Precision Agriculture Meets the Genomics Revolution

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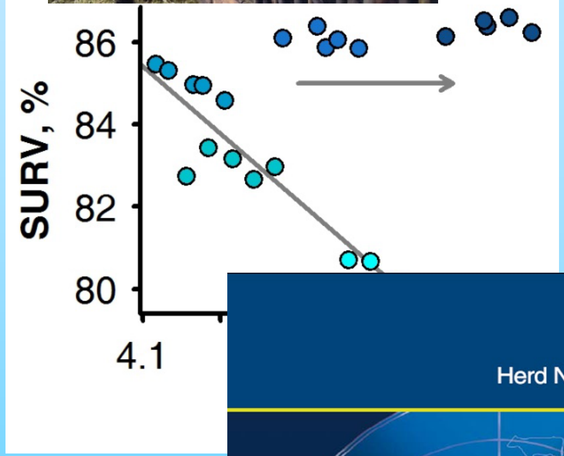
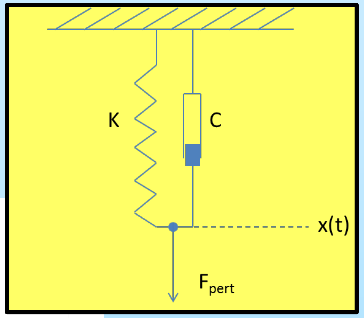
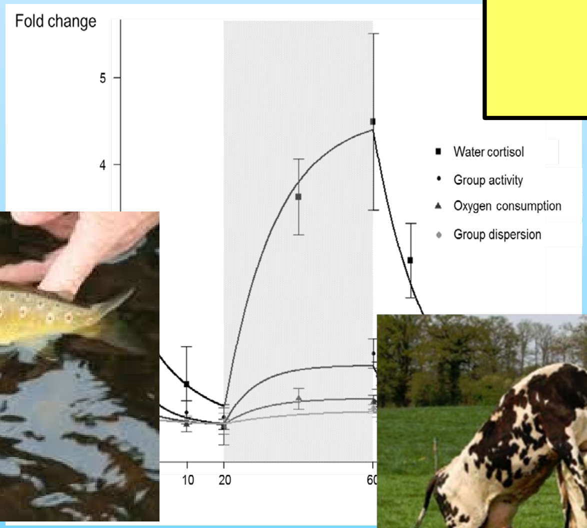
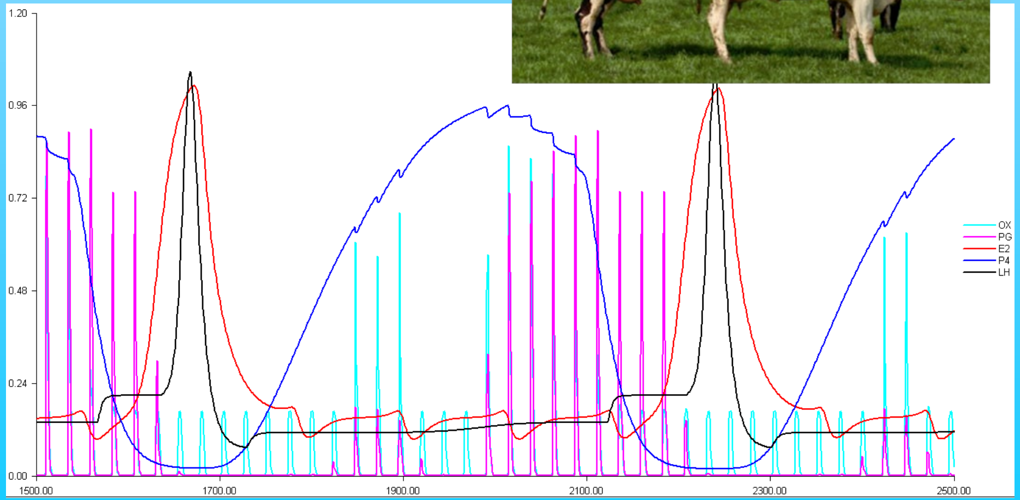


A diversity of models







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Genomic Management **T**ools to
Optimise **R**esilience and **E**fficiency
across the Bovine Sector

Genomics and Precision Farming Technologies

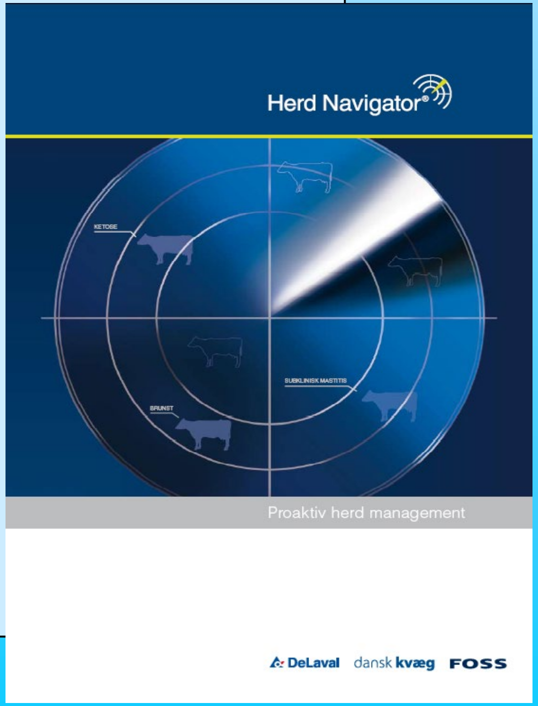
- Highly complimentary disciplines
- Strong synergy
  - If appropriately combined
- Opportunities and limitations from the genomics perspective
- Opportunities and limitations from the precision livestock farming perspective
- Synergies and future challenges

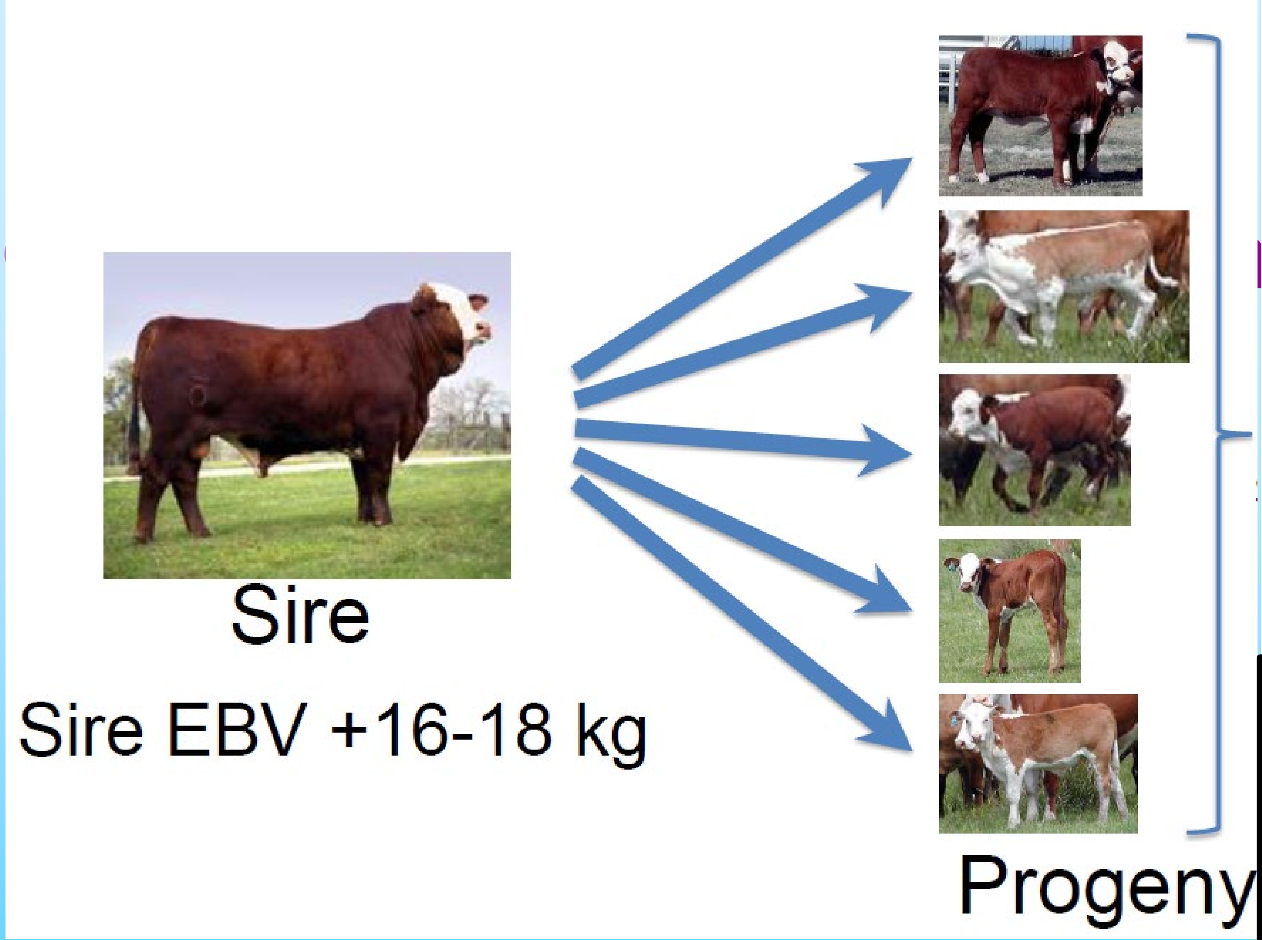
Genomics and Precision Farming Technologies

- Currently much easier in (dairy) cattle
  - Relative worth of the individual animal
  - Typically favourable environment for on-farm technologies
- Focus of a number of initiatives such as GenTORE
- However, the field is very rapidly evolving
- And there are a new initiatives in small ruminants

Example: Milk Progesterone Measurements

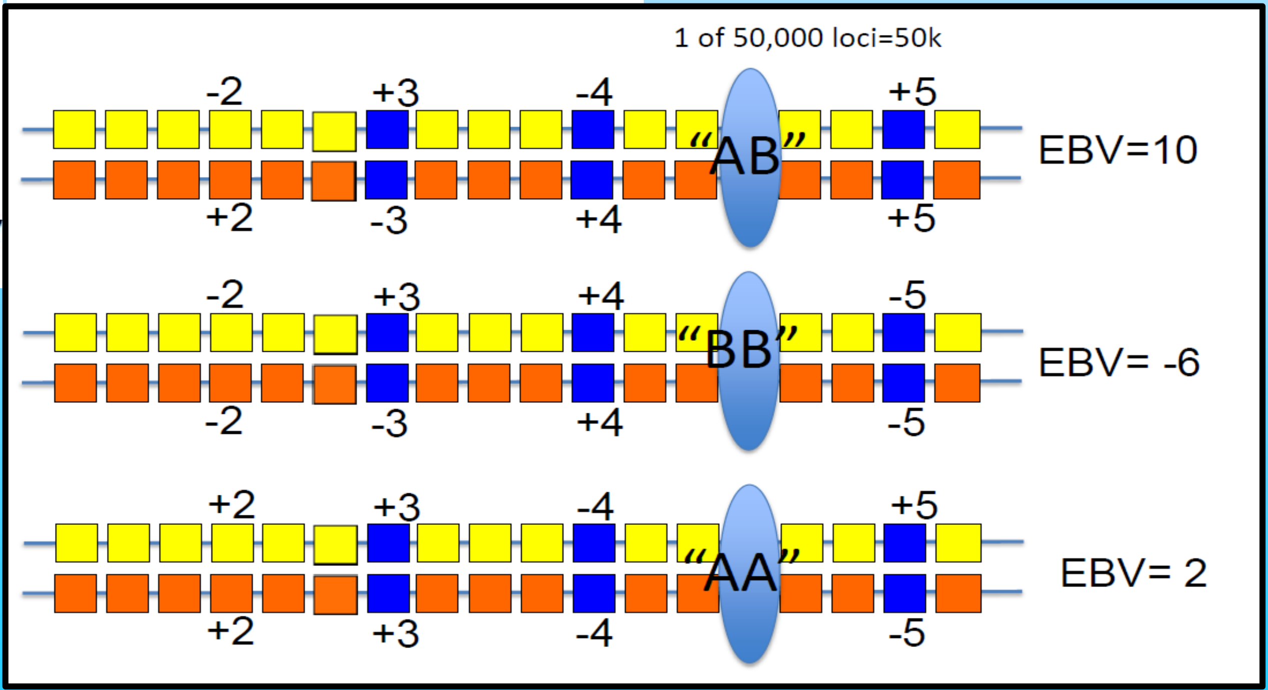
- laboratory based (1960s)
- on-farm manual tests (1980s)
- biosensors (1990s)
- in-line measurement:
  - Automated
  - Real-time
  - Commercially released: 2008





Expect them to be on average 8-9 kg heavier than progeny of the average sire

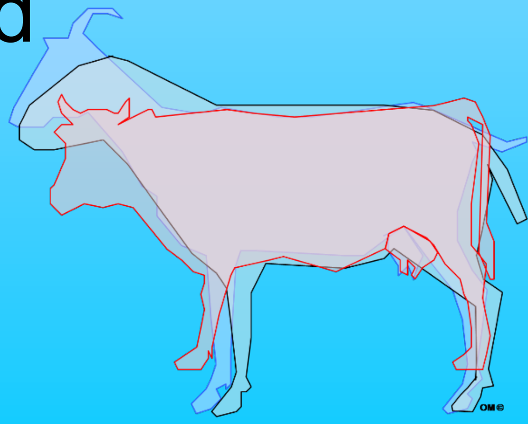
But can't tell which without "buying" additional information

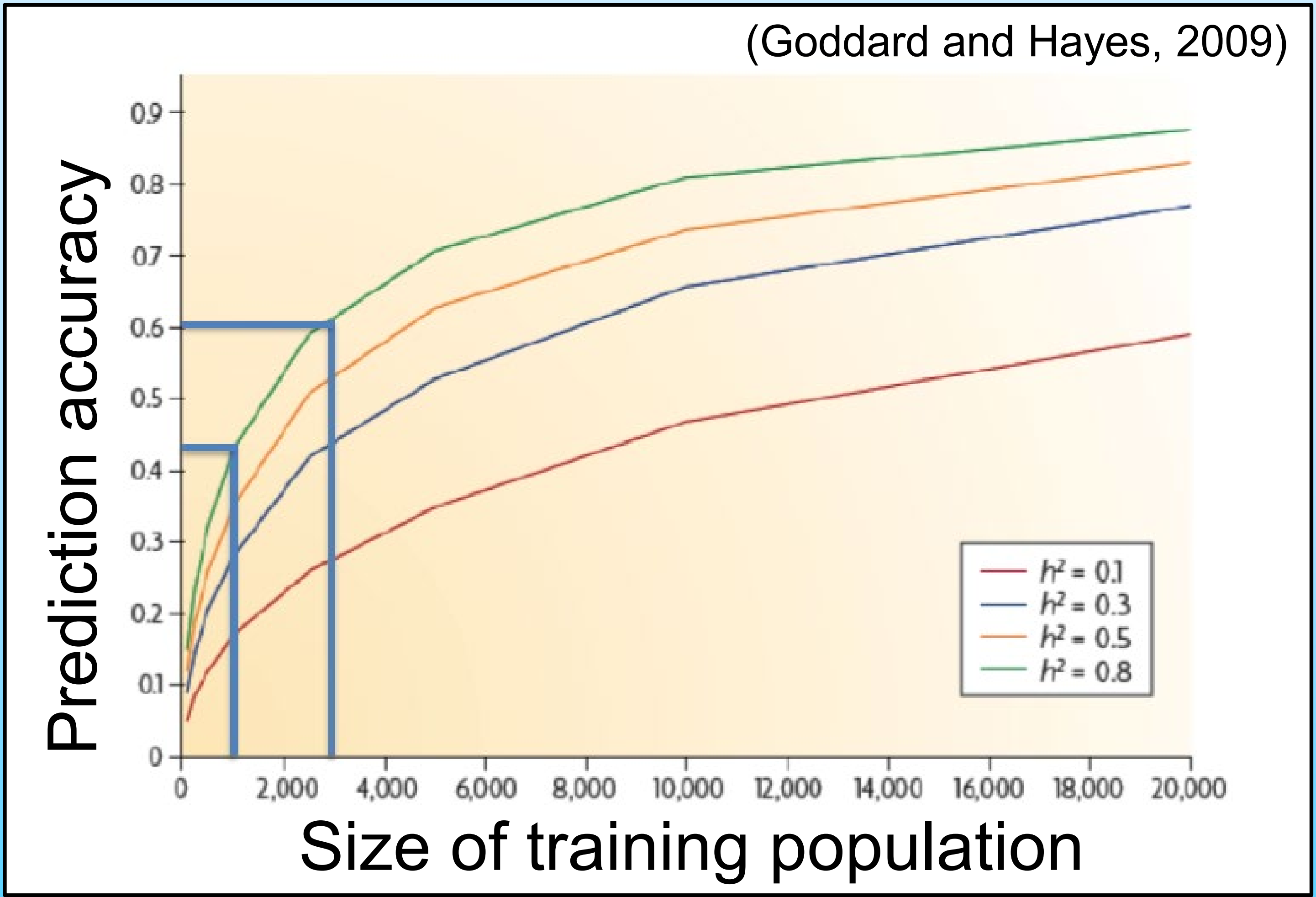


Slides of D. Garrick:
https://www.icbf.com/wp/wp-content/uploads/2013/06/2_Dorian_Garrick.pdf

Opportunities from the genomics perspective

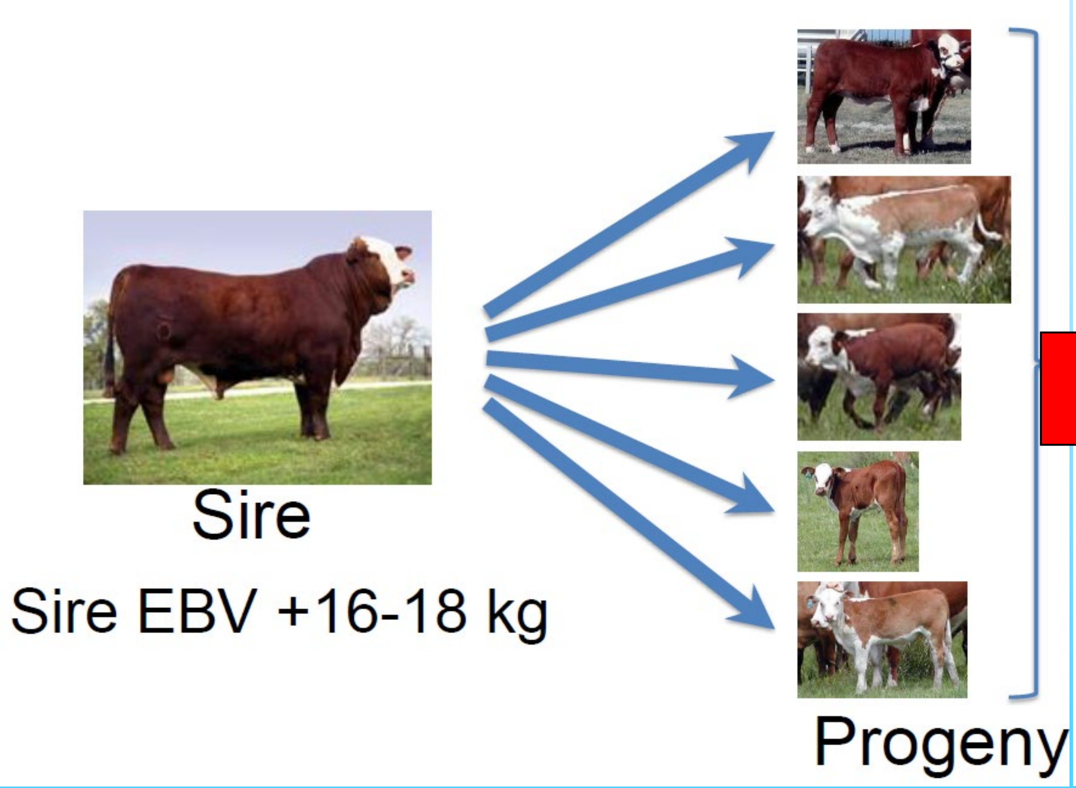
- Massive increase in precision of genetic evaluation
  - And thus in selection
- Predictions of the genetic merit of an individual based on its genome (genomic EBV) are derived from candidates with genotype and phenotype information
  - the so-called training population
- This is then used for the selection of genotyped candidates with no recorded phenotypes (selection candidates)
  - Need fewer animals

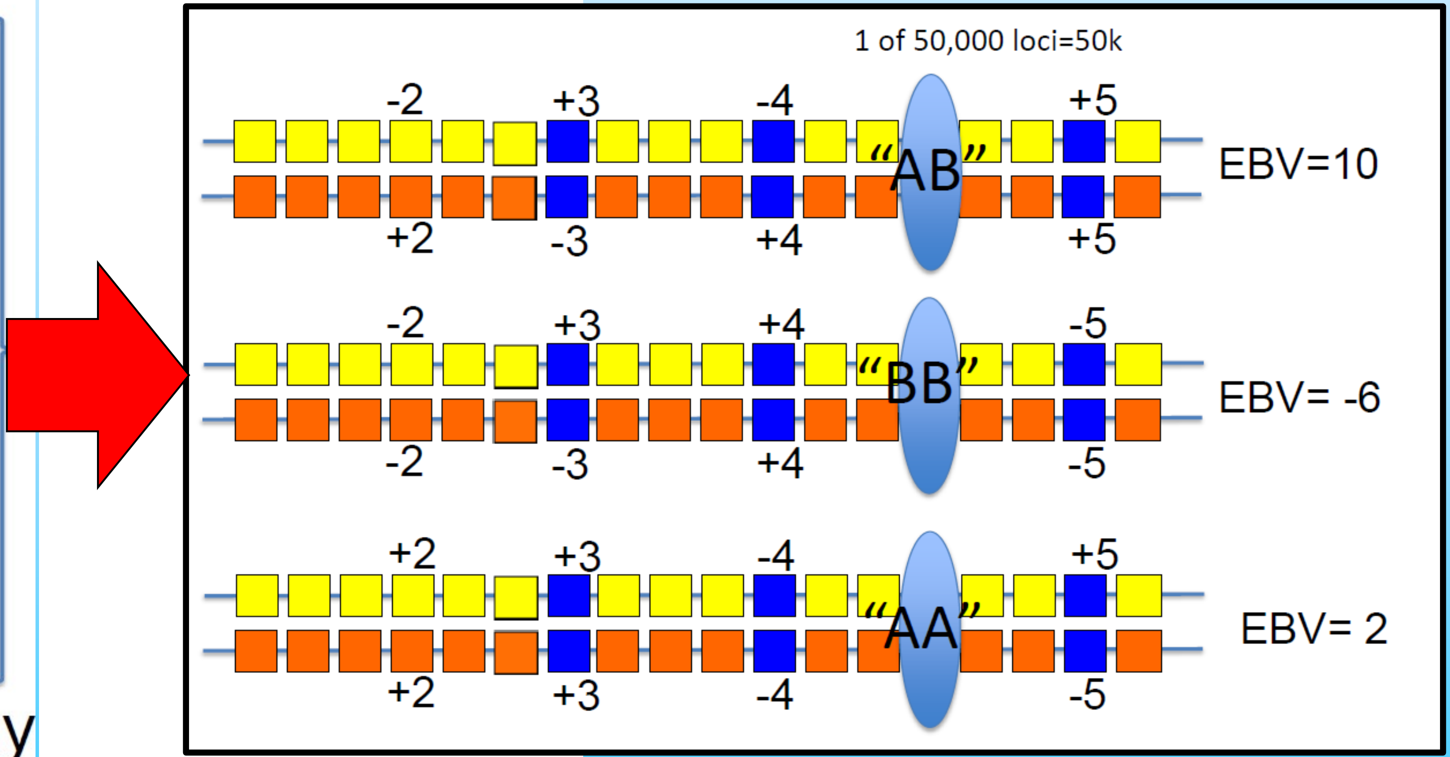




GS can be applied in practice for all main livestock species since genome-wide single nucleotide polymorphism (SNP) panels or even full sequence information are available (Jonas and de Konig 2015)

Opportunities from the genomics perspective





- The reduced need in selection to phenotype progeny
- Shortens the generation interval
- In dairy cattle from 5-6 yrs to 1.5 yrs

In sheep ?

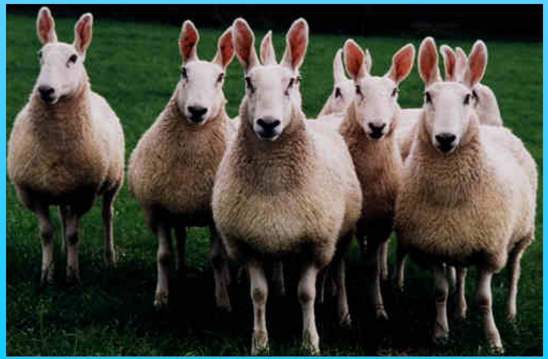
Opportunities from the genomics perspective

- Dramatically decreasing cost of sequencing
  - and increasing number of SNPs
- Rapidly increasing computing power
- Rapidly improving bioinformatics and statistical tools
  - e.g. K-mer approaches (Li et al. (2010). "De novo assembly of human genomes with massively parallel short read sequencing". *Genome Research*. **20** (2): 265–272.)

- Opens up for genotyping of females
- Genotyping newborn calves will be standard procedure

Opportunities from the genomics perspective

- Massive increase in precision of genetic evaluation
- Application to complex traits such as efficiency and resilience
  - Previously beyond the reach of 'classical' genetics
  - e.g. breeding for resilience to heat stress (Carabaño et al., 2017)
- Genetic determinism of the myriad components of complex traits becomes possible (e.g. Bouvier-Muller et al., 2018)



However…

"Currently, despite promising research results, in cattle, no large-scale breeding programme directly includes adaptation traits. However, current breeding objectives are indirectly affecting adaptation given the unfavourable correlations between resilience and production traits" (Egger-Danner et al 2015)

Limitations from the genomics perspective (1)

- Lower genetic correlations between traits in cross- and pure- bred animals
  - Important due to heterosis for traits such as resilience and efficiency
  - Makes application to cross-breeding difficult
  - More crossbreed, genotyped animals available

    in the future DxD, DxB, BxB

Limitations from the genomics perspective (2)

- Precision of phenotyping of complex traits
- "What are resilience and efficiency?"
  - Definitions AND measures frequently unclear

- Genomics methodology is fundamentally a spatial approach
  - Mapping, time-related aspects frequently ignored
  - Not well adapted to dynamic data

Efficiency definition

- The ratio energy in the product:energy ingested to achieve that production measured…
- … **over a time period that is relevant to ensure that any efficiency gains are sustainable**.

- This definition does not preclude the measurement of efficiency via residual feed intake type approaches.

Short- vs Long-term Efficiency

Efficiency: "Dilution of maintenance"

Intake
↓
Nutrient supply
↓
Nutrient Partition

Efficiency

Production (milk, lean)

Body reserves, maintenance
↓
(Rate of loss of body fat, protein)

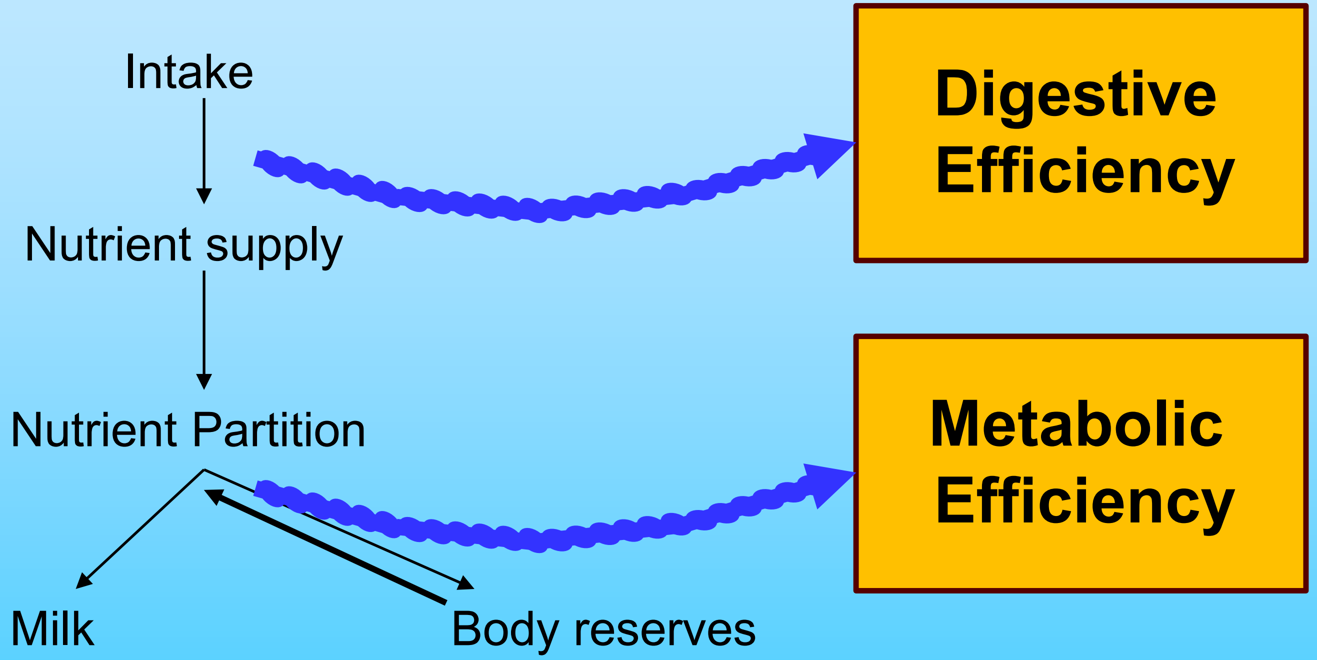
Health status
↓
Risk of disease

Ability to reproduce
↓
Reproductive problems

Well-being Robustness Longevity

Efficiency: "Dilution of non-productive lifespan"

Efficiency in which environment?



- Significant issues to:
  - measure on a large-scale
  - Separate in RFI methodology

Sustainable Efficiency

- The ratio energy in the product:energy ingested to achieve that production measured…
- … **over a time period that is relevant to ensure that any efficiency gains are sustainable**.

- The time element is key
  - efficiencies measured in the short-term do not include the longer term consequences of improving short-term efficiency.
- Thus, selection for growth rate in meat producing breeds has a negative impact on adult resilience, and selection for higher milk yield is associated with decreased productive longevity.
- Sustainable efficiency incorporates robustness and resilience (Friggens et al., 2017).

Resilience definition

- “Live to fight another day”
- The capacity to respond to environmental perturbations and thus safeguard future ability to contribute genes to the next generation.
- This includes both the ability to survive (or avoid being culled) until the next reproductive opportunity, and the ability to successfully reproduce (adequate numbers of viable offspring).

Resilience

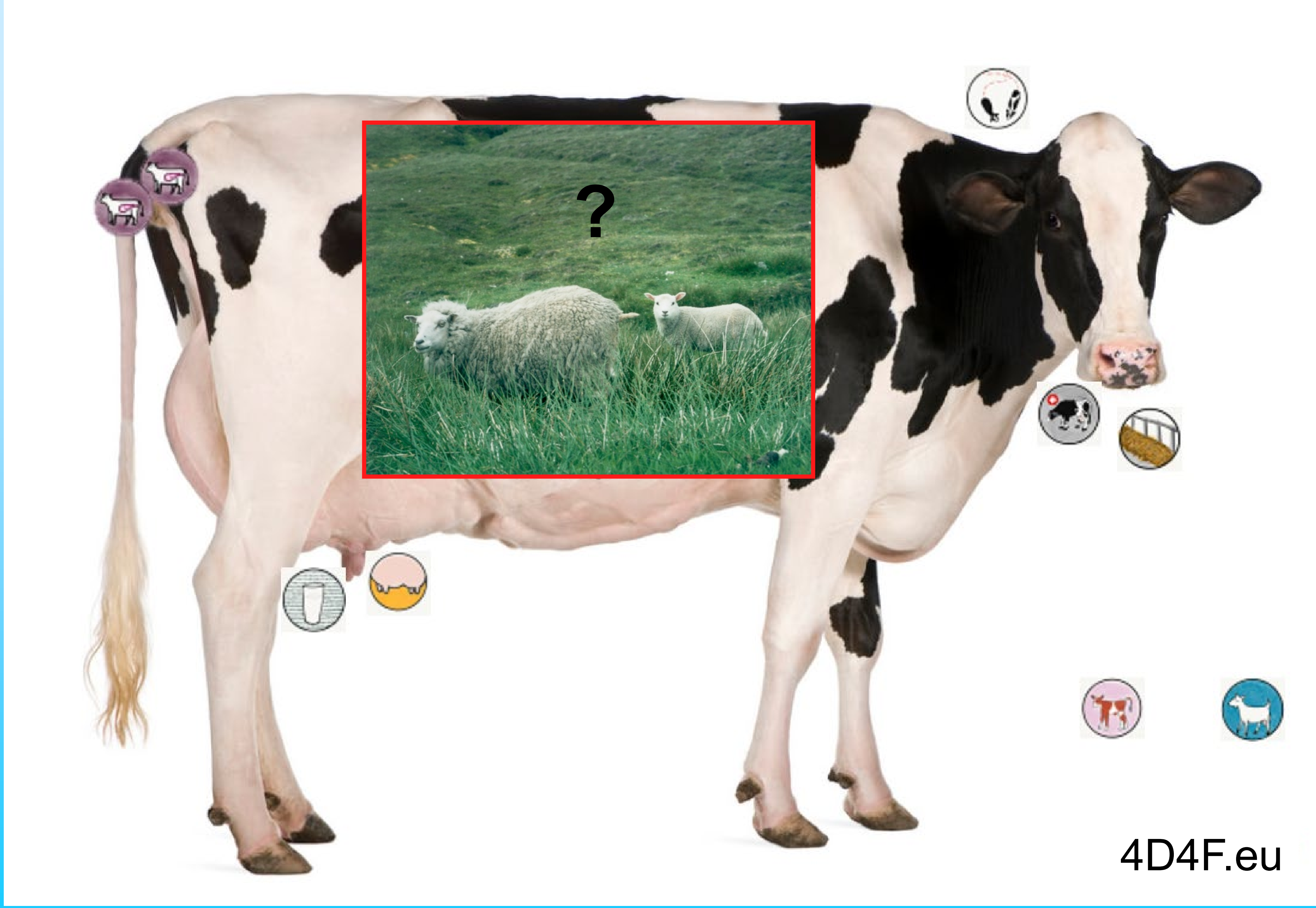
- Implies abilities to:
  - be able to absorb an environmental challenge through buffering mechanisms, and/or
  - modulate the allocation of available resources to life functions, down prioritizing those that are non-vital and up-prioritizing those that are needed to meet the challenge.

- Significant challenges to phenotype

Precision farming technologies

Opportunities and limitations from the precision farming perspective

- High-frequency time-series measures
  - Automated, reliable
  - Low-cost per measure
  - Performance (BW, MY, MIR), reproduction, and health indicators
  - Commercialized in cattle



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The precision livestock farming train has very definitely left the station but who is on board, and where is it going?

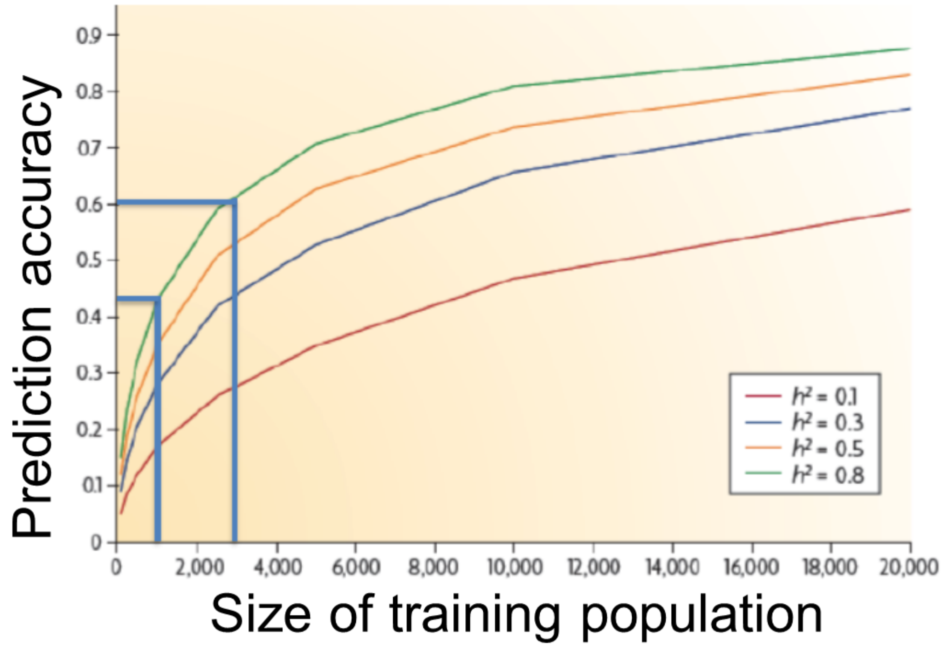
- Currently the focus is on monitoring to identify specific events (oestrus, disease)
- Its use for phenotyping has been largely ignored

The value of precision phenotypes

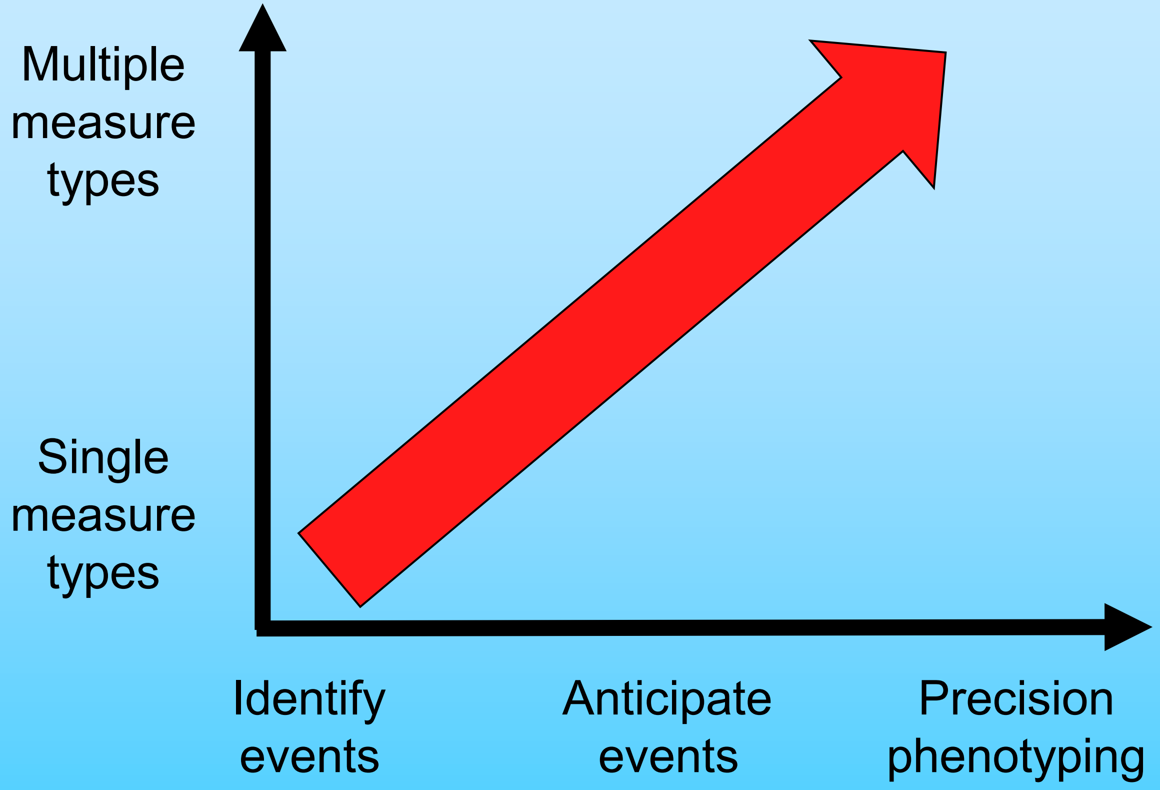
Example: Heritability (h^2) of reproductive traits

- Traditionally low $h^2 \sim 0.03$
- progesterone based $h^2 \sim 0.17$ (Royal et al)
- activity measures $h^2 \sim 0.17$

(Goddard and Hayes, 2009)



From monitoring to phenotyping



- Multivariate time-series statistics…..
- But also a clear view of the biological system

A clear view of the biological system. example: Energy Balance

- Traditionally EBal measured as
  - Difference between Eintake – Eoutput
  - Only research farms measure individual intake
- EBal = Body E change
  - Negative EBal = body reserve mobilization
  - Positive EBal = body reserve accretion
- EBal can be measured from body reserves

EBal from lipid and protein reserves

$$EBal = ec_l(dL/dt) + ec_p(dP/dt)$$

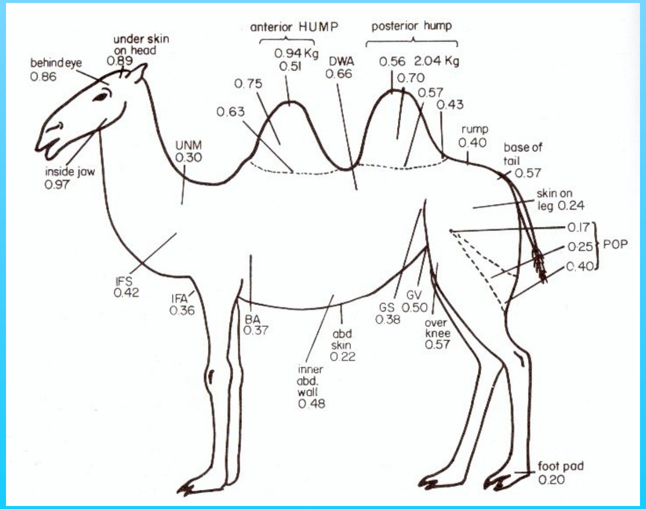
$$P = k(LFEB)$$

$$LFEB = EBW - L$$

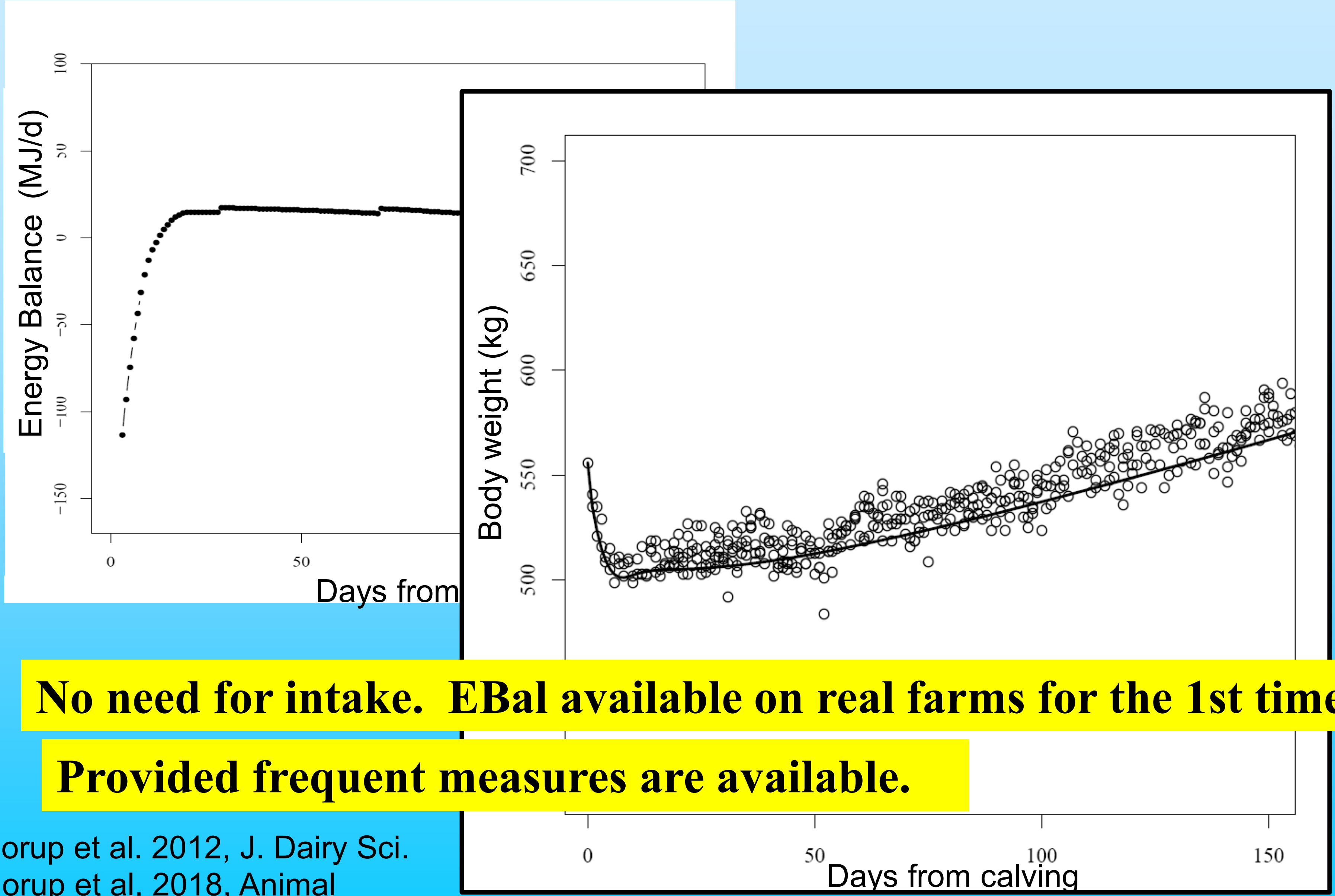
$$L = BFatContent \times EBW$$

$$= (a + b.CS).EBW$$

$$EBW = BW - Gutfill$$



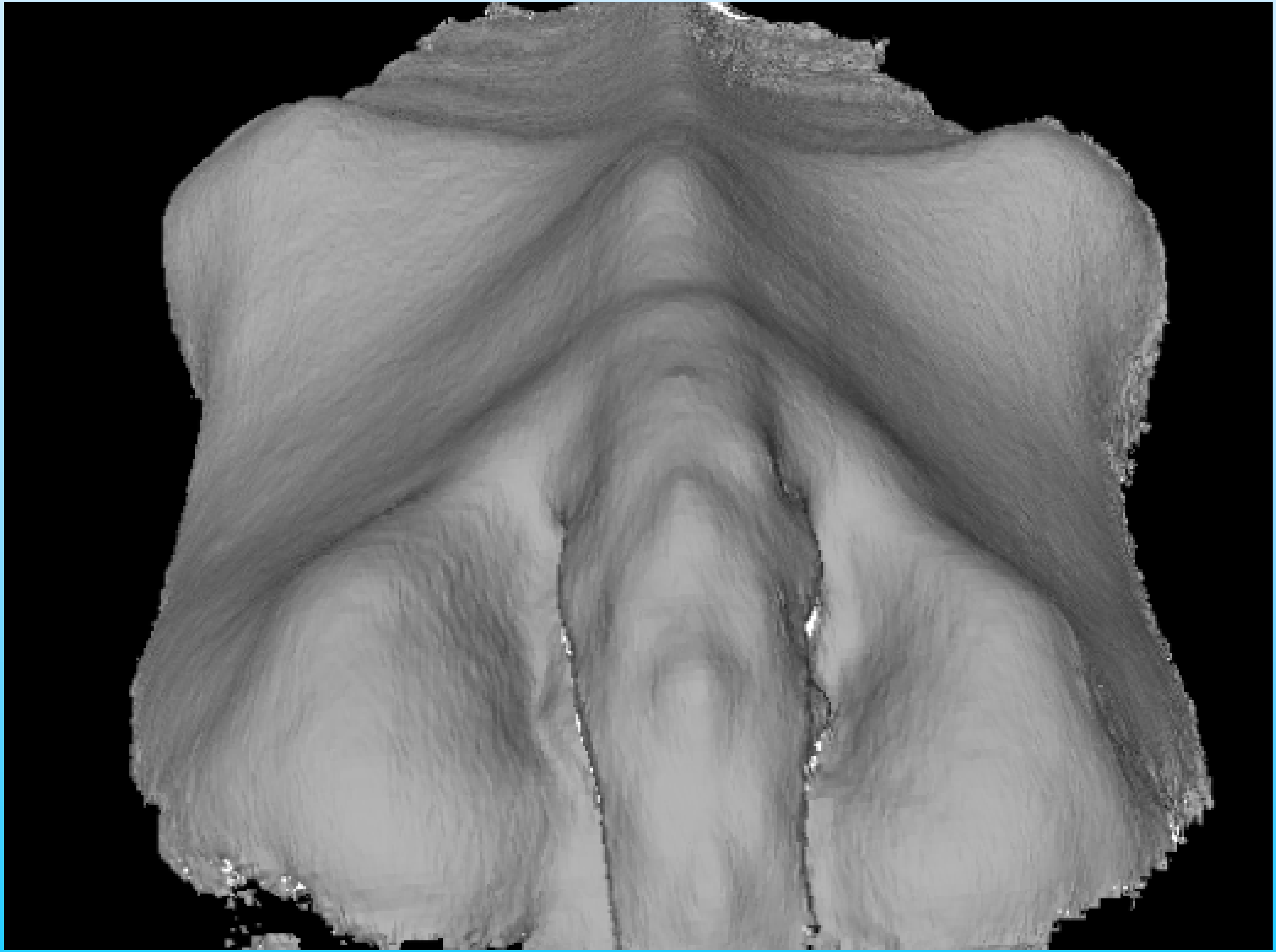
Low hanging fruit: energy balance derived from BW and CS



No need for intake. EBal available on real farms for the 1st time

Provided frequent measures are available.

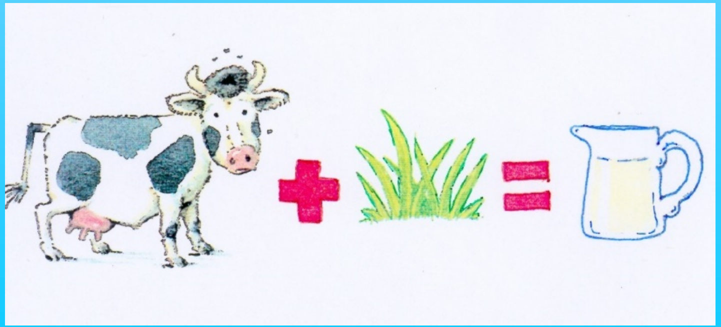
Thorup et al. 2012, J. Dairy Sci.
Thorup et al. 2018, Animal



Fischer et al. 2015 J. Dairy Sci.

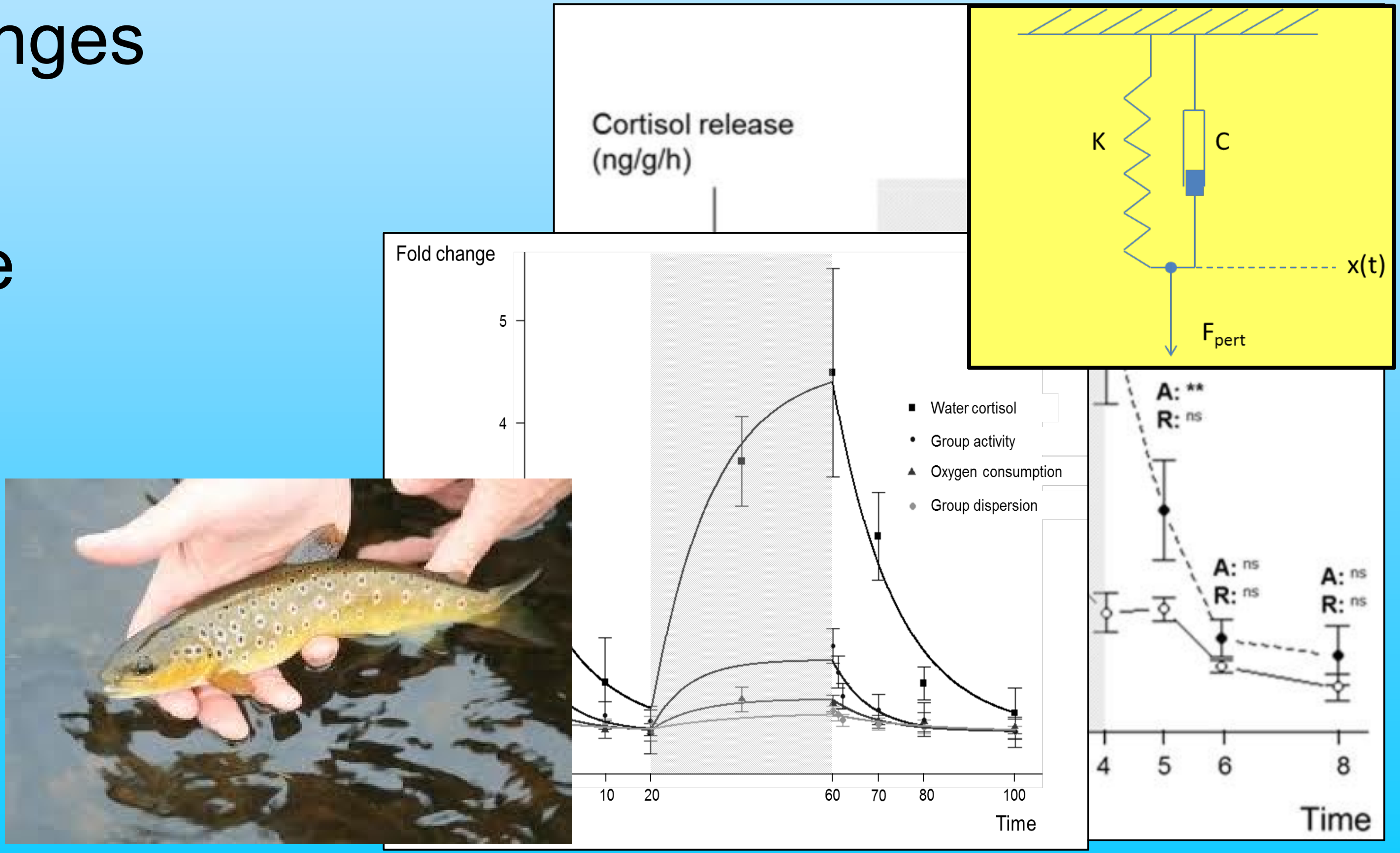
- On-farm energy balance now available
  - In-line weighing
  - Image analysis, e.g. automated body condition scoring
- Huge opportunity
  - Identifying at risk animals
  - Selecting on body reserve profiles

- A step in the right direction for large-scale phenotyping of efficiency

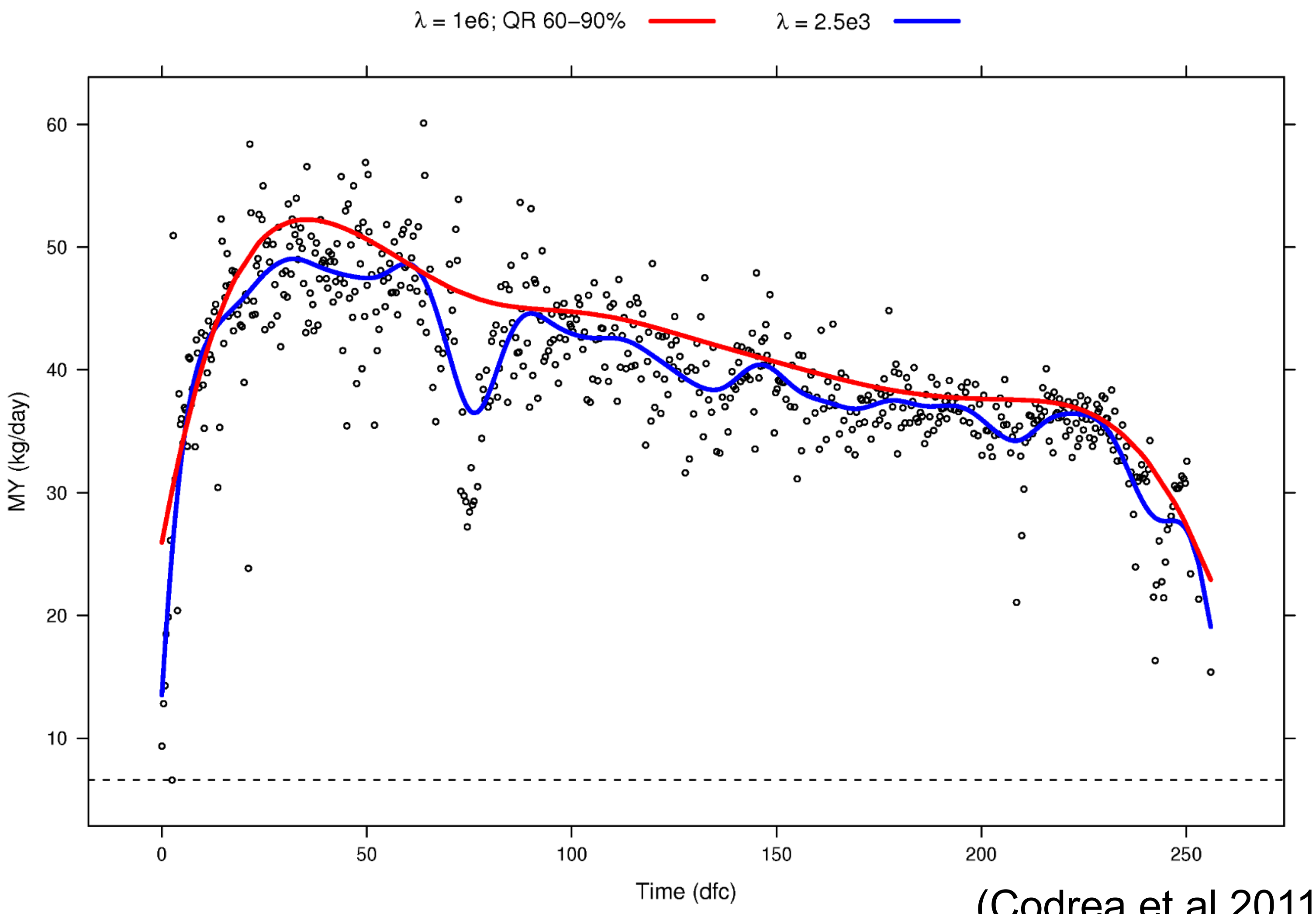


Precision monitoring technologies for resilience

- Exploiting
  - naturally occuring perturbations in time-series data
  - and/or planned challenges
- Characterize
  - Amplitude of response
  - Rates of recovery



Exploiting naturally occuring perturbations



(Codrea et al 2011)

Precision monitoring technologies for resilience

- Exploiting
  - naturally occuring perturbations in time-series data
  - and/or planned challenges
- Characterize
  - Amplitude of response
  - Rates of recovery
- Quantify effect of numbers of events on productive lifespan and efficiency (e.g. Elgersma et al. 2018)

Item	CaI	FL	DS	MS	UDH	CLW	KET	PER	LON
Best sires	102	100	99	101	104	101	105	105	298
Worst sires	100	100	99	100	99	101	98	102	92
P-value Student *t*-test	0.15	0.48	0.64	0.79	0.001	0.92	<0.001	0.03	0.003

Rapid progress with on-farm technologies

- Precision phenotyping of efficiency components
- Precision phenotyping of resilience components

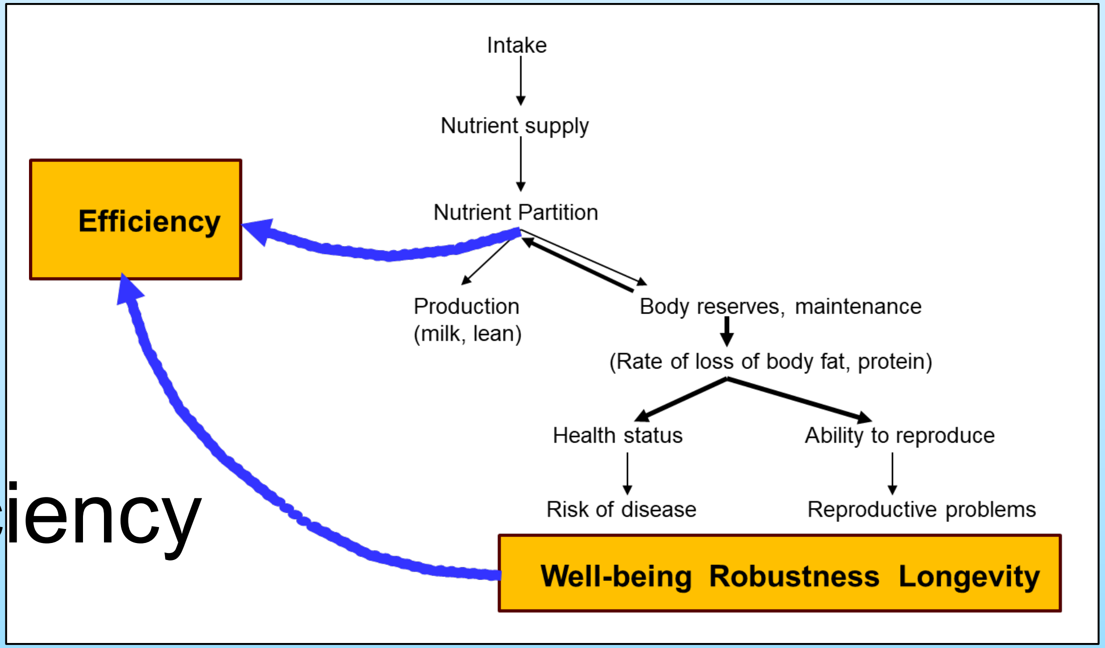
- Where are we heading?
  - – Predicting future scenarios
  - – Decision support tools

Balance between efficiency and resilience

- How much resilience should an animal have?
- Resilience versus production efficiency
- Local production context
  - Type of production
  - Types of environmental challenge
  - Matching genotypes to environments

- **Modelling** to explore
- Very hot topic:

Prediction: key issues



- Trade-offs
- Resilience vs short-term feed efficiency
  - Specialists vs generalists

- Highly relevant to adult producers (milk, eggs, offspring)
- Still relevant for meat-producers
  - Disease resistance
  - Resilience to variable feeds, temperature, etc
  - Behavioural resilience

Trade-off modelling example of GxE

Douhard et al. (2014) J. Anim. Sci. 92:5251–5266

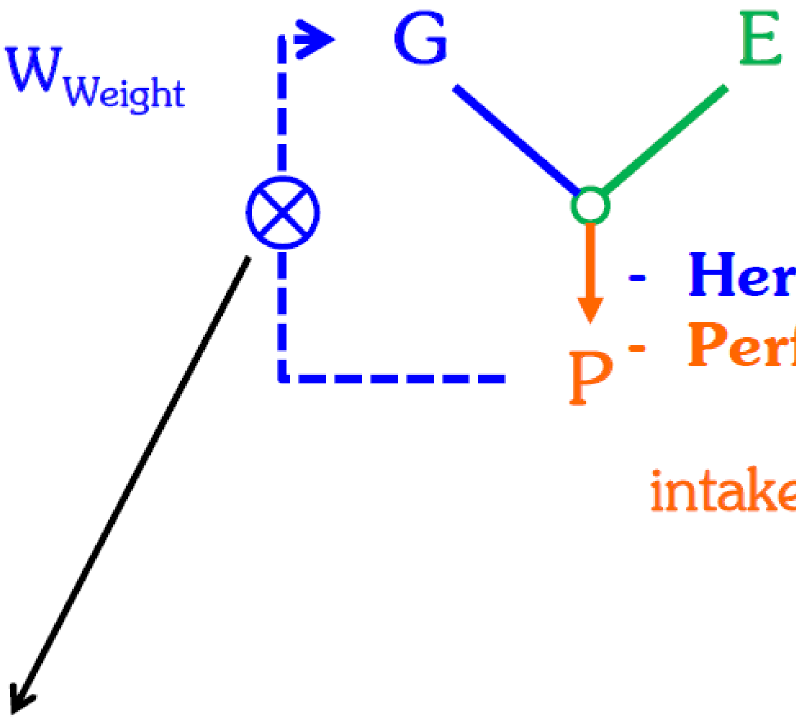
Model overview

INPUTS:

Selection criteria
$W_1, W_2, W_3, ..$

e.g. W_{Milk}, W_{Weight}

Resource availability
(Metabolizable energy)



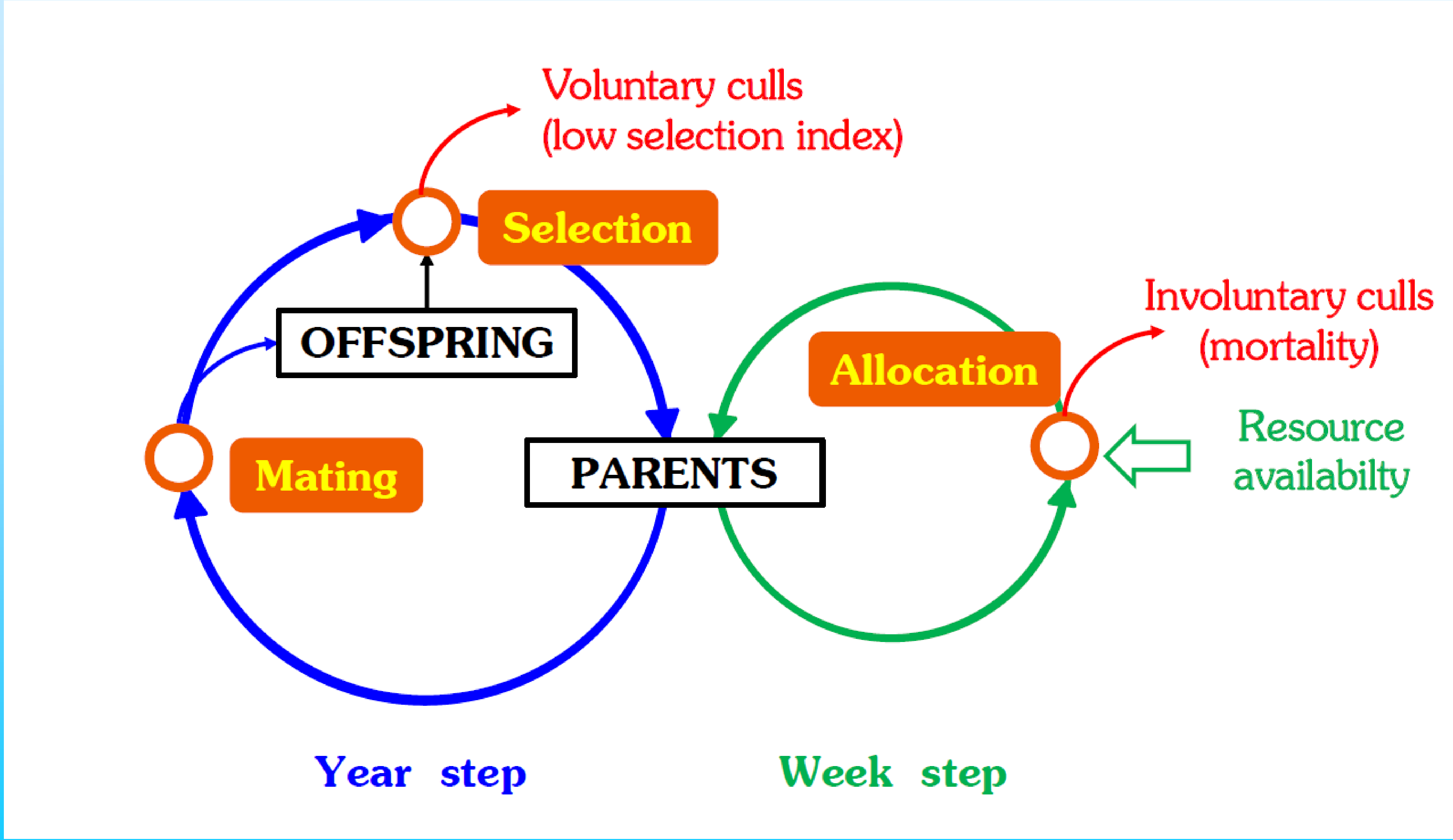
OUTPUTS:

- **Heritable traits of allocation**
- **Performance** $P_1, P_2, P_3, ...$

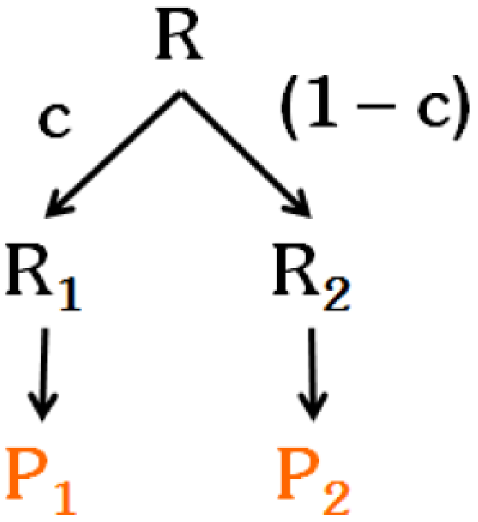
intake, body condition and size, milk,
probability of conception,
probability of survival

Selection Index = $(W_1 \times P_1) + (W_2 \times P_2) + (W_3 \times P_3) + \ldots$

Herd simulation



Animal model



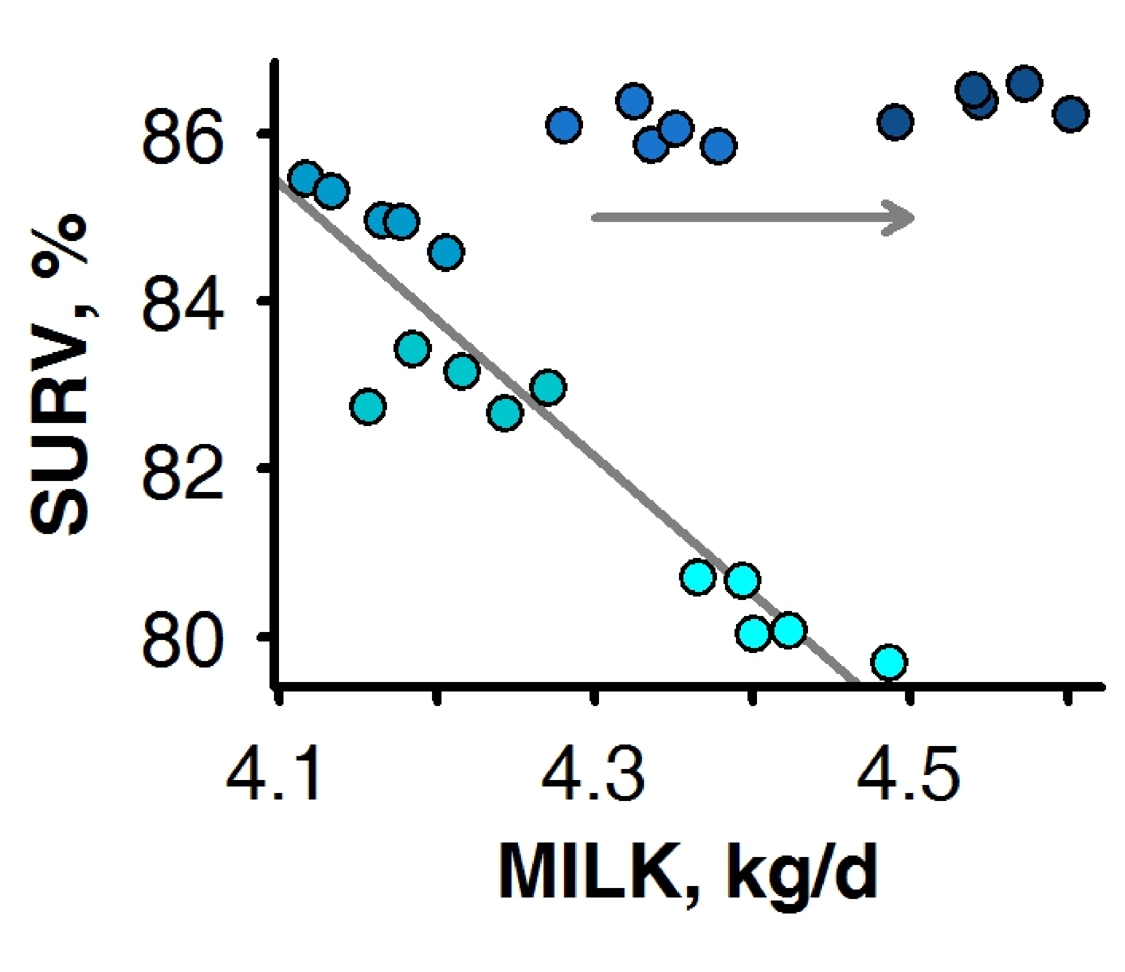
Prediction of individual performance every week:

intake, body condition, milk, bod
probability of conception,
probability of survival

$SelIndex = MILK \times W_{MILK} + PREG \times W_{PREG} + AGE \times \mathbf{W_{AGE}}$

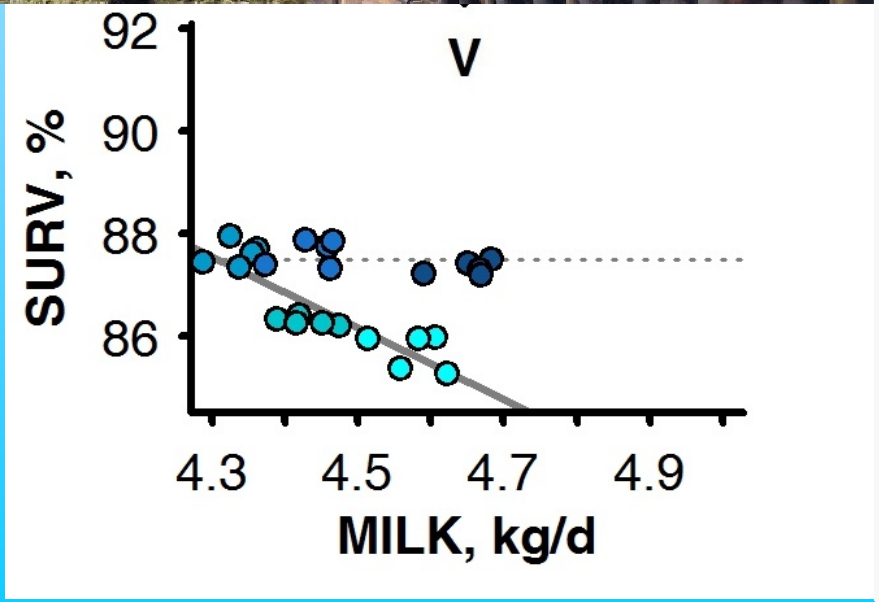
where W_{AGE} = 0, 0.05, 0.1, 0.25 or 0.5

EL% 0.7, 1.1, 3.1, 10.3, 19.3



Increased variability in age improves herd resilience

Emergence of trade-offs is environmentally dependant



Summary Douhard et al.

- In a constant, adequate, environment
  - Positive correlation MY and survival
- In a variable environment
  - Negative correlation MY and survival
- The trade-off avoided by a change in management (accepting extended lactation)
  - Recovery of body reserves is the biological key
- Simulates the development of G x E x M

Next steps

- We have the modelling tools to allow us to optimise the efficiency and resilience goals from a time-related perspective
  - Can ask the “what if” questions
  - Provided that we can describe the local production context

- Translation into practical tools
  - For breeders
  - For farmers

Genomics and Precision Farming Technologies: Synergies

- Considerable number of the limitiations disappear when applying genomics in the context of precision agriculture
- The combination opens up for:
  - Precision mating
  - Tailoring to local production environments

Precision Genomic Management

- Genotyping of females allows precision mating
  - Reducing unwanted recessive genes
  - Increasing favourable gene combinations

- Augmentation of genomic information with information on the animals phenotypic trajectory
  - Prior performance
  - Prior health events, etc.

Precision Genomic Management

- Prediction of an animals probability of:
  - Reproductive success
  - Completing the coming production cycle
- Relativised to the local production environment
  - Herd as own control
  - Weighting of e.g. resilience vs efficiency
- Used to make culling and breeding decisions

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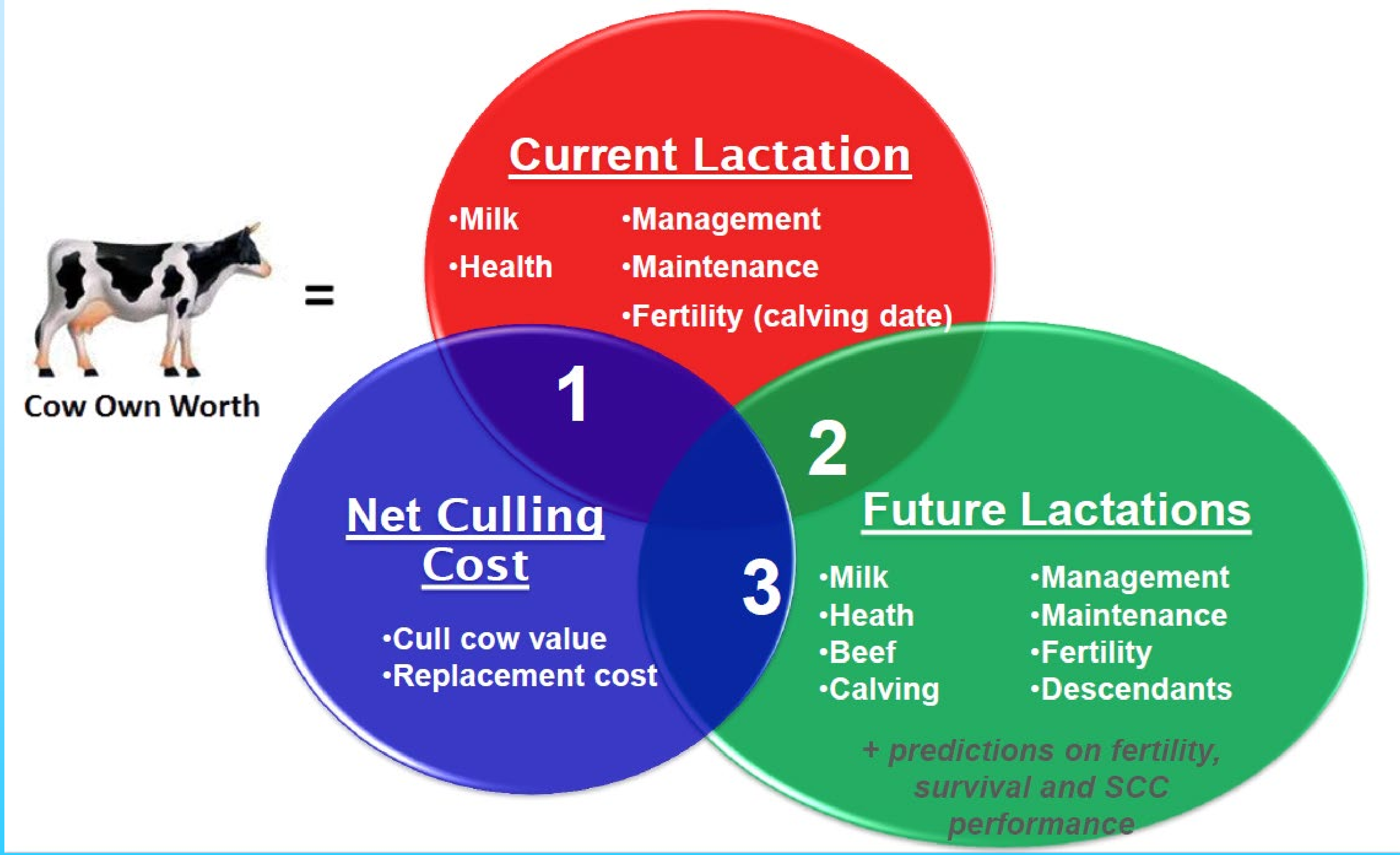
Example: C.O.W. Index

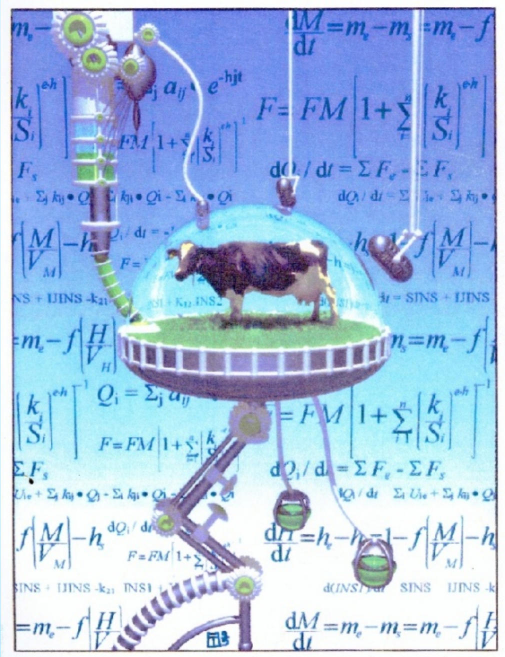


Kelleher et al., (2015)

Challenges (1)

- Optimizing problems
  - How to find the right balance between resilience and production efficiency?
  - Resilience to what? disease, nutritional stress? (Star et al 2007)
- How does this scale up to the farm systems level
  - Achieving the right mix of animals to give better herd level resilience (Tichit et al., 2011)

Challenges (2)



- Uptake in the real world
  - Data overload (Martin-Collado et al., 2018)
  - The need for integrated solutions
  - User-friendliness
  - Demonstrable value for money (Banhazi et al., 2012)
- Societal considerations
  - Technology as a de-humanizing factor
  - Technology as an aid to improve animal well-being

Automatic oestrus detection

All determinants of success are met, reflected in adoption

Survey of 109 farmers globally
41% had activity technologies for oestrus
75% rated it has very useful
(Borchers and Bewley, 2015)

Survey of 512 farmers
41% of AMS farmers
70% of conventional farmers
28% also for young stock
(Steeneveld and Hogeveen, 2015)

500 surveyed conventional farms
15% has it
70% ranked it in top 3 of sensors with benefit
(Edwards et al, 2015)

Automatic lameness detection

Uncertainties about proven reliability and economic value contribute to (s)low adoption

Survey of 109 farmers globally
4.6% had technologies to detect lameness
51.4% considered it as useful
(Borchers and Bewley, 2015)

Survey of 512 farmers
3% of AMS farmers
10% of conventional farmers
(Steeneveld and Hogeveen, 2015)

500 surveyed conventional farms
not listed
(Edwards et al, 2014)

Farmer perceptions

- Farmers with higher IT literacy, and intending to intensify production, more likely to adopt EID technology
- Farmer's beliefs play a significant role in technology uptake
- Ease of use, practicality, clear utility
- Negative feelings about technology adoption (Lima et al 2018)

- 22% of farm owners indicated expectations did not match performance reality
- 26% of farm owners wished for more training support in in the first 2 months (Eastwood et al., 2015)

Concluding Remarks

- The genomics and precision farming technology drives give new synergistic opportunities
- Precision phenotyping is key to:
  - large-scale phenotyping of efficiency
  - large-scale phenotyping of resilience
- On-farm precision genomic management to optimise to local production environments
  - Culling and breeding decision support
  - Including farmer perceptions and cultural context

Thank you for your attention

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Biology vs Measures

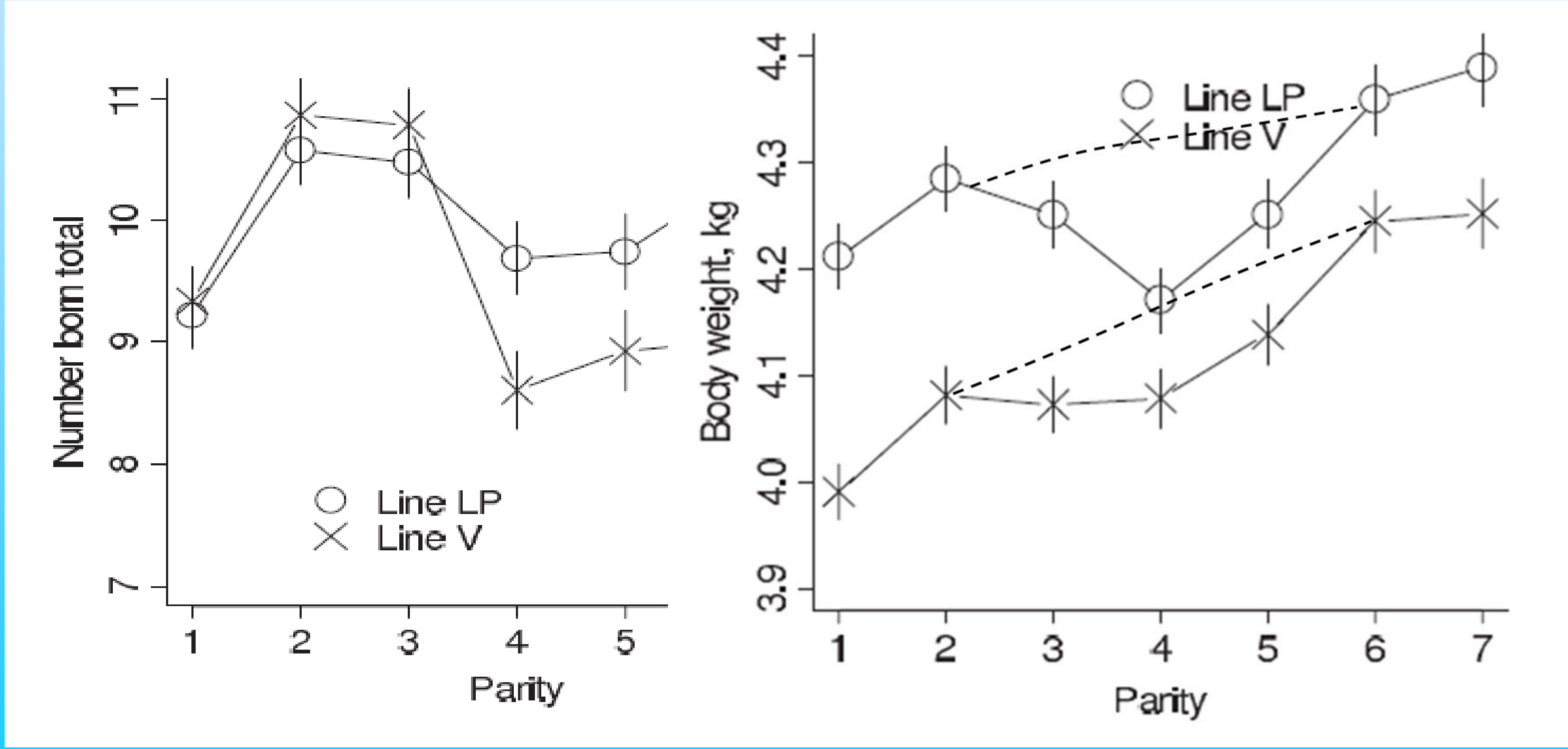
- Biological phenomenon
  - Unlikely that one measure captures the whole phenomenon
  - Distributed across a number of measures
  - Likely that one measure reflects several phenomena

- Biological feature extraction
- Combine features to describe latent process

A little aside: Resilience vs Robustness

Resilience and robustness

- Resilience is the mechanism that allows overall robustness



Theilgaard et al. 2007

Resilience and robustness

- Resilience is the mechanism that allows overall robustness
- The notion of different levels of organisation
  - Robustness is the consequence of an underlying resilience
  - Resilience itself is an emergent property of multiple underlying mechanisms