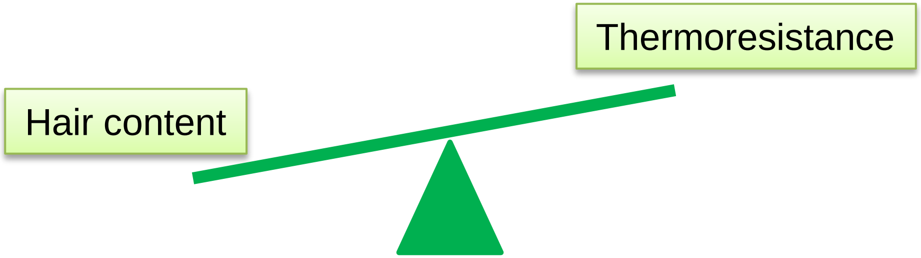
Example from cattle:

The slick hair coat (SLICK) gene:

- Short, sparse hair phenotype
- Common in tropical cattle breeds
- Associated to improved thermo-tolerance

introgressed →

Holsteins



Slick coat Holsteins have:

- Improved capacity of body temperature regulation
- Higher milk yield under heat stress

Dikmen et al.,2014

Breeding to improve production traits

Animal genetic improvement for production traits

Breeding objective
(increasing the economical productivity of an animal)
Beef cattle : growth

↓

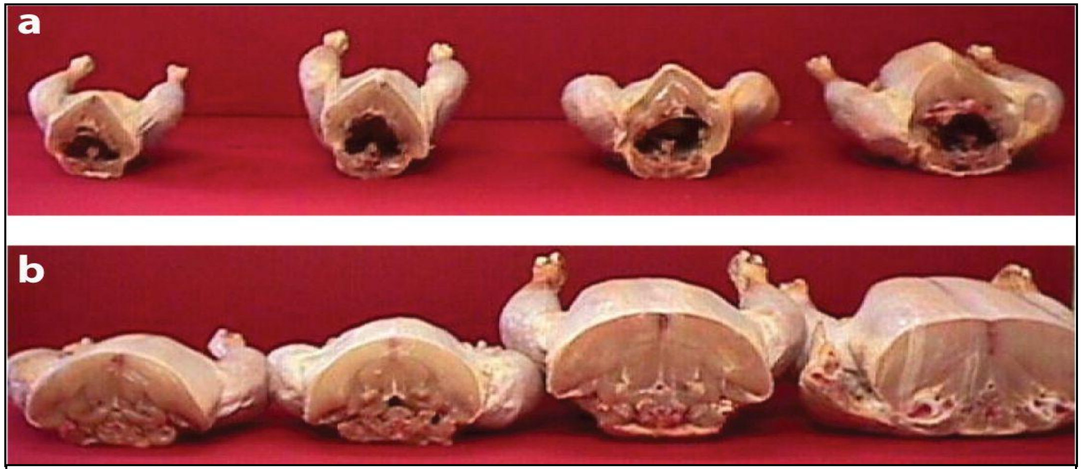
Selection criteria : body weight
- *related to the breeding objective*
- *easy (and cheap) to measure*
- *known genetic determinism (heritability , QTL,…)*

↓

Breeding value
- *BLUP (performance plus pedigrees)*
- *Genomic selection (SNPs)*

Historic breeding goals

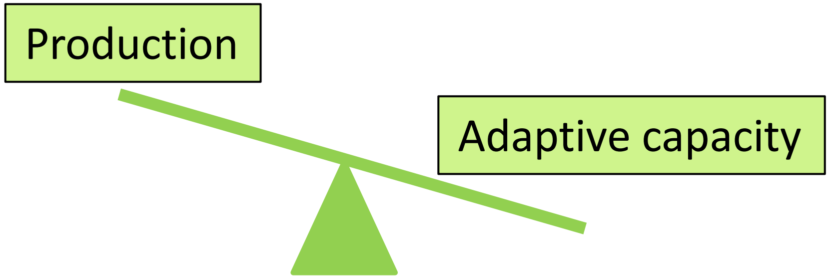
- Growth
- Yield
- Efficiency

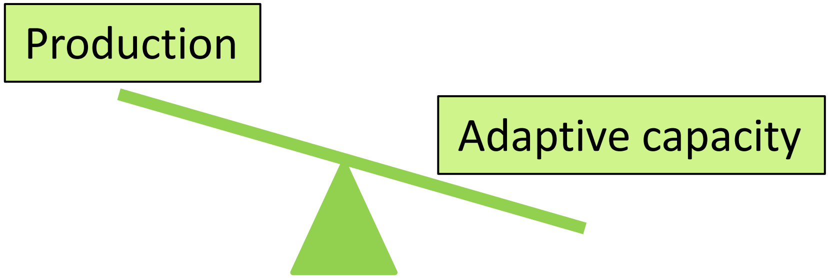


Contemporary comparison of (a) 1957 Control and (b) 2001 Selected broiler carcasses slaughtered at 43, 57, 71, and 85 days, from left to right (Hill & Kirkpatrik, 2010)

→ Animals with outstanding performance under optimal farming conditions

→ Animals more sensitive to variability in the farm environment





The example of feed efficiency

Selecting to improve feed efficiency without affecting production levels

Feed Efficiency

Input (Feed)

Output (Products)

Feed efficiency

low-efficient animals

Observed FI

>

Predicted FI

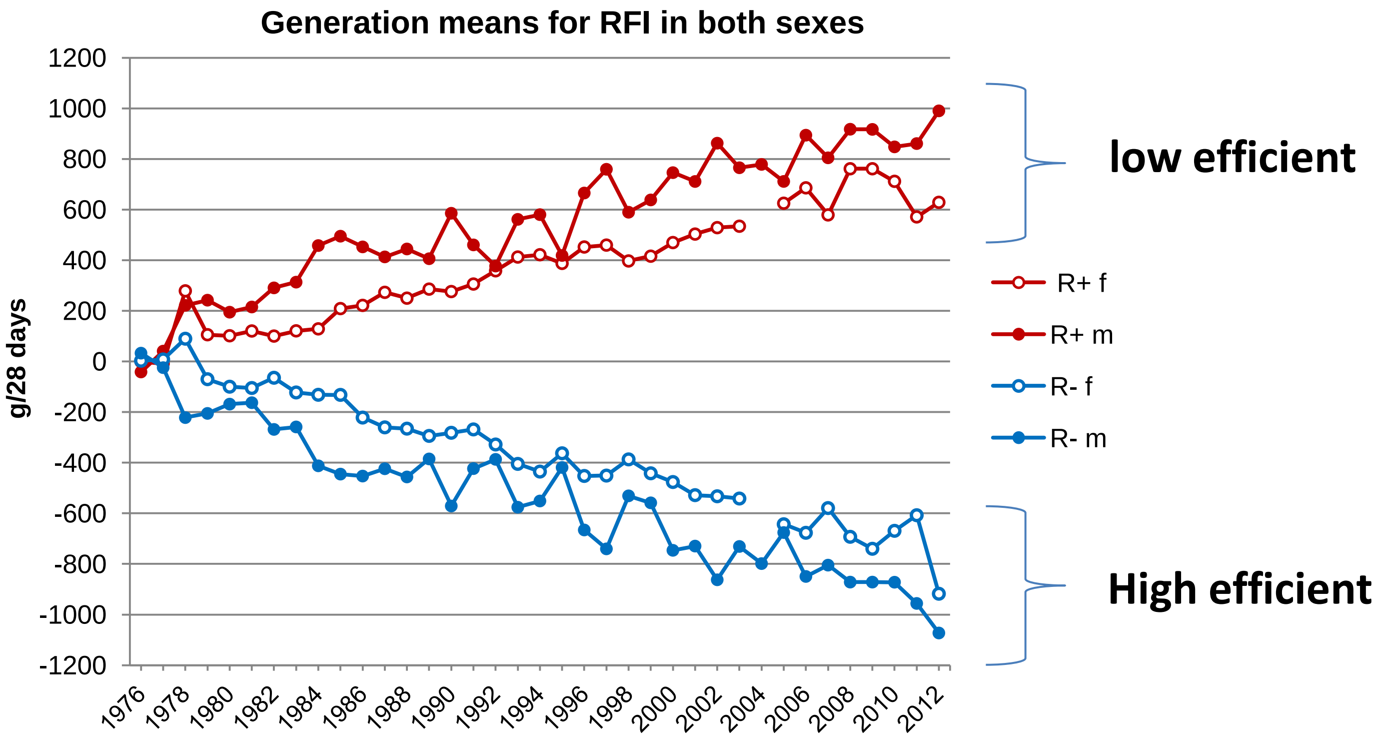
high-efficient animals

Observed FI

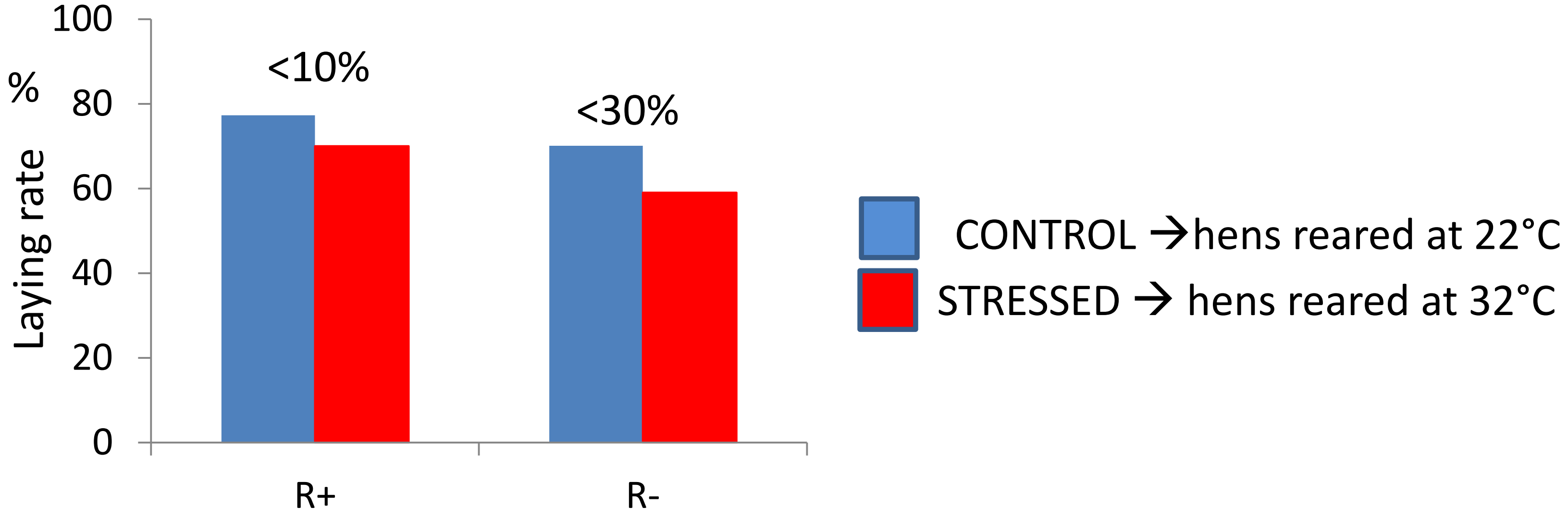
<

Predicted FI

High efficient and low efficient chicken lines



Heat stress test



The high efficient line is more sensitive to environmental changes

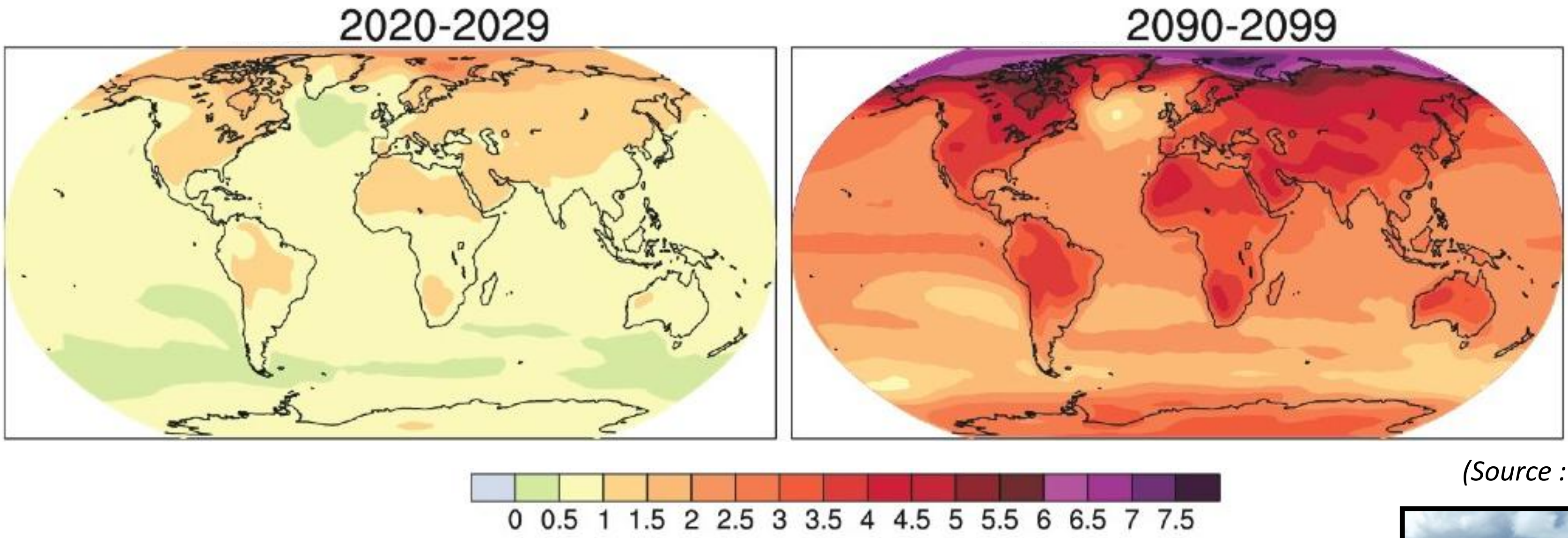
⇩

Different allocation of resources between lines

Breeding to improve robustness in the light of environmental change

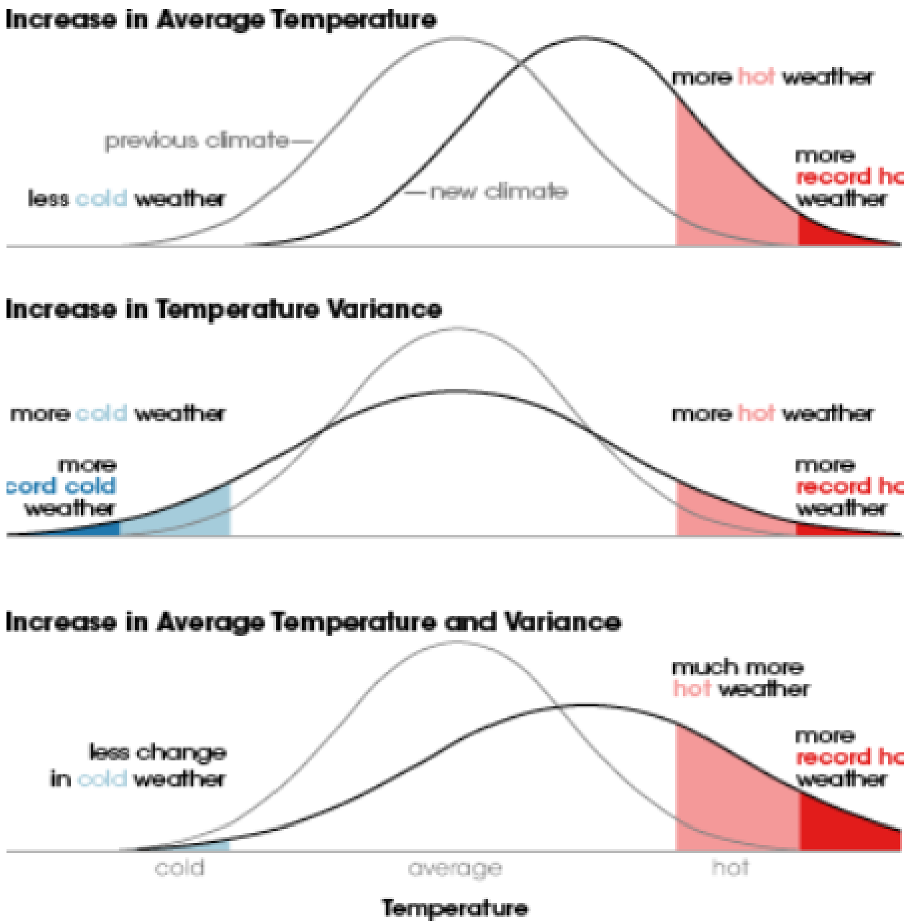
Why is it important to improve adaptation to hot climates?

An increase of global average surface temperature of 1-5 °C (according to various climatic scenarios) is expected by the end of the century



(Source : IPCC 2014)

Climate Change



http://earthobservatory.nasa.gov/Features/RisingCost/rising_cost5.php

From Gwendal Restoux 2016

Direct and indirect consequences of climate change

Change in climatic conditions

- Temperature
- Humidity

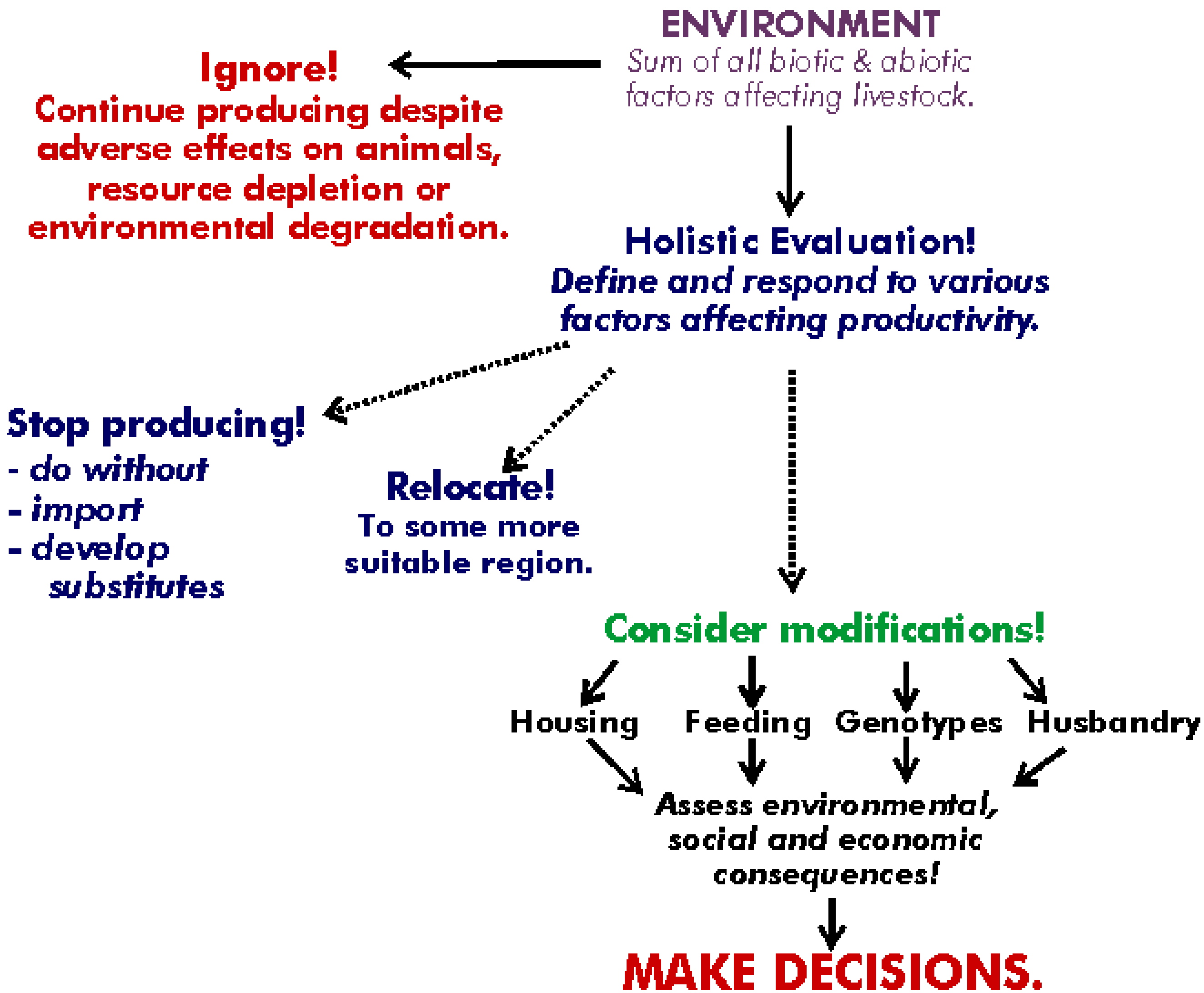
More frequent extreme climatic events

- Unpredictability of environment

Change in other organisms environment

- Food supply
- Modification of diseases distribution and their vectors

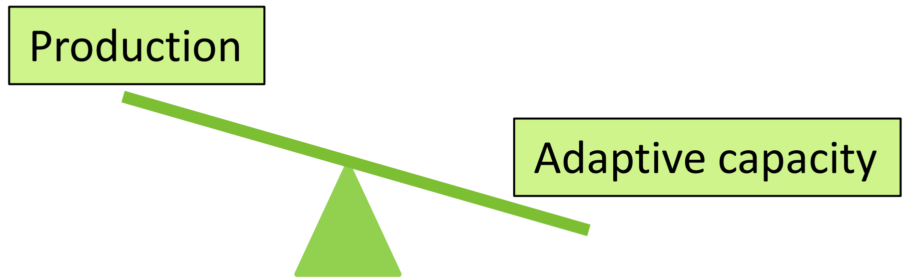
Options to cope with climatic change



From Gwendal Restoux 2016

New selective breeding strategies

Historic breeding goals
- Growth
- Yield
- Efficiency



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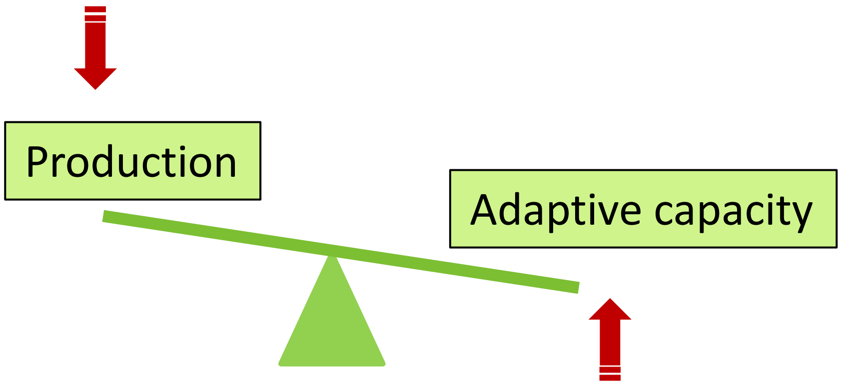
New breeding goals
- Robustness
- Resilience
- Disease resistance
- Welfare
- Food quality
- Fertility
- Behaviour
- …



Why selecting for adaptive traits is harder than selecting for production traits?

i. e. higher temperatures, lower quality diets , greater disease challenge etc.

Not a simple breeding objective

- *Antagonisms with production traits*
- *Long terms breeding objectives →*
  No short-term economic gain

↓

Selection criteria : What Adaptive trait?
How to measure it (what phenotypes)?
Genetic determinism not always well known

↓

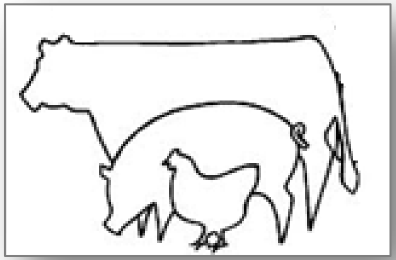
Genetic prediction

- *BLUP*
- *Genomic selection*

New phenotypes to better understand animal adaptation

Environmental stressor

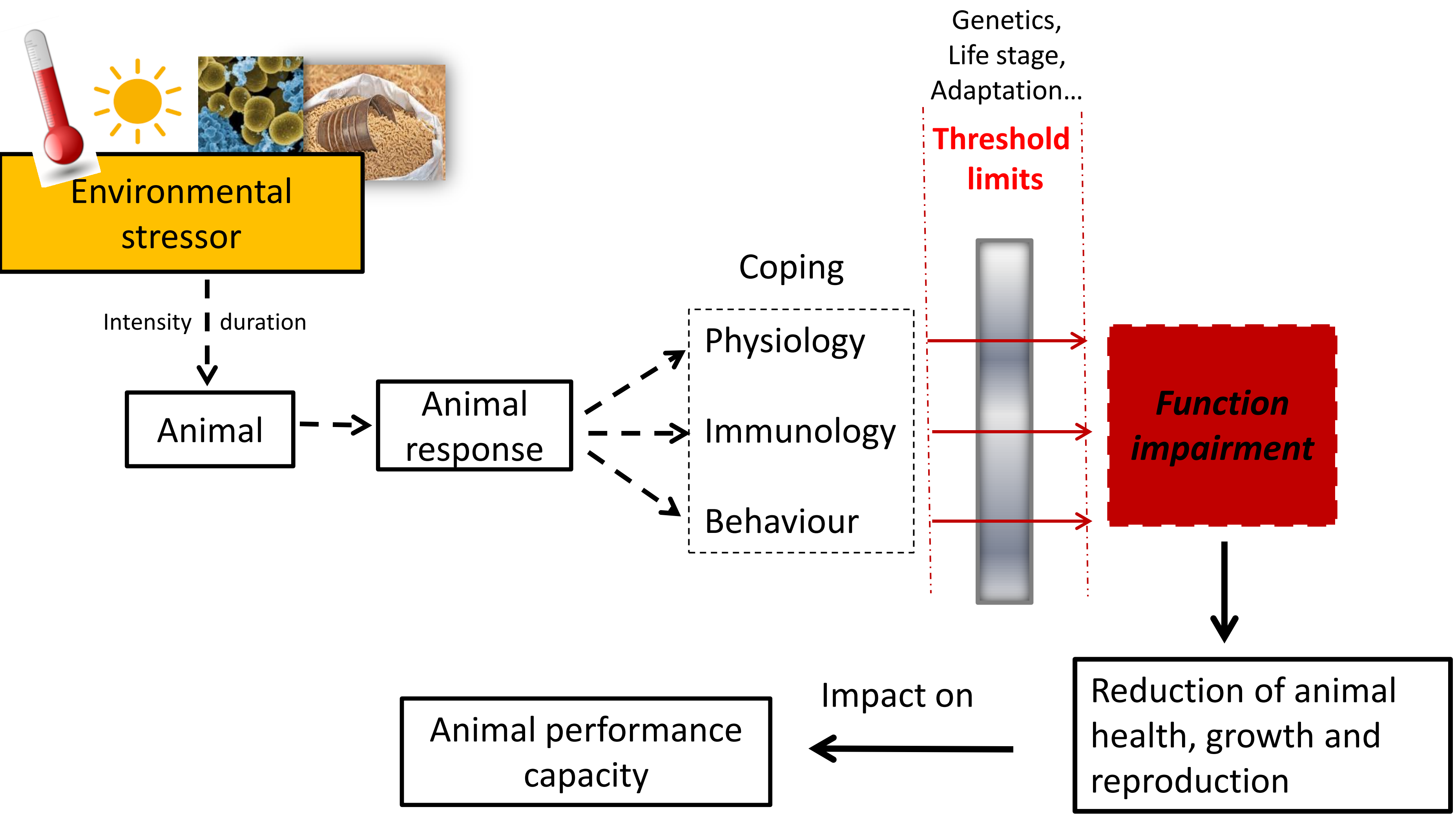
Quantify the impact



Measure the reaction

Animal adaptive capacity

Animal response to a stressor



Adapted from Hann and Becker, 1984

Environmental stressor

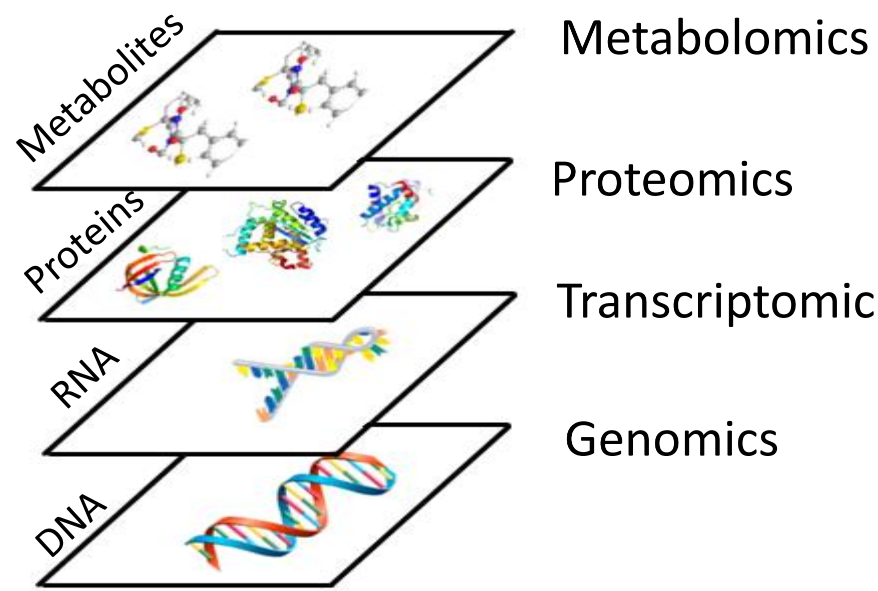
It is necessary to:

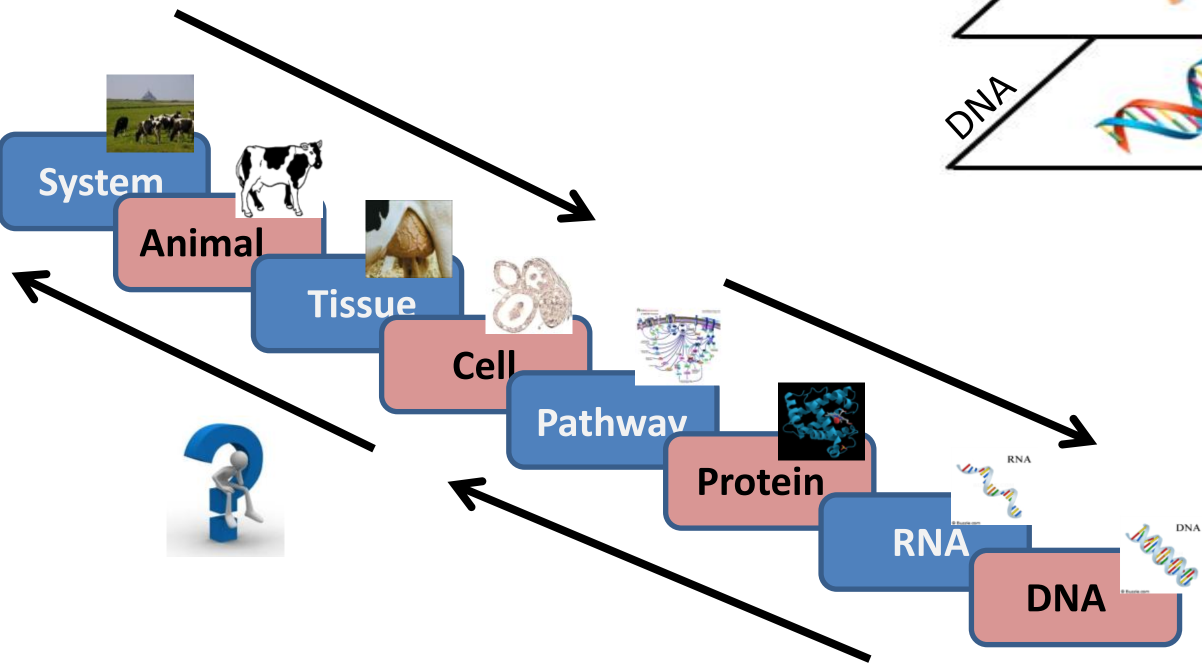
- Improve the understanding of the physical and biological mechanisms to be able to dissect complex phenotypes into individual components
- Improve the phenotyping strategies to better predict or measure phenotypes

Necessary to focus on new (and complex) traits

New phenotypes to better understand animal adaptation

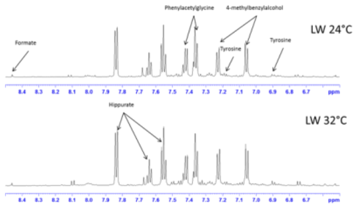
The “omics” revolution



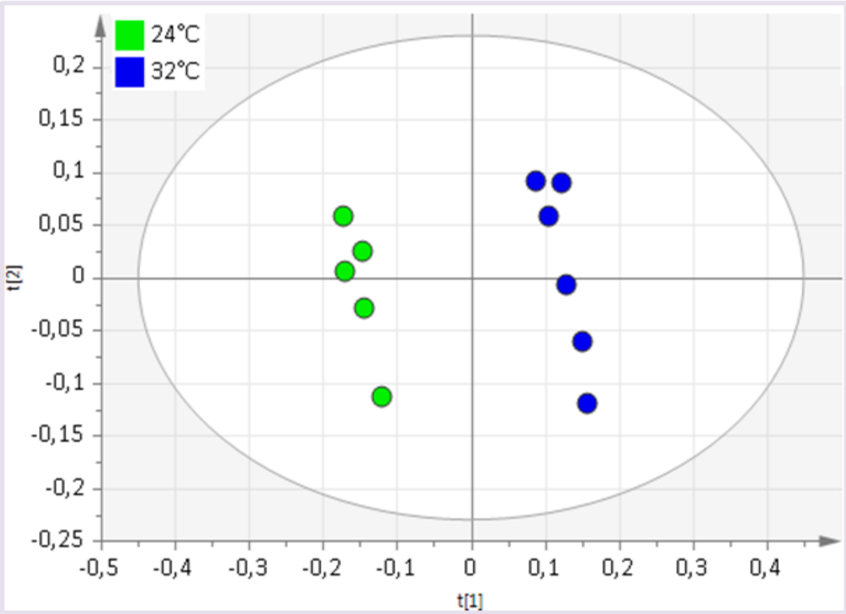


Example of traits for phenotyping heat tolerance in pigs

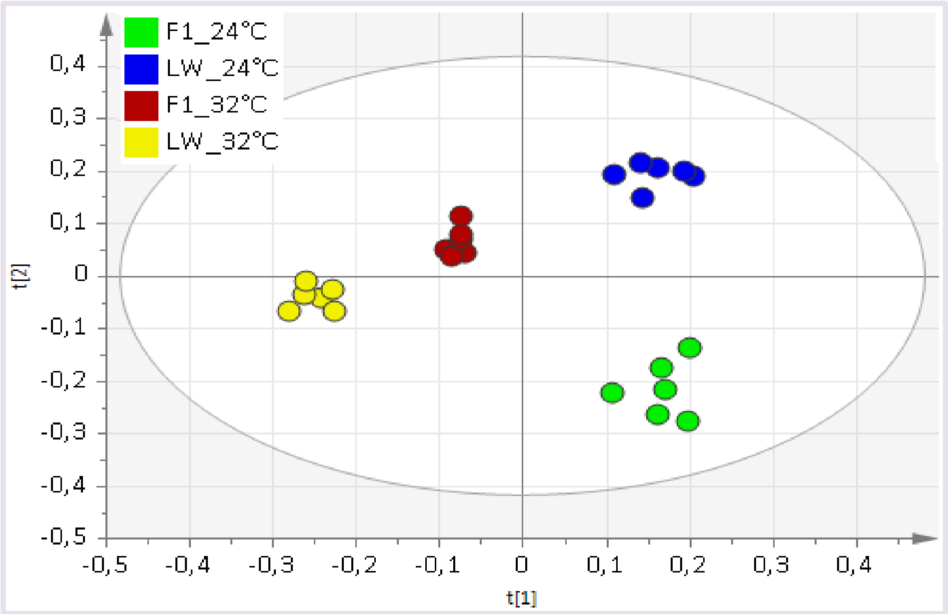
Metabolome from plasma or urine



Plasma (dispositif 2)



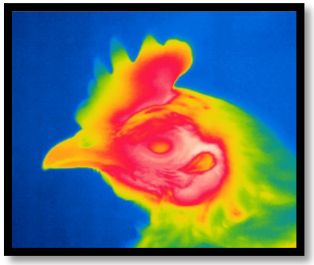
Urine (dispositif 2)



INRA on-going experiments (Renaudeau, Canlet, Labrune, Riquet, Gourdine et al)

New technologies for new phenotypes

Image analysis techniques



To measure
- body temperature
-body tissue reserves

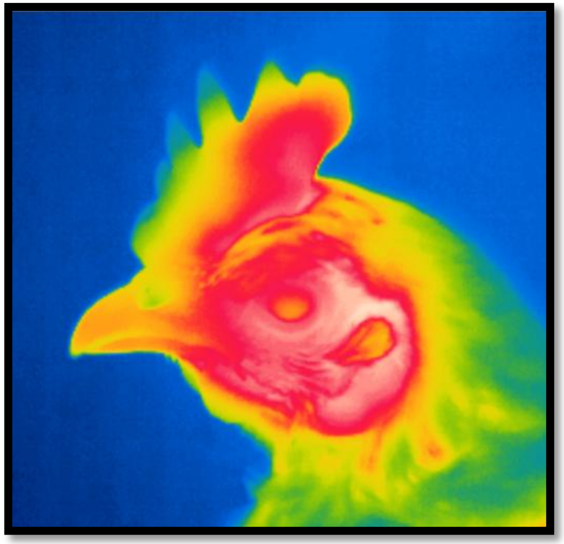
Electronic devices

To measure
-physiological status
-activity parameters

New technologies for new phenotypes

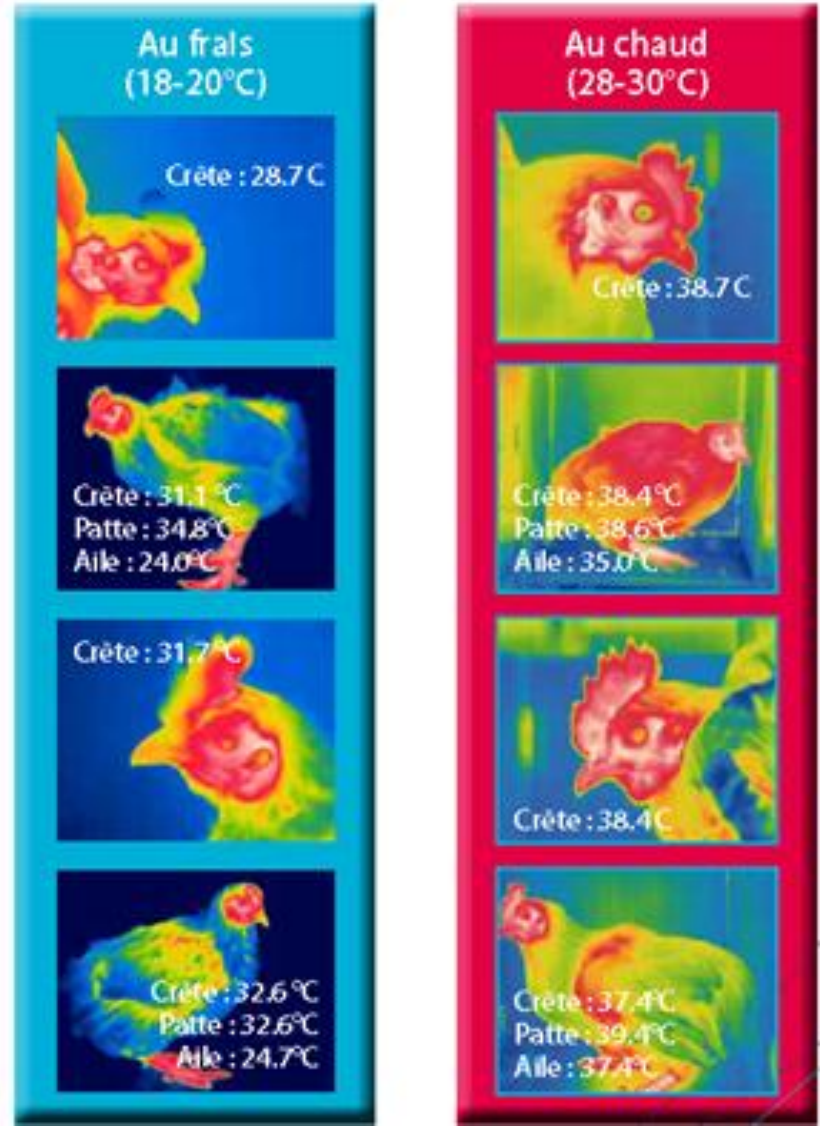
Example from chicken

Image analysis techniques
infrared thermography

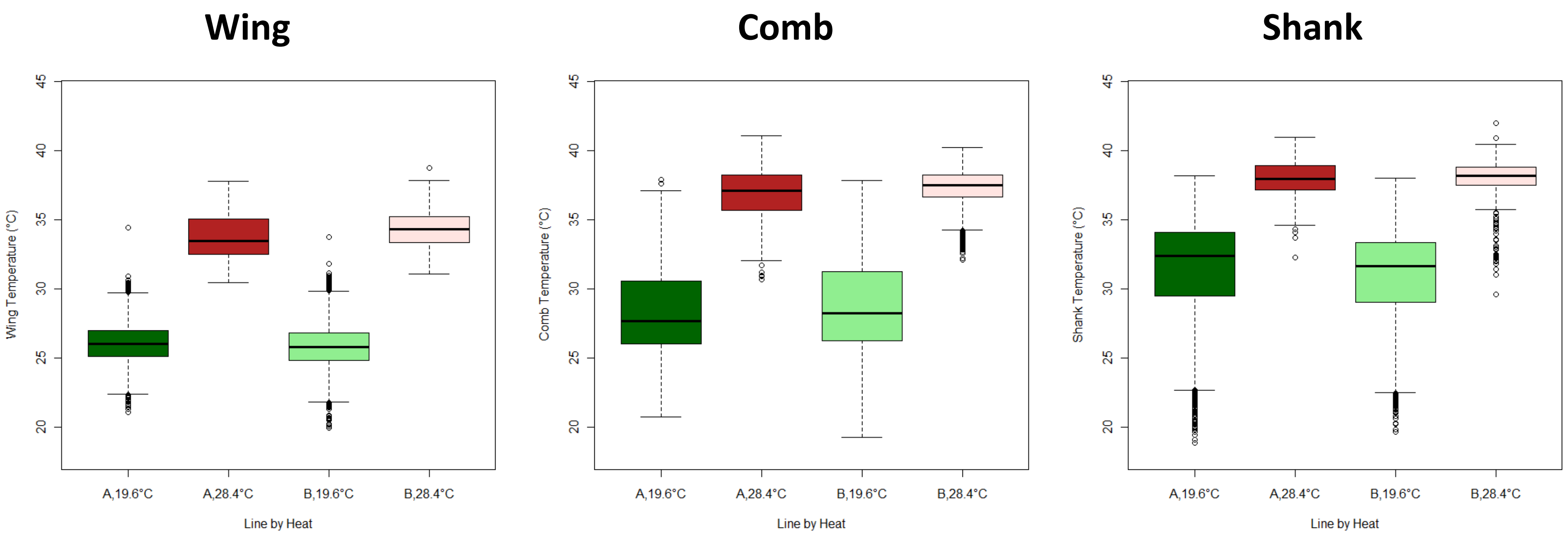


Infrared camera

It allows to measure temperature differences at the body surface



S. Grasteau and T. Zerjal

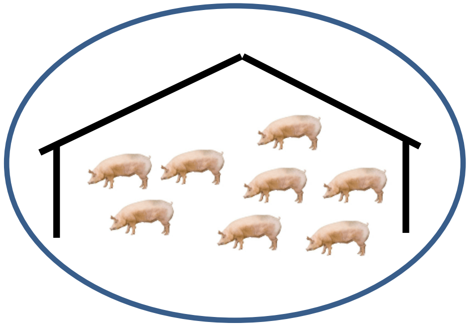


28.4°C

19.6°C

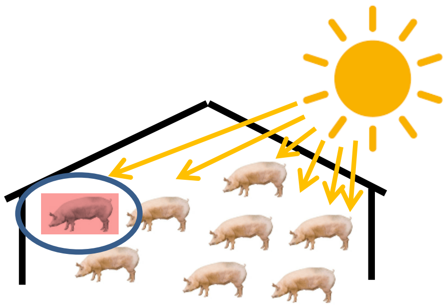
- Increase in mean values (+20.6 to +32.6%)
- Reduction in variability in the comb (-9.8 to -18.2%) and in the shank (-57.5% to -64.7%)

New technologies for new phenotypes



At the farm level

Acquire precise measurements of the animal production environment (farm microclimate)



At the management level

Develop management strategies for helping the farmer to manage their livestock better :
« Precision livestock farming » concept

Future management
Specific to the animal which really needs to be treated

→ Automatic measurements to ensure a constant monitoring for an early problem detection

→ Focus on phenotypes which allow to anticipate/ to identify at-risk animals

Summary

- Natural Selection acts on whatever variation is present at the time. This variation is generated randomly with respect to selection pressures
- Selection can be directional, stabilizing or disruptive
- Natural selection can operate so quickly that we can observe it in a single generation

Summary

- Animal adaptive capacity can be improved using genetic/genomic approaches
- There is the necessity to identify adaptive related traits that are relevant, simple, sensitive and reliable.
- The mechanisms of adaptation are complex and further studies are required to understand underlying mechanisms -> biomarkers

Acknowledgments

Sandrine Grasteau
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David Renaudeau

For further discussion and presentations on the adaptation of animals and farming systems to the effects of climate change visit the RECOLAD web-site:

https://www6.inra.fr/recolad_eng

Thank you for your attention