



HAL
open science

Selective Breeding - Lessons learned from terrestrial animals and status of aquaculture implementation

Marc Vandeputte

► **To cite this version:**

Marc Vandeputte. Selective Breeding - Lessons learned from terrestrial animals and status of aquaculture implementation. Aquaculture Europe 2011 "Mediterranean Aquaculture 2020", Oct 2011, Rhodes, Greece. 47 diapositives. hal-00999948

HAL Id: hal-00999948

<https://hal.science/hal-00999948>

Submitted on 5 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

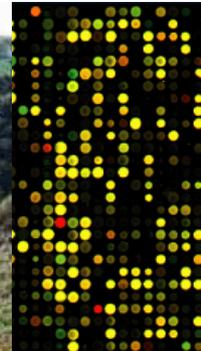
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Selective Breeding – Lessons learned from terrestrial animals and status of aquaculture implementation

Marc Vandeputte

INRA UMR1313 Animal Genetics and Integrative Biology, Jouy en Josas, France
Ifremer UMR110 Intrepid, Palavas les Flots, France



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT



Selective breeding ?

➤ The visible part: specific breeds (for specific uses)



Eggs

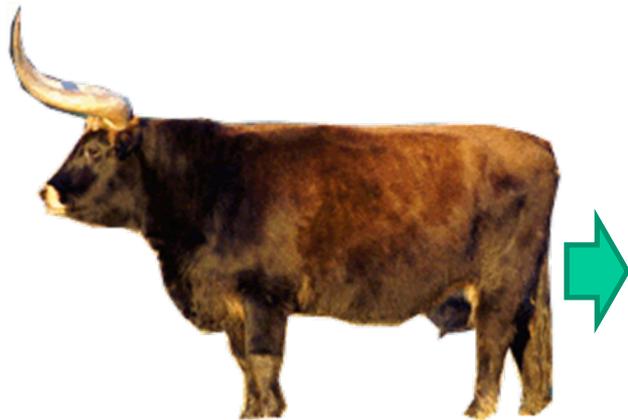
meat

dual

exhibition

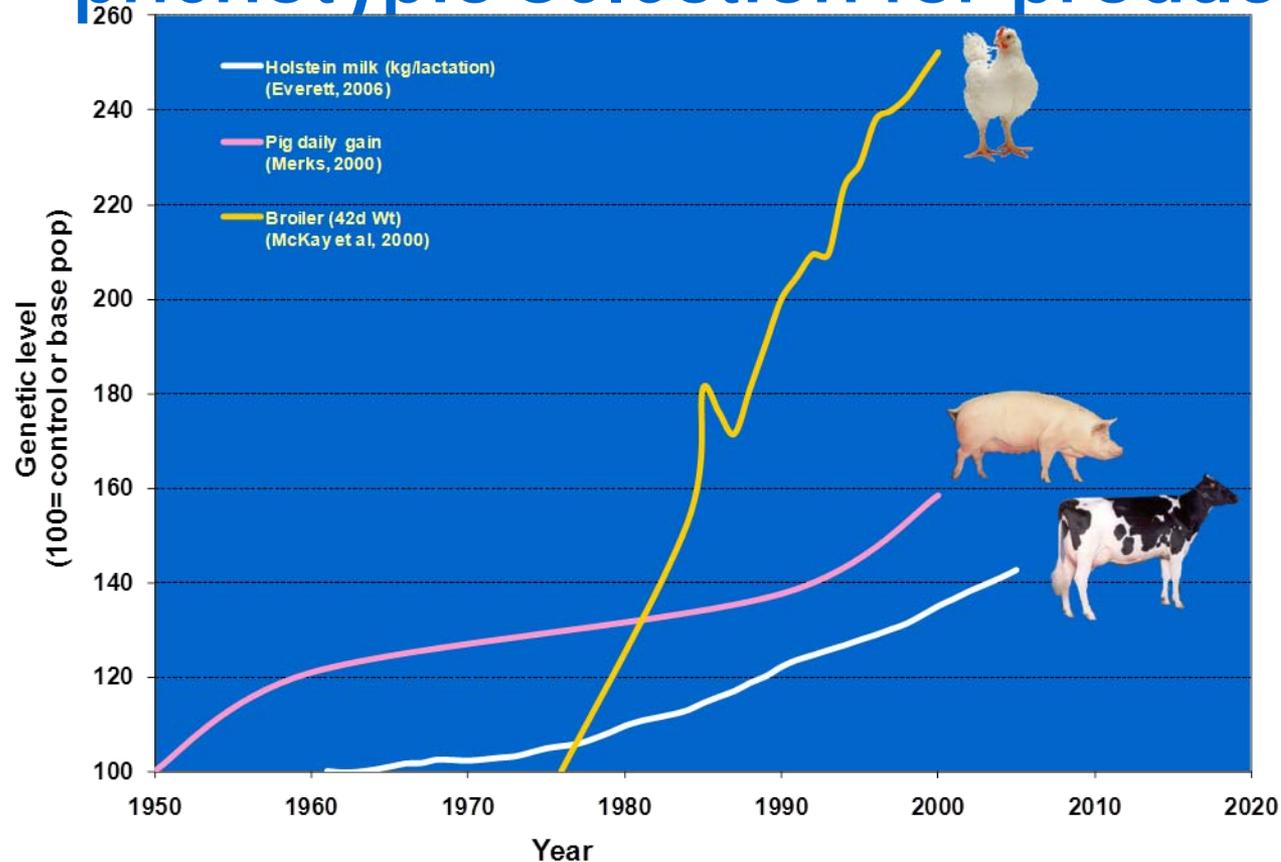
game

Not visible today: domestication



Domestication: 8000 BC in Asia
Last wild aurochs: 1627 in Poland

Not easily seen but with major impact: phenotypic selection for productivity



A progressive,
directional
process

Can be impressive when you can compare !

➤ Comparison of 1957 and 2001 broiler strains

1957



➤ Body weight
810g → 3950g

➤ Carcass Yield
60.8% → 74.4%

➤ Breast Yield
11.4% → 21.3%

Day 43

Day 57

Day 71

Day 85

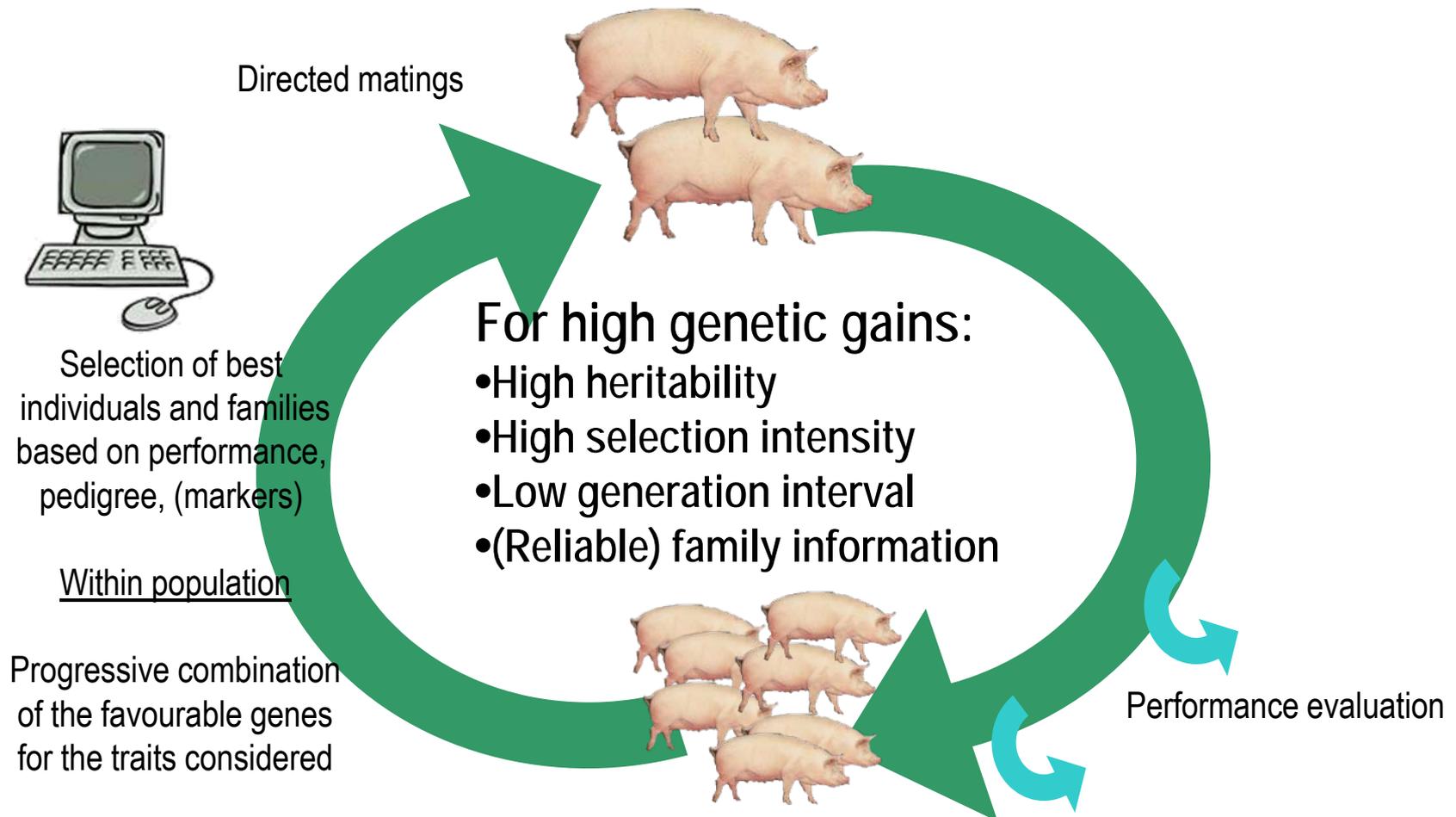
2001



All were fed 2001 feed

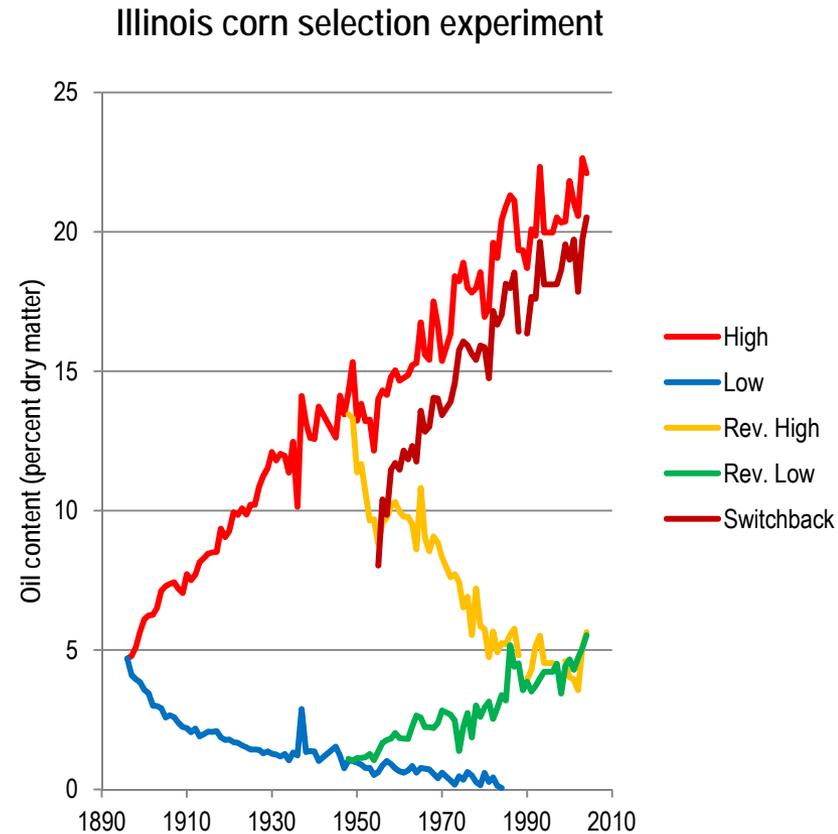
Havenstein, 2006, Lohmann Information 41: 30-37

How does selective breeding work ?



Major facts about selective breeding

- Any trait can be selected for (growth, processing yields, shape, fat %, disease / stress tolerance,...)
 - ➔ can shape the animal to a desired standard
- Gain is incremental over generations
 - ➔ what is gained is gained
 - ➔ there is no limit except fitness
- Possibility to make the breeding objective evolve
- Phenotypic selection: no need to know about the genes implied !



Data from Department of Crop Science. University of Illinois



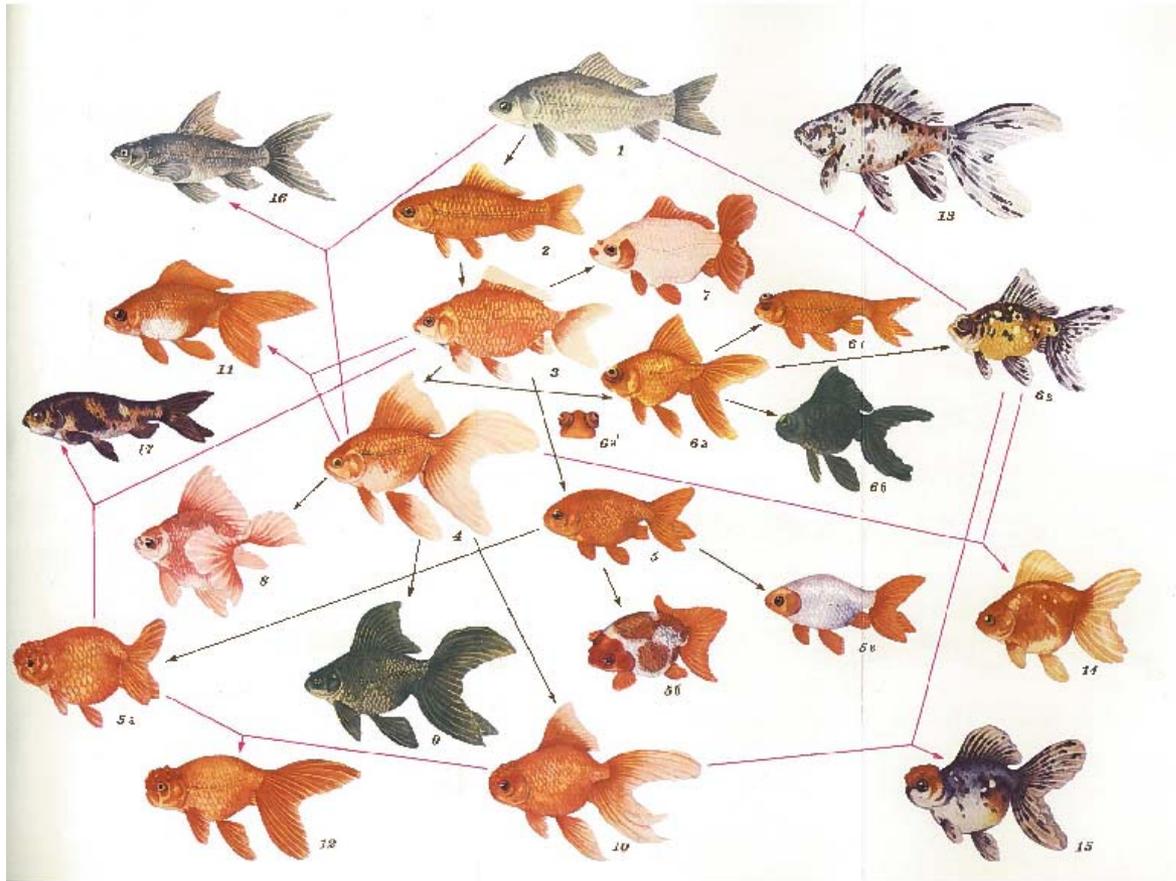
SO...WHAT ABOUT FISH ?



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

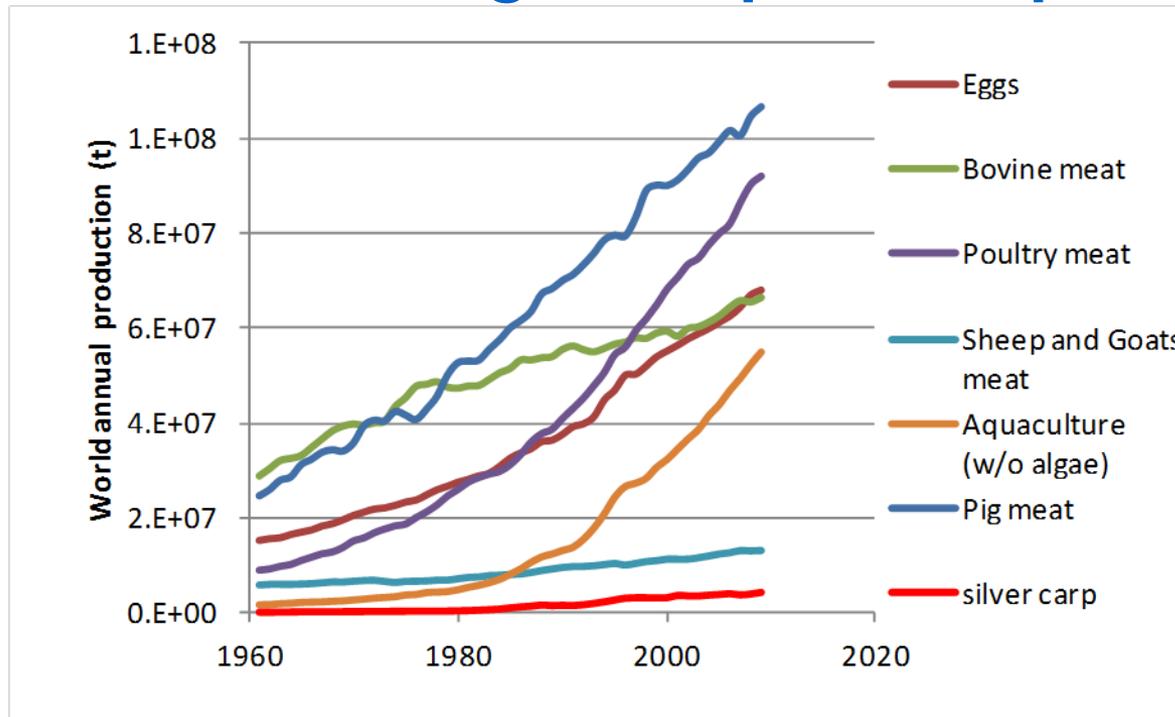


Genetics theory is the same in fish!



Kirpichnikov, 1987

Aquaculture : a global protein provider



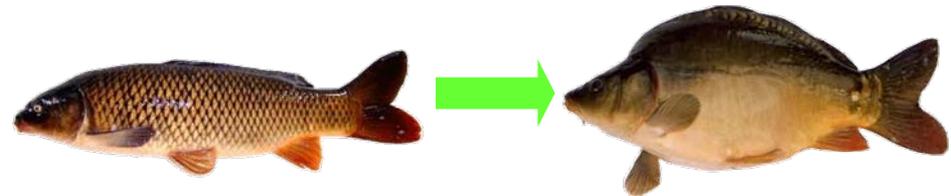
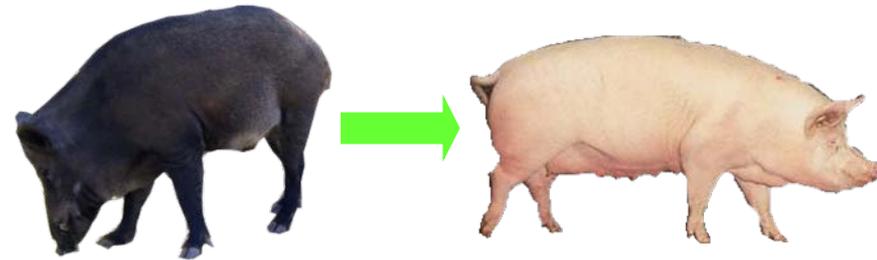
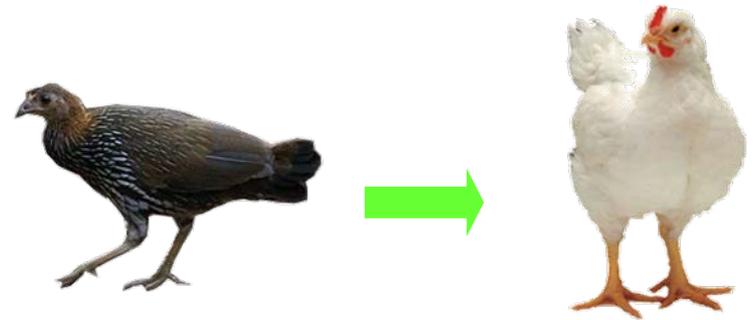
➤ Should be as advanced as land animals but...

- More recent (70's)
- many species (>200, largest= 4MT)

All other farm animals are domesticated and selected

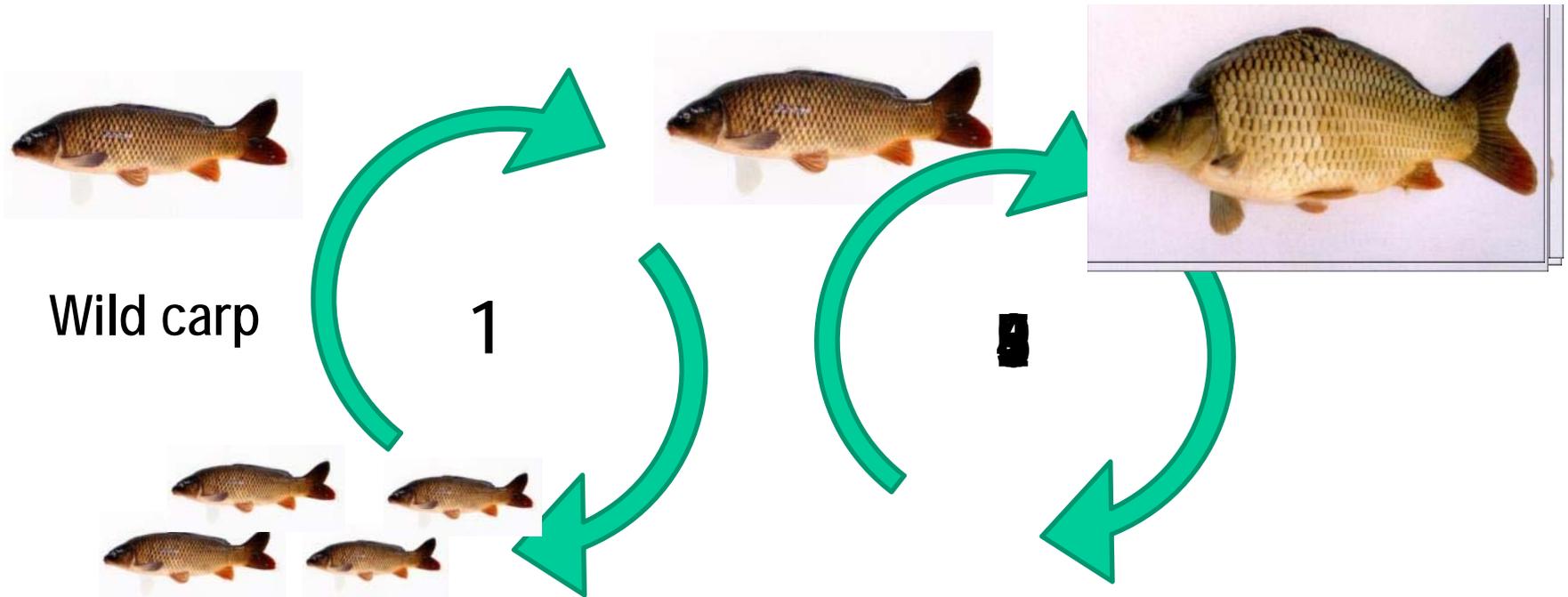
Why domesticate ?

- Limit dependance on natural stocks
- Improve sanitary status of stocks
- Better adaptation to farming
- Model the animal to the market needs (selection)



What about fish ?

How does domestication work ?

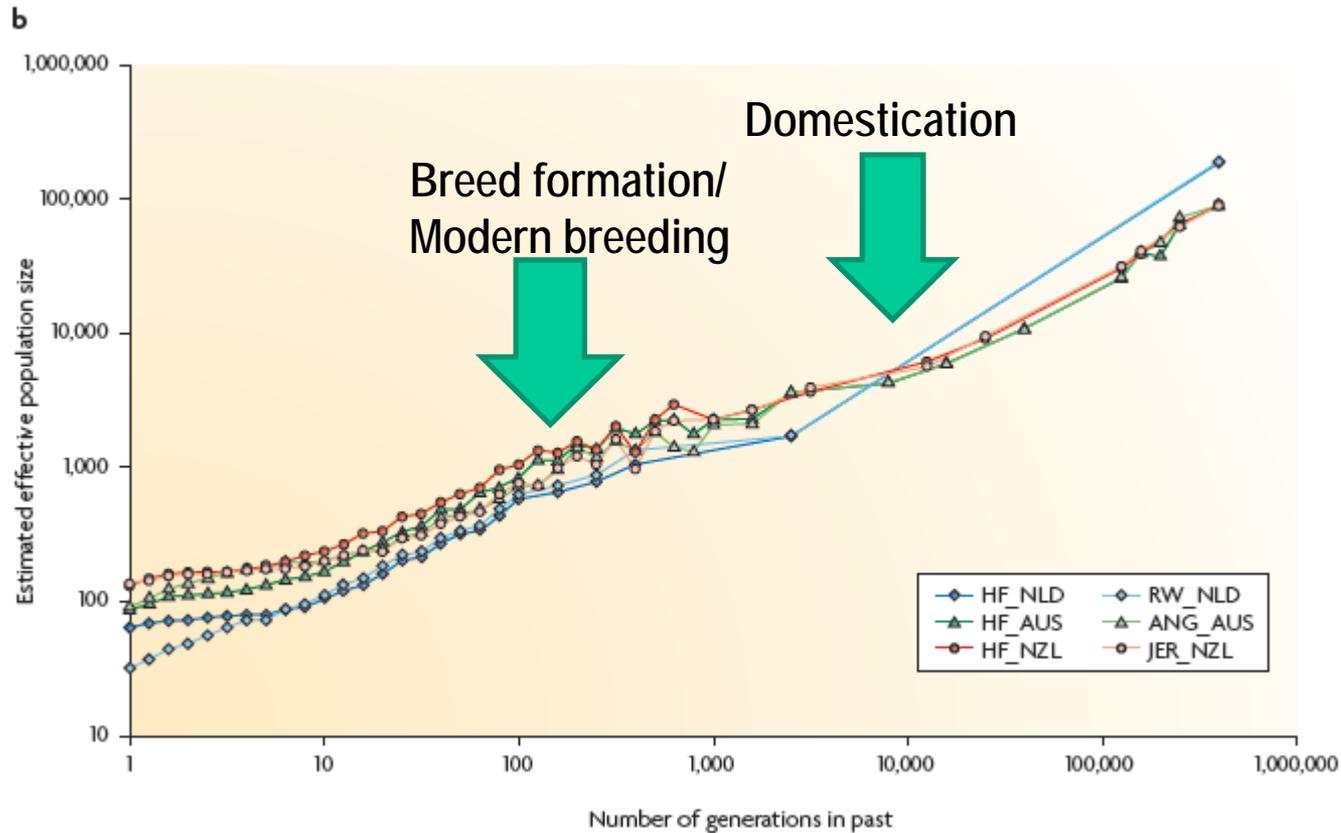


- Need for continuous controlled reproduction (closed population)
- «Natural selection » for captive environment
- Relaxation of natural selection

Pictures: M. Rodina, VURH

Impact of domestication on population size

➤ Domestication in cattle *(Hayes & Goddard, 2009; Roos et al., 2008)*



What will be specific about fish domestication ?

- One cow → 10 calves in a lifetime
- One fish.... 1.000 to 10.000.000 offspring
- ➔ Selection intensity (and speed of domestication) much higher
- In intensive aquaculture:
 - Environments strongly differ from the wild (more selective)
 - Selection of fish breeds is highly concentrated in a few hatcheries
- ➔ Careful management of genetic diversity is essential to avoid detrimental effects of inbreeding

One more specificity: natural populations still exist



Questions and options

- Are selected/domesticated populations a threat to wild populations ?
- Do we have to concentrate on a few species and have global fishes like we have global livestock ?
- Can they become unable to live in the wild ?
- Could we domesticate more local species ?



FISH BREEDING: WHERE ARE WE NOW ?



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT

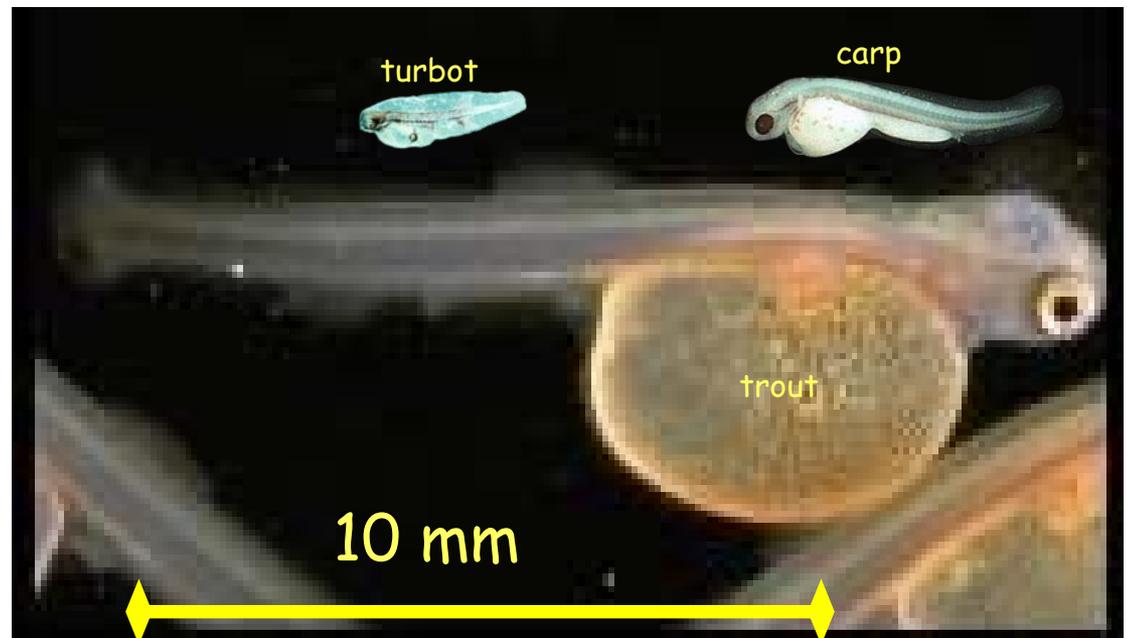


One big problem: getting family information

Hatching size: no tagging possible → no easy pedigrees

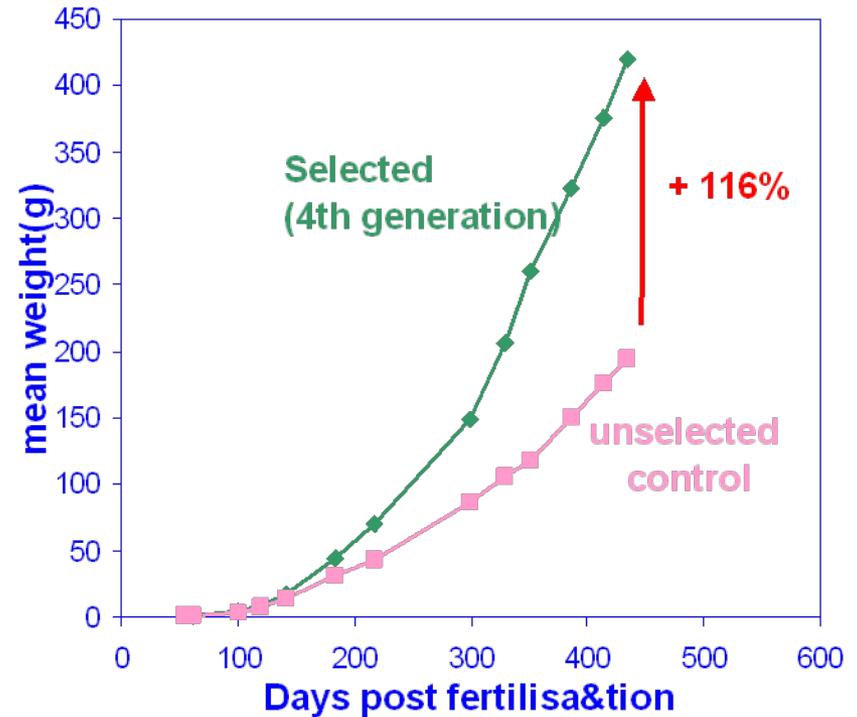
What can we do ?

1. Not use them
2. Use separate rearing
3. Use genotyping



The simple option: individual selection

- Up to +20-30% / generation (growth)
- No side effects on quality
- improvement in FCR ?
- Also possible for fat content, appearance
- Need to monitor inbreeding

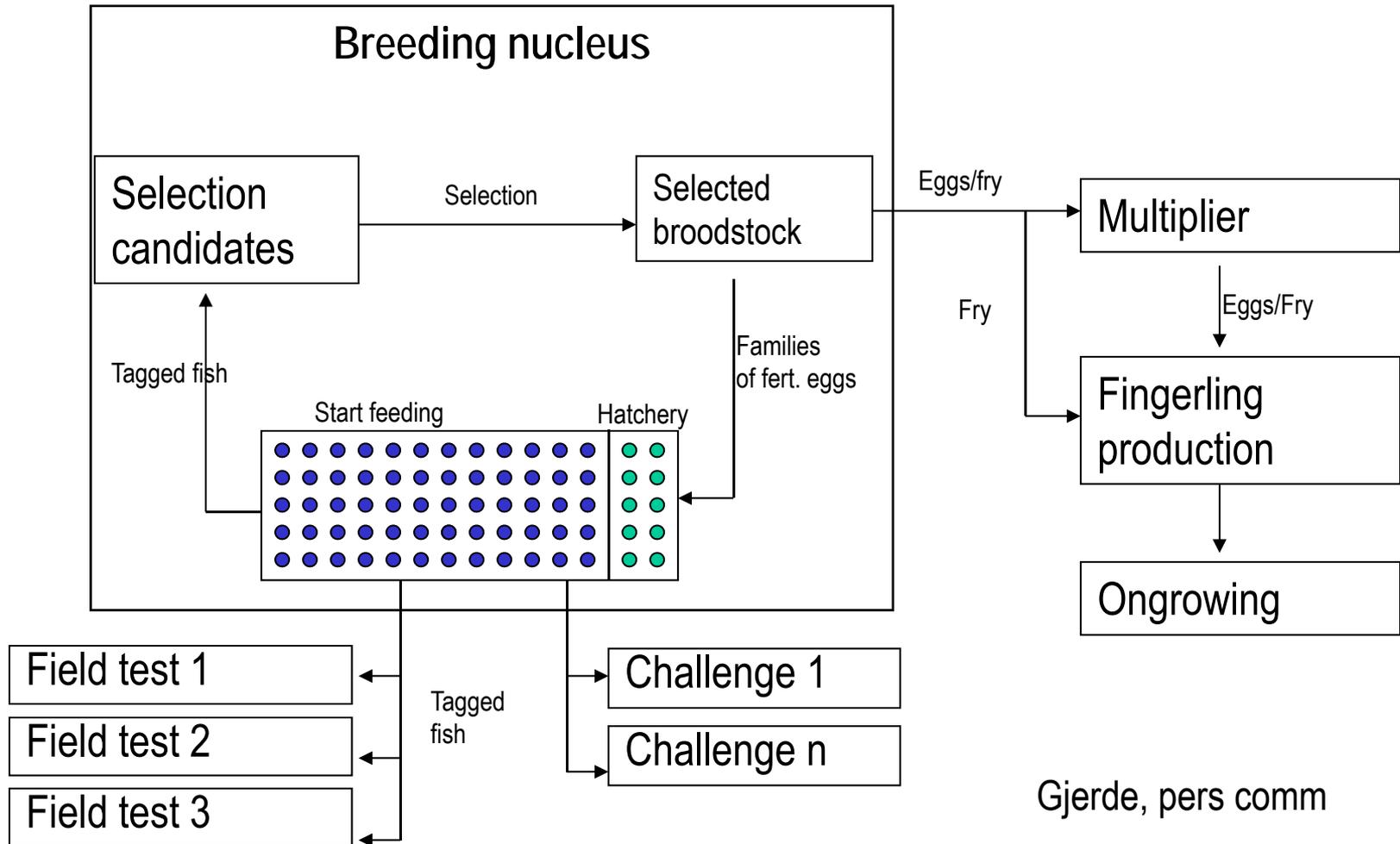


Growth performance of 4th generation
PROSPER selected and control brown trout

Why family information ?

- More precision in identifying the best genotypes → higher gains
- Needed for lethal traits (disease resistance, processing yields)
- Allows inbreeding control

The Norwegian scheme for salmon

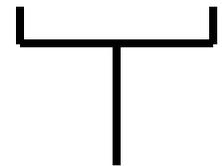
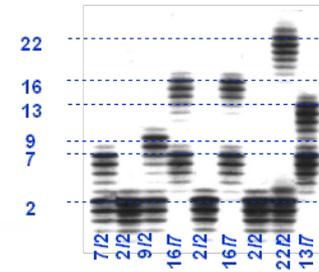


A revolution in fish breeding: parentage assignment

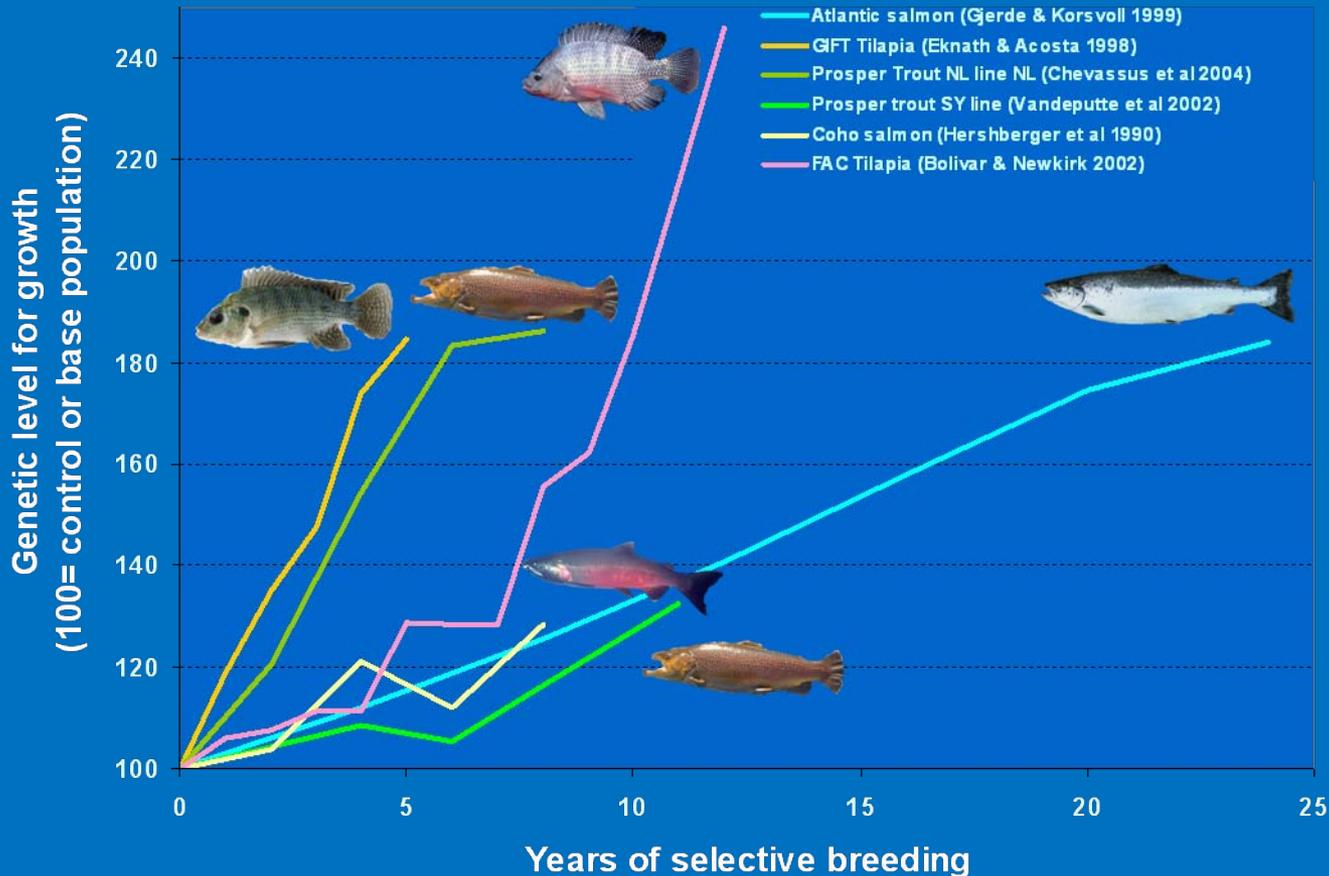
- For access to family information
- Using highly variable markers (microsats, SNPs)
- An alternative to « classical » separate rearing of families (no tank effects)
- Well suited to SMEs



Fin clip
in ethanol 100



Increasing growth: it works well!

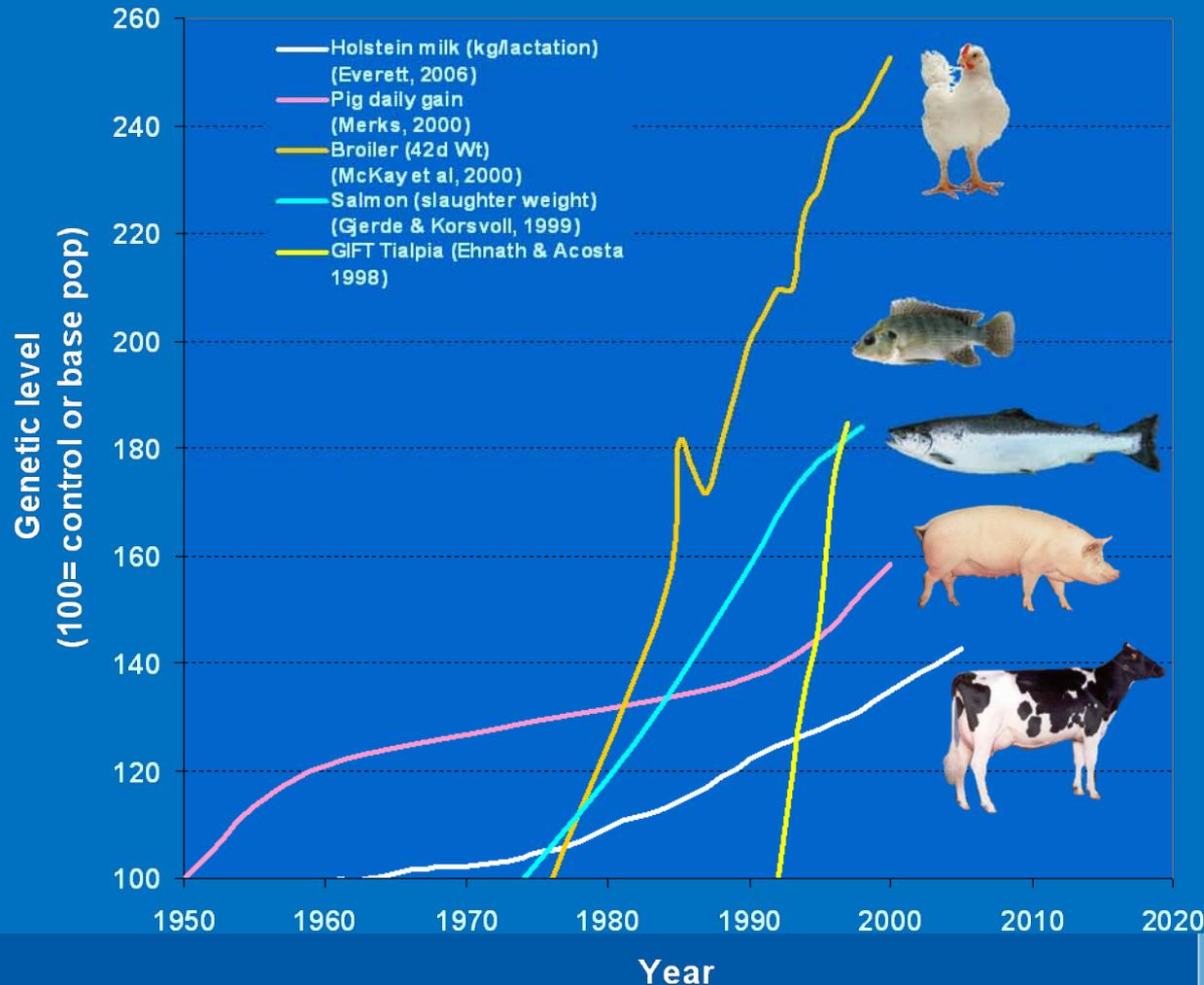


High potential of fish because:

- Often starts from wild (domestication)
- High selection intensities possible

Even higher with tropical species (short generations)

Comparison of genetic gains with livestock



The drawbacks of selecting for productivity

➤ Important problems in birds

- Turkey males too heavy for females
- Lower immune performance
- Defective eggs in broiler strains
- Legs problems and heart failures in broilers

➤ More balanced in pigs and dairy cattle

- Negative impacts on reproductive performance
- Little health effects
- But selection intensity is lower...

➔ We have to be specially careful in fish

How wise is it to increase fillet yield in carp?

- Negative genetic correlation head length/fillet yield



+fillet



-fillet

$R_A = -0.86$

- Selection for smaller head will result in an increase in fillet yield (+1.4% fillet/gen, mean 31.2%)
- Fillet yield is a very profitable trait (net gain) !
- But head (+ respiratory organs ?) will also decrease...
how far can we go ?

Kocour et al, 2007, Aquaculture 270: 43-50

Evolution of breeding goals in salmon

Example of increasing number of traits AquaGen population

Trait	Generation	Year class			
		1	2	3	4
Base populations	0	72	73	74	75
Growth rate	1	76	77	78	79
Early maturation	2	80	81	82	83
	3	84	85	86	87
	4	88	89	90	91
Filet colour/furunculosis	5	92	93	94	95
Fat contents/-distribution	6	96	97	98	99
IPN resistance	7	00	01	02	03

Sonesson & Fjalestad, Aquabreeding 2008



Table 1. Percentage weighting of traits 2001. Source: AQUAGEN

Main-traits	Sub-traits	Main weighting	Partial weighting
Growth		25	
	Smolt weight		5
	Slaughter weight		20
Sexual maturation		5	5
Disease		30	
	IPN		10
	ISA		15
	Furunculosis		5
Quality		40	
	Filet colour		20
	Body shape		5
	Total fat		10
	Visible fat		5
Total		100	100

➔ Move towards more balanced breeding objectives



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT



Future traits for a finite world

- Produce more with less inputs and impacts
 - Less importance given to growth rate?
 - Feed efficiency, nutrient retention, adaptation to new feeds, disease resistance, processing yields contribute to efficiency
 - Should we aim at « robust », adaptable fish or « Formula1 » for very controlled systems ? → study GxE interactions
 - Need for integrative methodologies (LCA) to evaluate the global impacts of potential modifications of fish by selective breeding

Selective breeding in Europe (2009)

14 species
37 programs
22 family-based



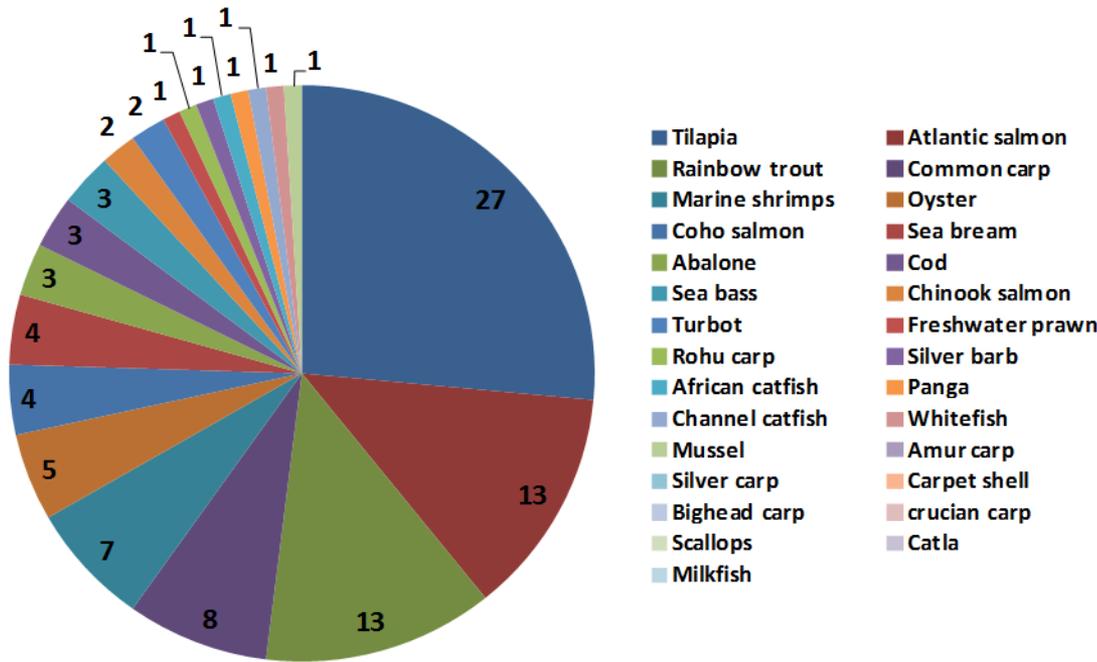
**AQUA
BREEDING**



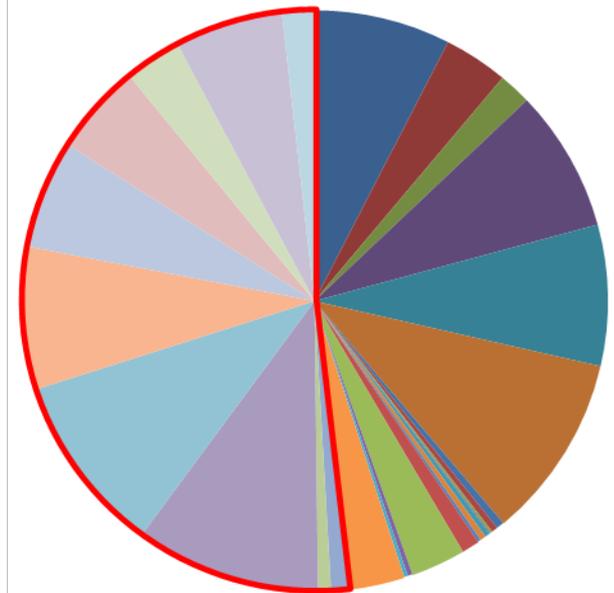
FP6-2005-SSP-04442

Aquaculture breeding in the world

Number of Breeding programmes



world prod 2009



Some major species (carps, molluscs, milkfish) are not improved
 Some minor species improved: low cost programs needed

Data from Neira, 2010; Rye et al, 2010; FAO

Economic impacts of breeding

- From a national perspective, the Benefit/Cost ratio is estimated to be :
 - 15 in salmon (Gjedrem, 1997),
 - 8.5 to 60 in tilapia (Ponzoni et al, 2007),
 - 22 to 420 in common carp (Ponzoni et al, 2008).
- But all benefits do not necessarily go to the breeding companies
- Some important species do not benefit from breeding (filter feeders/extensive management)
- ➔ how to help increase use of efficient breeding ?



USING THE GENOTYPE TO GO FURTHER



ALIMENTATION
AGRICULTURE
ENVIRONNEMENT



How to use the genotype ?

- Identify portions of the genome that have a large influence on the traits (QTLs)
- Systematic evaluation of the effects of all portions of the genome (genomic selection)
 - ➔ Enrich the population in the « favourable » genes
- Transfer genes with high impact on the trait of interest (Transgenesis)



Transgenesis

- Genome integration of foreign DNA to produce new proteins and **new phenotypes**
- First trials in the early 90s (in fish)
- Main target trait : growth rate (GH transgenesis)

Principles of transgenesis

- Building of DNA constructions associating a gene and a promoter



- Injection in egg cytoplasm just after fertilization
- Random integration to the genome during development (1-6% success)
- The promoter will regulate transcription
 - Permanent, induced, ubiquitous, tissue-specific, strong, weak,...
- The gene will code for the desired protein
 - GH, antifreeze protein, cecropin, desaturases...
- Both promoters and genes can be homologous or heterologous
- **Important: 3-4 generations needed to obtain a stable transgenic line**

It works in mud loach...

➤ mI β Act-mIGH (Nam et al)

Growth x16 to x36 at 6 months
(in competition)

Smaller growth in homozygotes

Deformities in homozygotes

TG/+



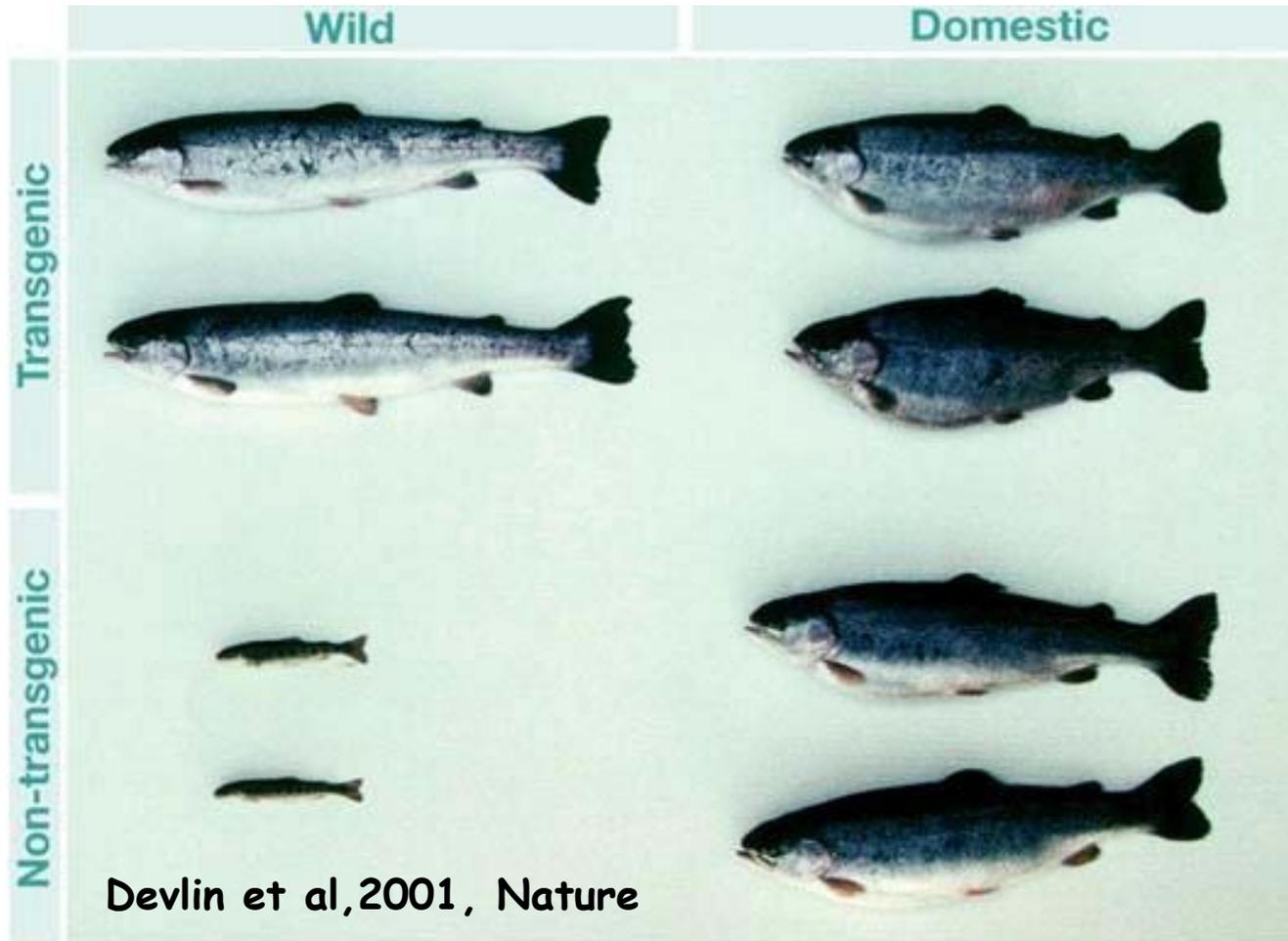
TG/TG



+/+



...but not in domesticated rainbow trout



Not efficient
in carp either
(domesticated)

Aquadvantage[®] salmon

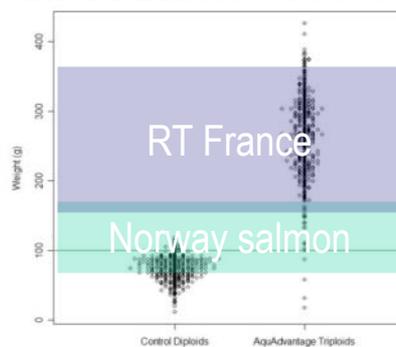
- *S.salar*, GH gene, opAFP promoter
- In FDA authorization process
- What is its growth rate?



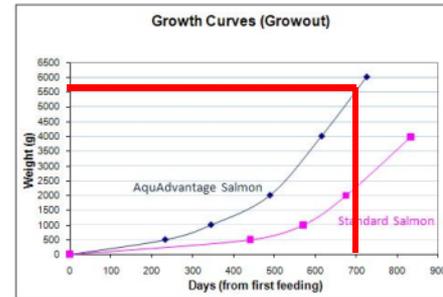
At the same age
Length x1.9: BW x7 ??

VMAQ Drafting Packet
AquAdvantage Salmon
Page 134 - Claim Validation

Figure 7. Weight of AquAdvantage Salmon and Comparators at 2700 deg C days



261g vs 73g: x 3.6 ?



Norway: 5.5kg at D700



FDA Claim

"Significantly more of these Atlantic salmon grow to at least 100 g within 2700 deg C days than their comparators."

Compatible with a 10% gain!!!

No claim for commercial weight !



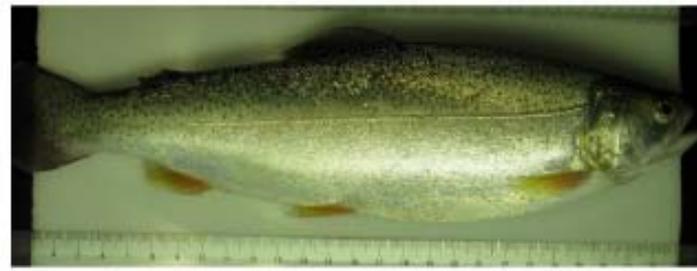
ALIMENTATION
AGRICULTURE
ENVIRONNEMENT



Future for transgenesis ?

➤ Double muscling (« six-pack » trout)?

Medeiros et al, 2009



- Overexpression of follistatin → deregulated muscle growth. Yields ?
- But breeding can improve carcass & fillet yield (~1%/gen*)
- Beware of negative correlated effects

➤ In livestock: mostly highly specialized transgenics

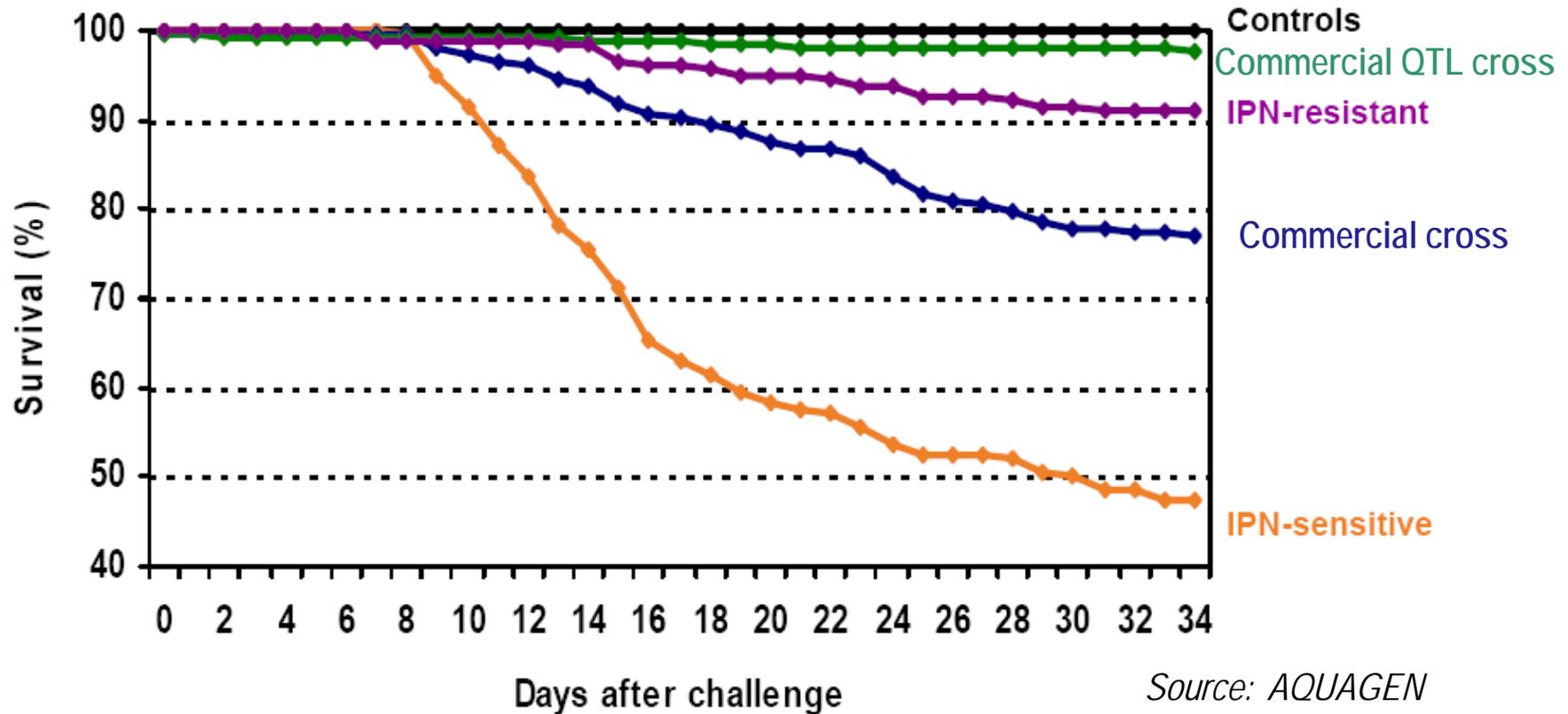
- Goat:
 - “spider goat” (spider silk in milk),
 - FDA approved ATyra: anticoagulant (anti thrombotic) in goats milk
- Pigs:
 - “humanized pigs” for xenotransplantation
 - Enviropig™ : phytase in saliva → no PO₄ suppl. → 30-70% less PO₄ in manure
- Cows:
 - lysozyme to make “human” milk (protecting from infections – absent in cows milk)



Searching for QTLs for MAS

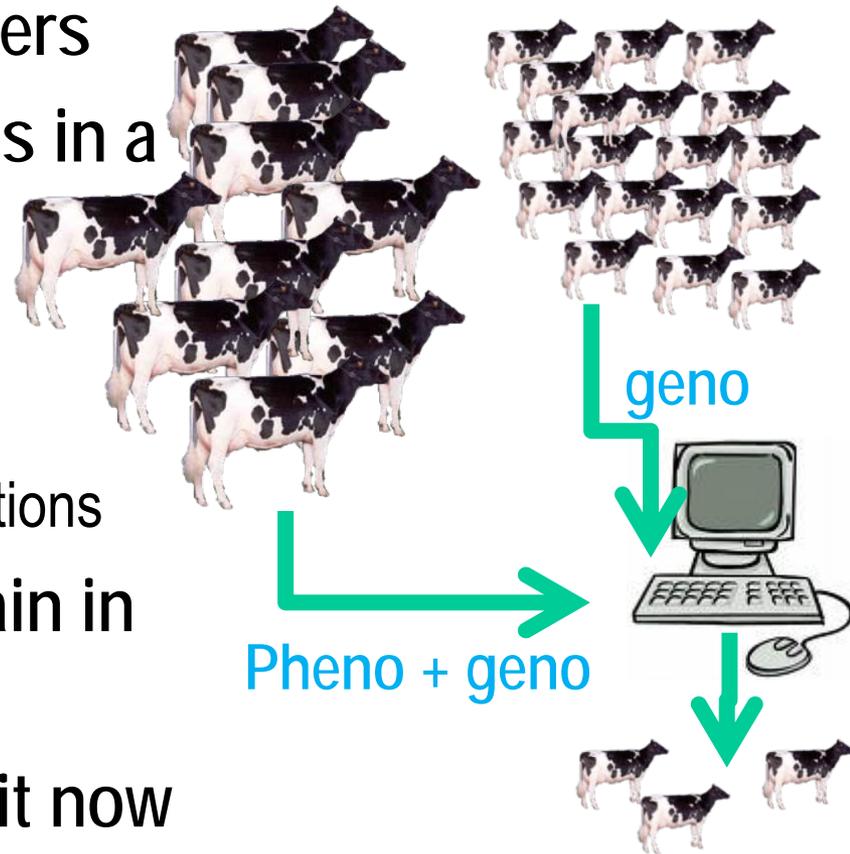
- Association between markers (100s) & phenotypes
- Developed in livestock in the 90's
- Interest for late, difficult, one sex phenotypes
- Little used in practice as
 - Associations often weak (not valid in all pops/families)
 - Many traits are indeed governed by many genes with small effect
 - Causal mutation most of the time unknown
- Successful implementation : elimination of fishy odour in eggs

IPN resistance with a QTL



Then next frontier: genomic selection

- QTLs with 10000's (SNP) markers
- Marker-phenotype associations in a reference pop (1000-20000)
 - ➔ Can deal with plurigenic traits
 - ➔ Can match causal mutations
 - ➔ Provides population-wide associations
- ➔ Expected to double genetic gain in dairy cattle at a lower cost !
- ➔ Almost all dairy breeders use it now



And if you're not producing milk ?

- Lower unit price of brooders (100.000s € for a top dairy bull, with a 50.000 € evaluation cost in the old system)
- Shorter generation intervals
- Higher selection intensities possible for productivity traits: an alternative to higher precision
- Genome not available in all species (but will come)
- Like QTLs, should be focused on difficult traits: behaviour, disease resistance, longevity, reproductive abilities

And for aquaculture ?

- Low unit price of broodstock
- Many species, not all with genome data
- Very high selection intensities possible

➤ BUT

- Imputation methods may help
- Disease resistance: genic selection ?
- Promise for difficult to measure traits ? (repro, quality, robustness)
- Simulation and implementation on the way

Technology Strategy Board
Driving Innovation

Knowledge Transfer Network
Biosciences

Improving disease resistance in salmon



The Biosciences KTN has assisted the UK's premier salmon breeding company in the groundbreaking use of genomic technologies to produce salmon with reduced susceptibility to disease.

The need

Disease susceptibility is a major threat to the global salmon farming industry. The fish are generally reared in pens that are tethered to the sea bed and controlling exposure to pathogens and diseases is consequently very difficult. When a disease occurs it can have catastrophic consequences. For example, in 2007, infection with Infectious Salmon Anaemia virus caused major decimation and near collapse of the Chilean salmon farming industry (the second largest global producer in 2006).

Increasing the salmon's robustness to diseases and pathogen challenges is therefore a major driver for the industry. The ability to provide stock with high resistance to specific diseases can confer a significant competitive advantage to a salmon breeder.

The results

Landatch Natural Selection (LNS) is the UK's premier aquaculture breeding company selling young stock and eggs globally. LNS employ a selective breeding programme that allows them to deliver year on year genetic improvement for a range of important characteristics.

The availability of new genomic tools offers the potential for LNS to accelerate the rate of improvement within their breeding programmes and allows selection for important characteristics, such as resistance to disease.

A collaborative project between LNS and SAC, funded by a Biosciences KTN SPARK Award, helped develop a database to hold and analyse genetic and genomic data. The Biosciences KTN then assisted LNS to secure a Knowledge Transfer Partnership (KTP) project with The Roslin Institute that has resulted in the company being able to successfully use marker-assisted selection to breed fish that have a high level of resistance to infectious pancreatic necrosis virus (IPNV, Figure 1), which can cause devastation to salmon stocks.

LNS secured a further SPARK award to collaborate with the University of Glasgow to investigate whether the approach could also be extended to help breed salmon that have a high level of resistance to sea lice, parasites which are estimated to cost the global industry £300m per year.

Following this review, LNS are now leading a collaborative research project part funded by a £323k grant won through the Technology Strategy Board Genomes UK competition. The project will see the first high-density salmon single nucleotide polymorphism (SNP) chip (~100k) being used in the selective breeding of salmon, in the first instance to improve resistance to the sea louse.

This project should enable LNS to be the first global company to market sea lice resistant stock selected using this technology. This achievement could see LNS's share of the global market increase to 20% by 2015 leading to an increase in turnover of \$9m.

www.innovateuk.org/biosciencesktn

The knowledge based bio-economy of the 21st Century

So... what to learn from livestock ?

- Good farmed fish will be domesticated
- There is a huge potential of genetic improvement
- Quantitative genetics (and genomic selection ?) will provide the bulk of the gain
- It is important to monitor and prevent negative effects of high productivity on fitness traits



More specific to fish

- Need to care about inbreeding/genetic variability
- Escapees problem: use of sterile triploids ?
- Breeding for extensive/polyculture systems remains a challenge

We have to use this very high potential !



Thank you for your attention !

→ Gain 5-6 months to harvest size in 10 years,
or harvest at 700g

Vandeputte et al, 2009, Aquaculture,