Genetic Improvement of Beef Cattle: Current Practice and Future Prospects

Alison Van Eenennaam, Ph.D.

Cooperative Extension Specialist

Animal Biotechnology and Genomics

Department of Animal Science

University of California, Davis, USA

Email: alvaneenennaam@ucdavis.edu

Twitter: @BioBeef BLOG: **http://biobeef.faculty.ucdavis.edu**

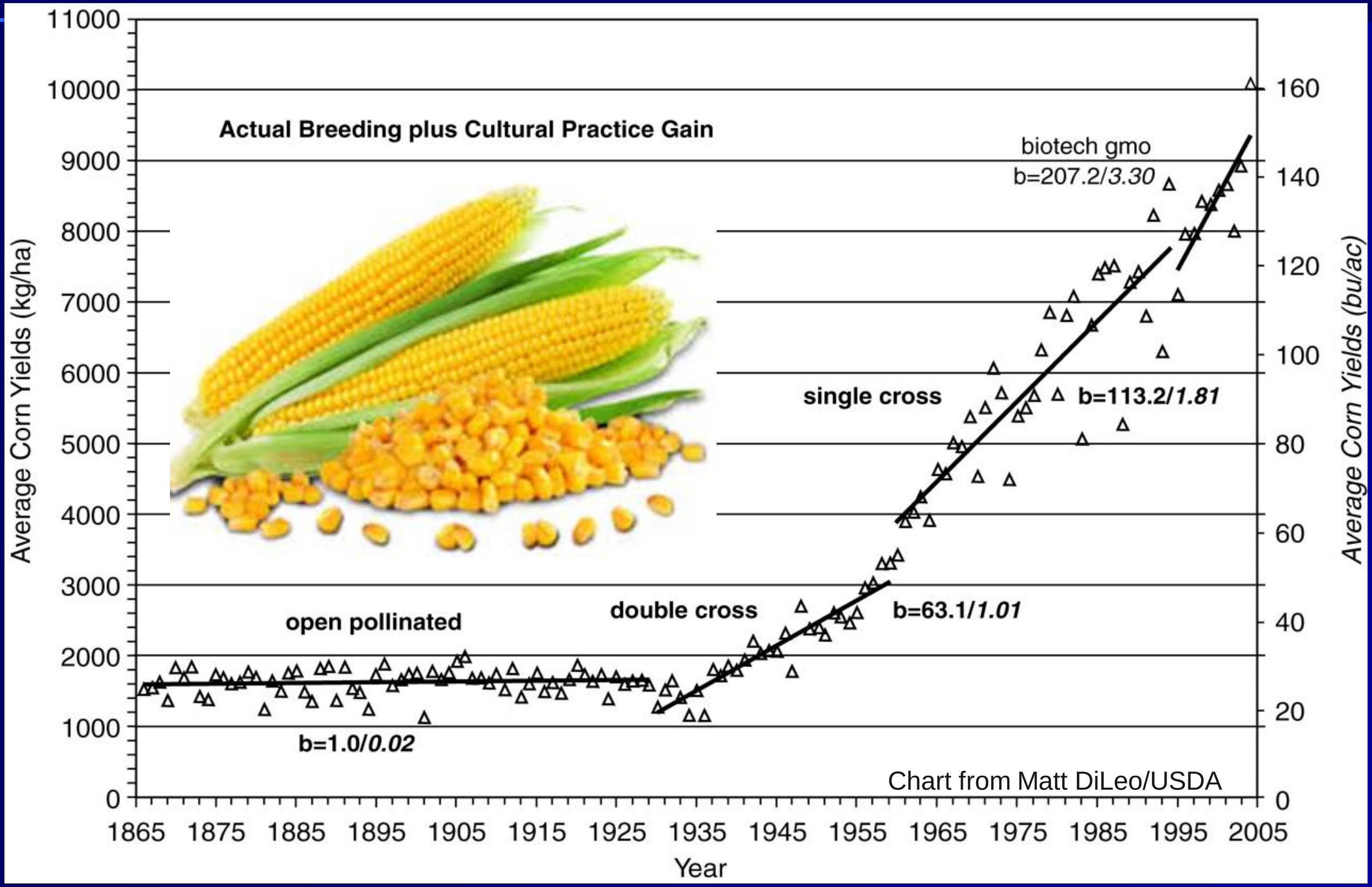
http://animalscience.ucdavis.edu/animalbiotech

Animal breeders have used selection on phenotypes to great effect!





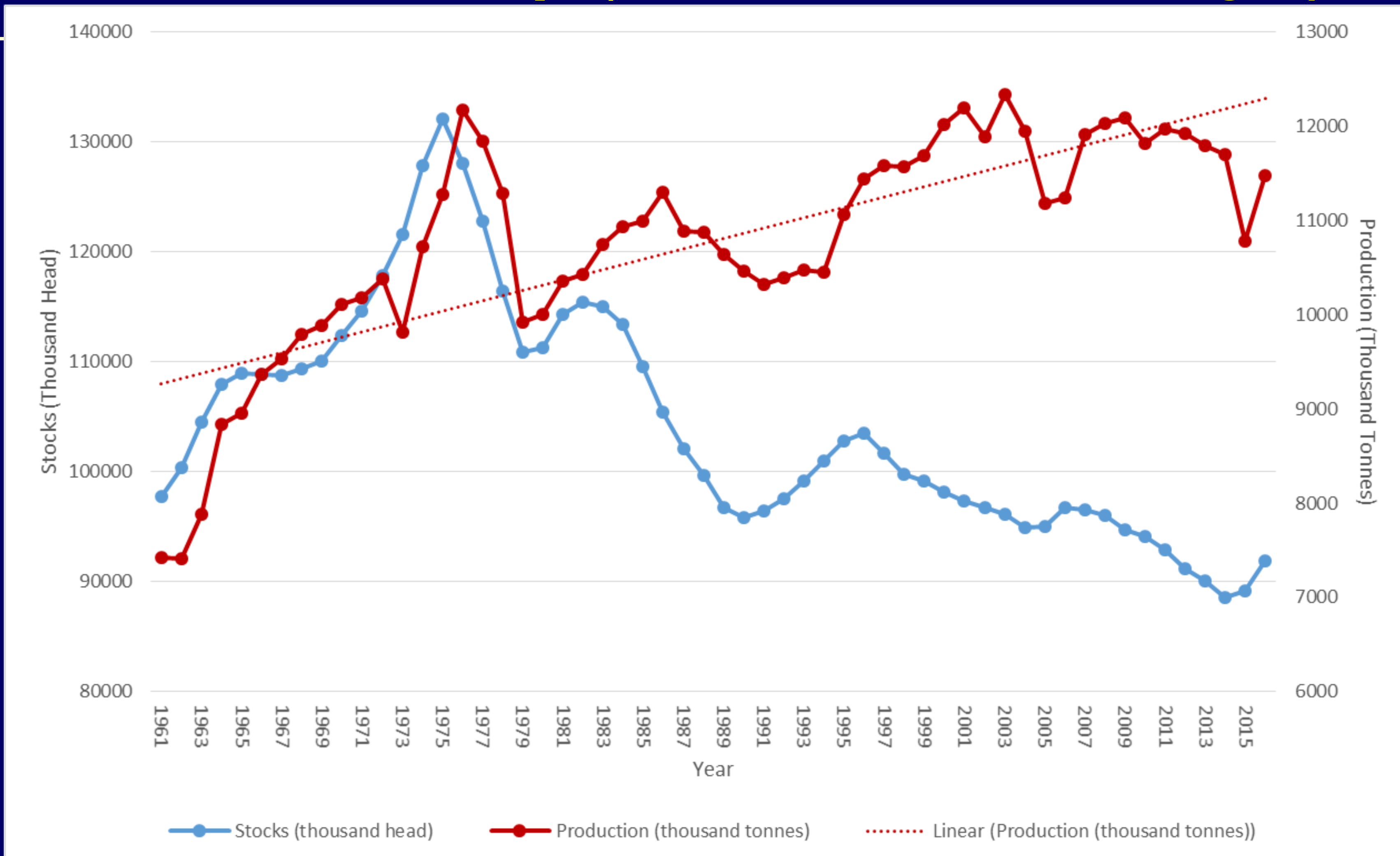

Plant and animal breeders have perhaps the most compelling sustainability story of all time



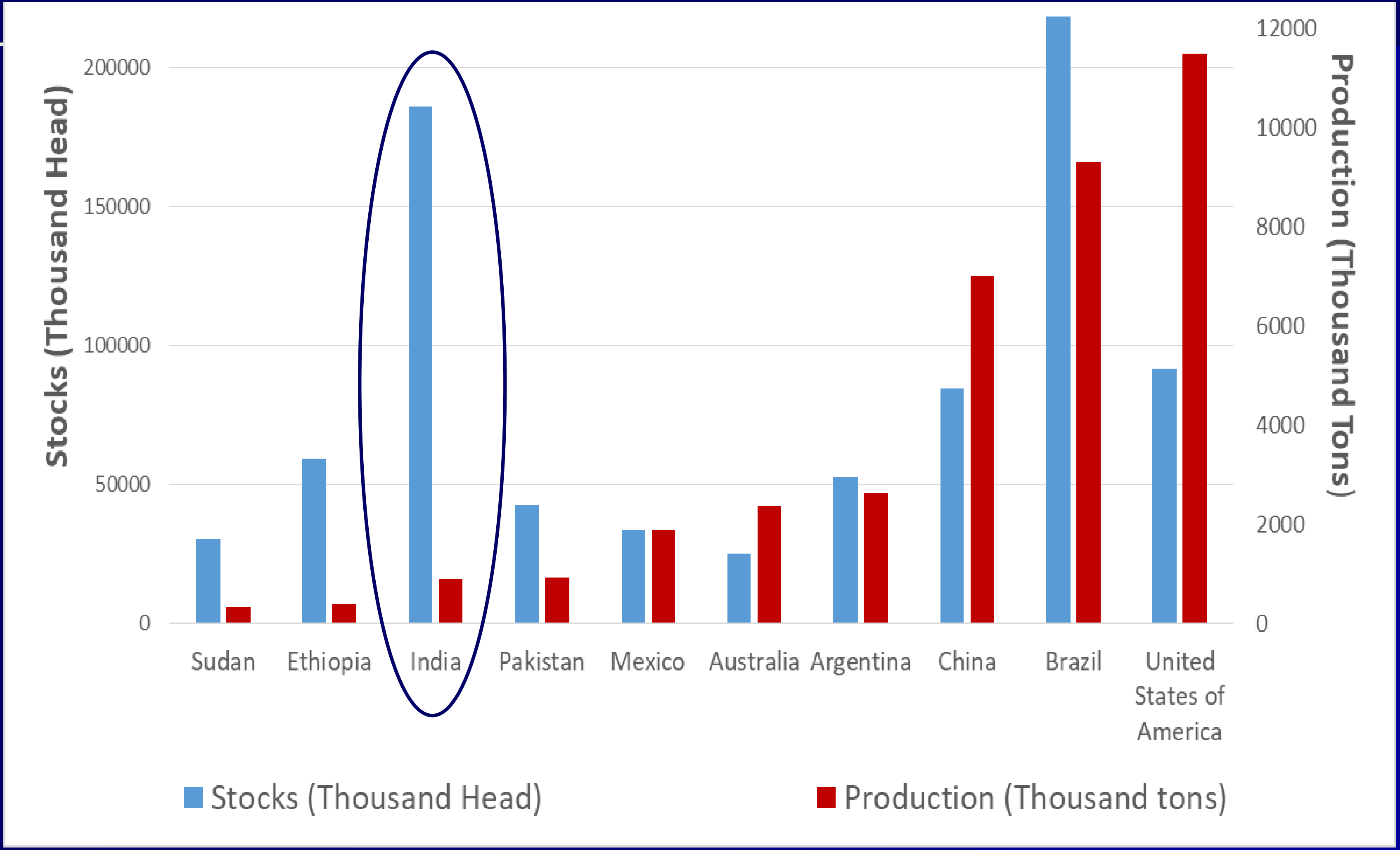
https://grist.files.wordpress.com/2015/12/corn-hybrid-yields.jpeg

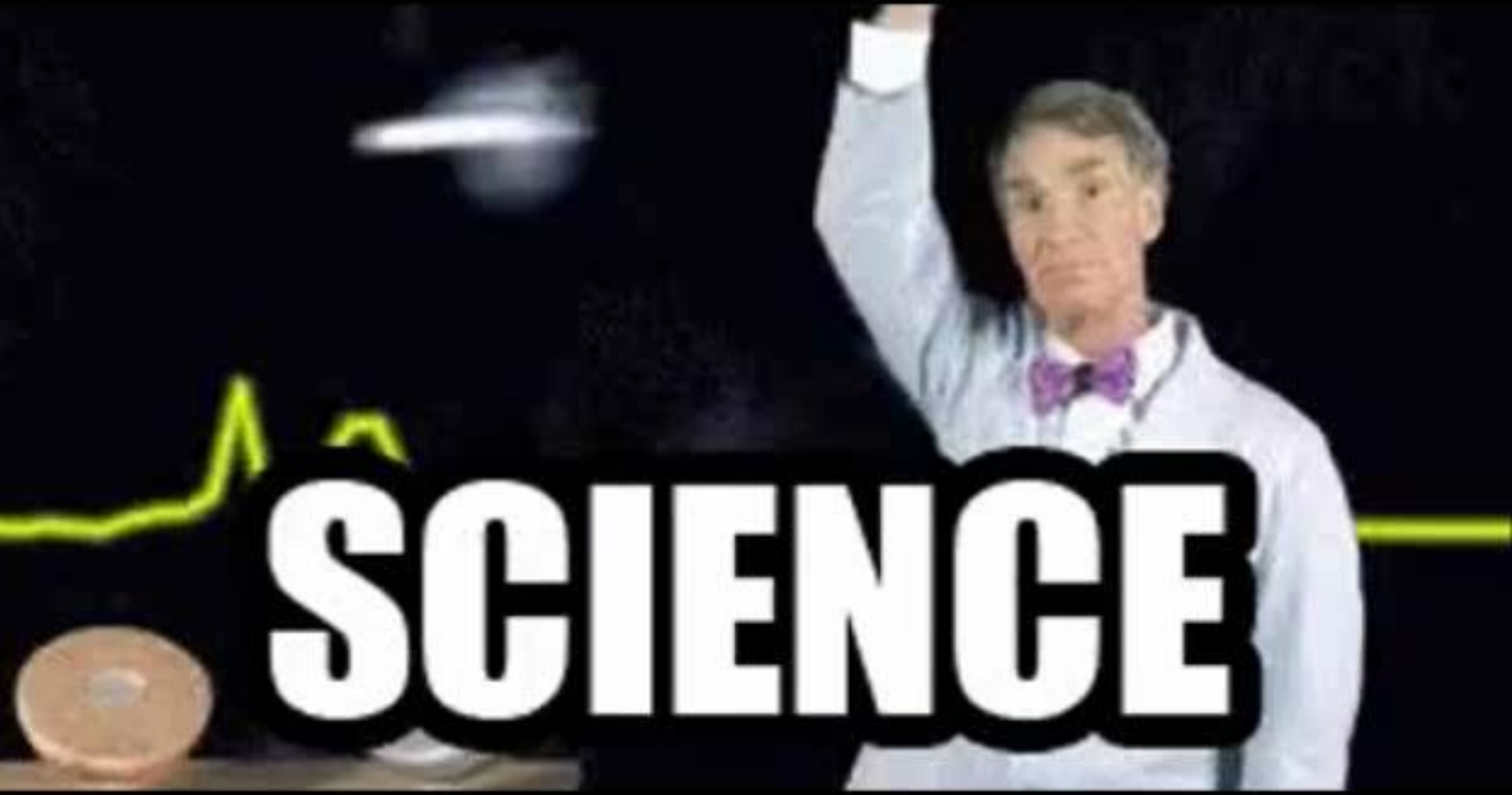
US Cattle Inventory 1961 – 2015

Stocks Down (‘000 Head; blue, left) vs. **Production Up** (‘000 Tonnes; red, right)



2016 Global Beef Production Numbers Cattle numbers ('000 Head; blue, left) vs. Beef production ('000 Tonnes; red, right)




SCIENCE

Time line for beef breeding

Bull purchase/selection

Image adapted from "***More Beef from Breeding***" Workshop (2007). Meat and Livestock (MLA), Australia

Progeny born

Progeny slaughtered

Female progeny used for breeding

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028

Practical Guide to Bull Buying

- Determine marketing strategy
  - Will heifers be retained?
- Determine management level
  - Nutrition
  - Labor
- Assure bulls are reproductively sound
  - BSE
- Check for structural soundness

EPDs

- Best tool for selecting for performance traits
- Uses all information: actual measurement, relatives, environment, genomics
- Risk management tool

Information sources for EPDs

What EPDs are available?

EPD Definitions

	BULL A	BULL B
Calving ease direct	10	6
Birth weight	2.0	3.5
Weaning weight direct	20	22
Yearling weight	40	52
Yearling height	0.3	0.6
Milk	3	-2
Maternal weaning weight	13	9
Gestation length	-0.1	1.1
Calving ease maternal	4	6
Mature daughter height	0.5	1.0
Mature daughter weight	0	30
Scrotal circumference	0.1	-0.45
Heifer pregnancy	6	9
Udder	0.4	-0.1
Teat	0.5	0
Carcass weight	2.0	20
Percent retail cuts	0	0.2
Marbling	0	-0.3
IMF	3.0	1.0
Rib-eye area	0.06	1.6
Fat thickness	-0.01	-0.09
Rump fat thickness	-0.03	-0.10
Tenderness	-0.01	0.1
Days to finish	15	10
Residual average daily gain	-0.1	0.05
Residual feed intake	-0.05	0.10
Dry matter intake	0.2	0.4
Stayability	10	6
Maintenance energy	0	10
Docility	6	2

EPD

+65 lbs

+50 lbs

Direct weaning weight

Expect the average difference in offspring to be 15 pounds.

EPD

+25 lbs

Direct weaning weight

+15 lbs

Expect the average difference in offspring of the sires daughters to be 10 pounds.

Calving Ease

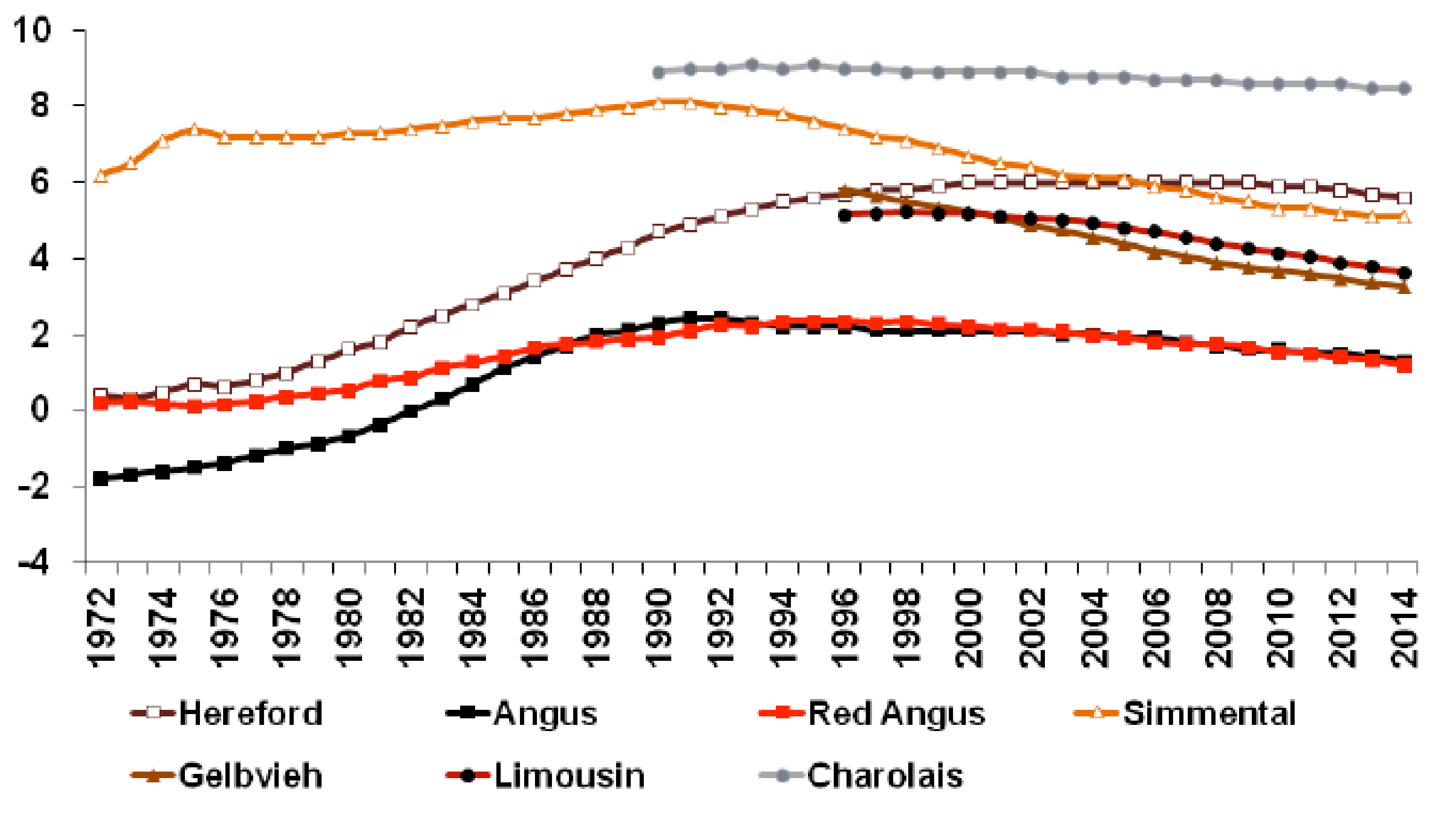
- Bull – Calving Ease Direct
  – Heifers/Cows
  – Time spent with calving females
- Heifers – Calving Ease Maternal
  – If replacements are kept
  – Does not replace buying CED bull

Be careful not to put too much emphasis on selection for calving ease

Smallest calf

An 850-pound Angus cow, owned by Paul Utz of Madison, Va., licks the face of her calf. Weighing 16 pounds at birth, the calf is the world's smallest, according to officials at the Guiness Book of World Records. (AP Laserphoto)

Birth Weight Trends



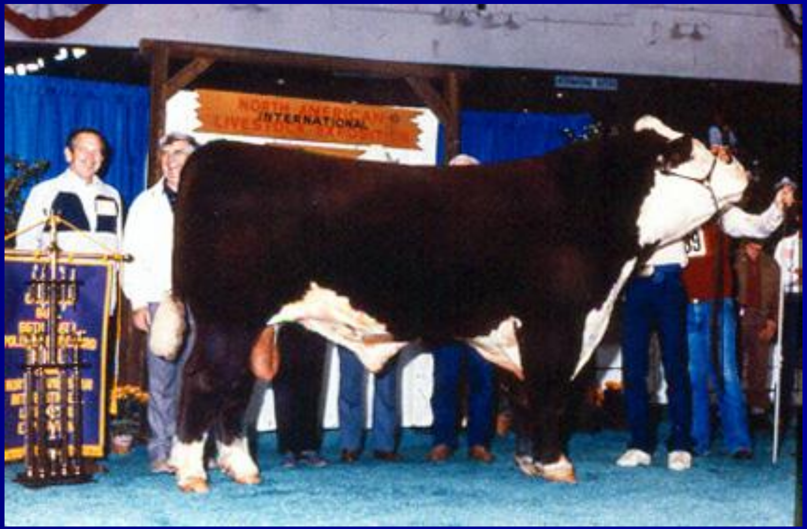
Growth

- Use EPD closest to marketing endpoint
  - Weaning Wt EPD
  - Yearling Wt EPD
  - Carcass Wt EPD
- Be aware of correlated traits
  - Milk
  - Mature Size
  - Calving Ease

1953. Grand Champion Angus Female, International, 1953

1950. Grand Champion Steer, International, weighing 1025 lbs

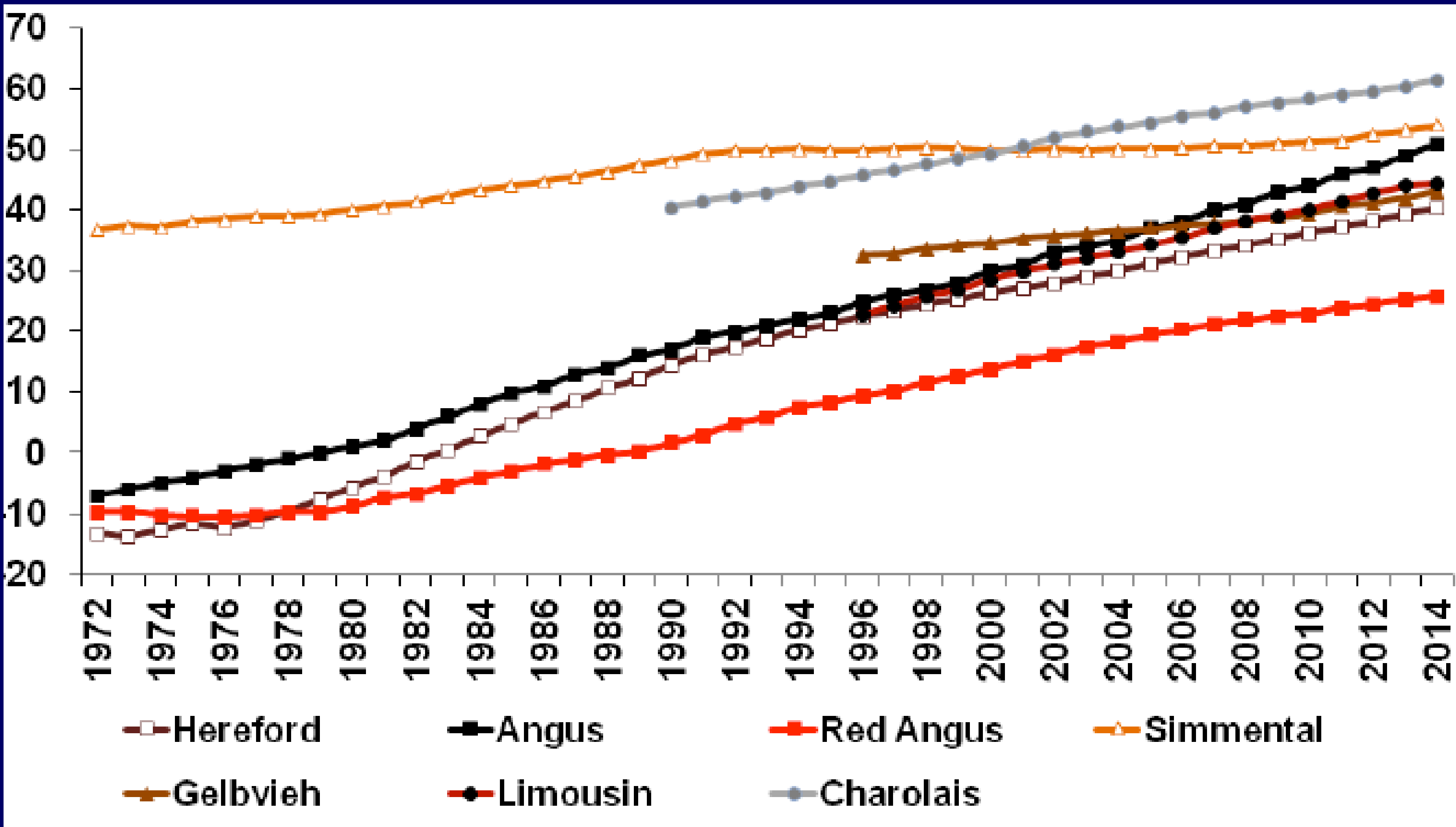
1986. "Coblepond New Yorker" weighed 2529 lbs and measured 65 inches tall at 35 mos. (Frame 10) when he was Denver Champion.



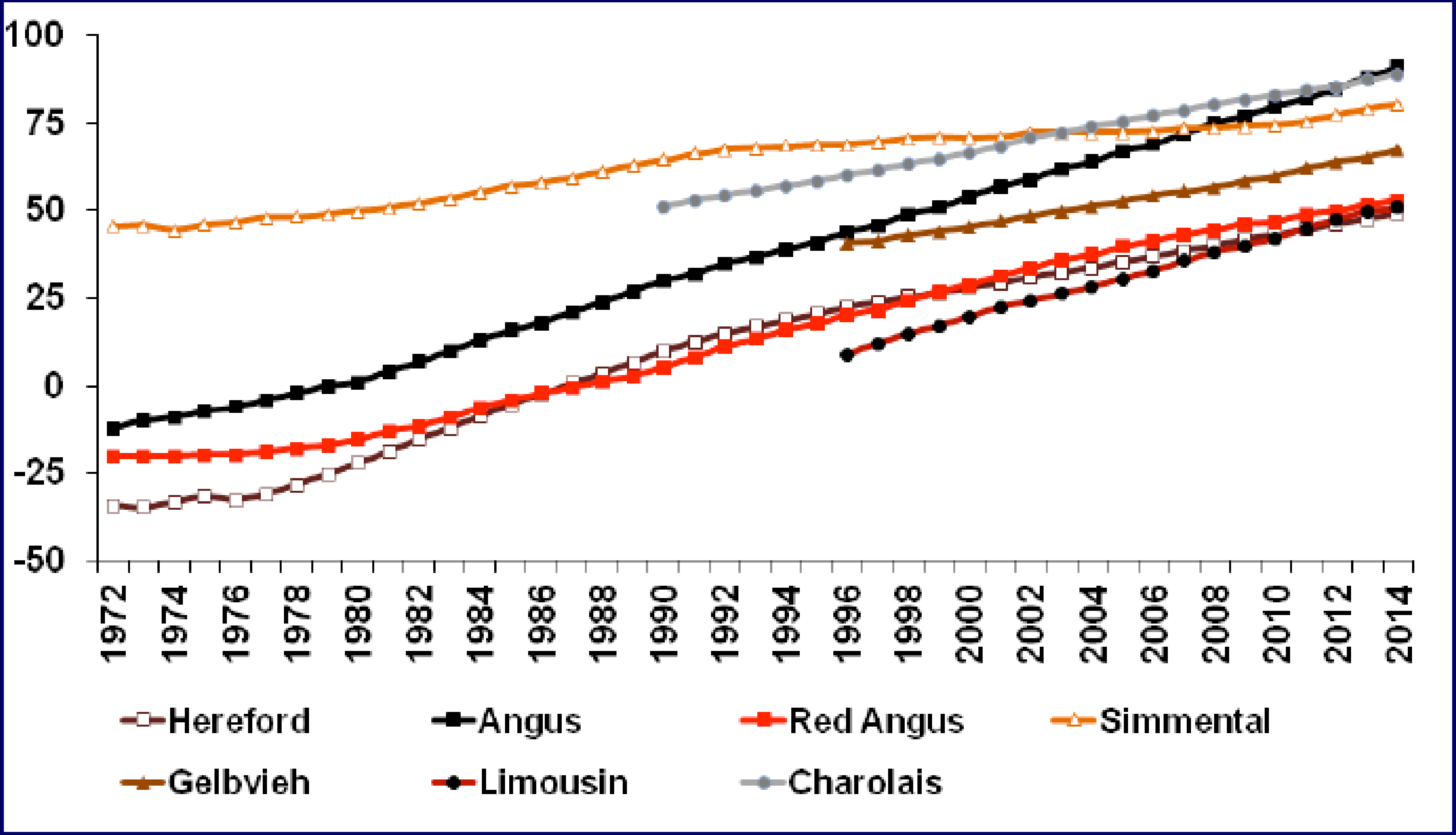
1988 Grand Champion Bull, National Polled Hereford Show (frame 10).

Images from Harlan Ritchie's historical review of type
https://www.msu.edu/~ritchieh/historical/cattletype.html

Weaning Weight Trends



Yearling Weight Trends

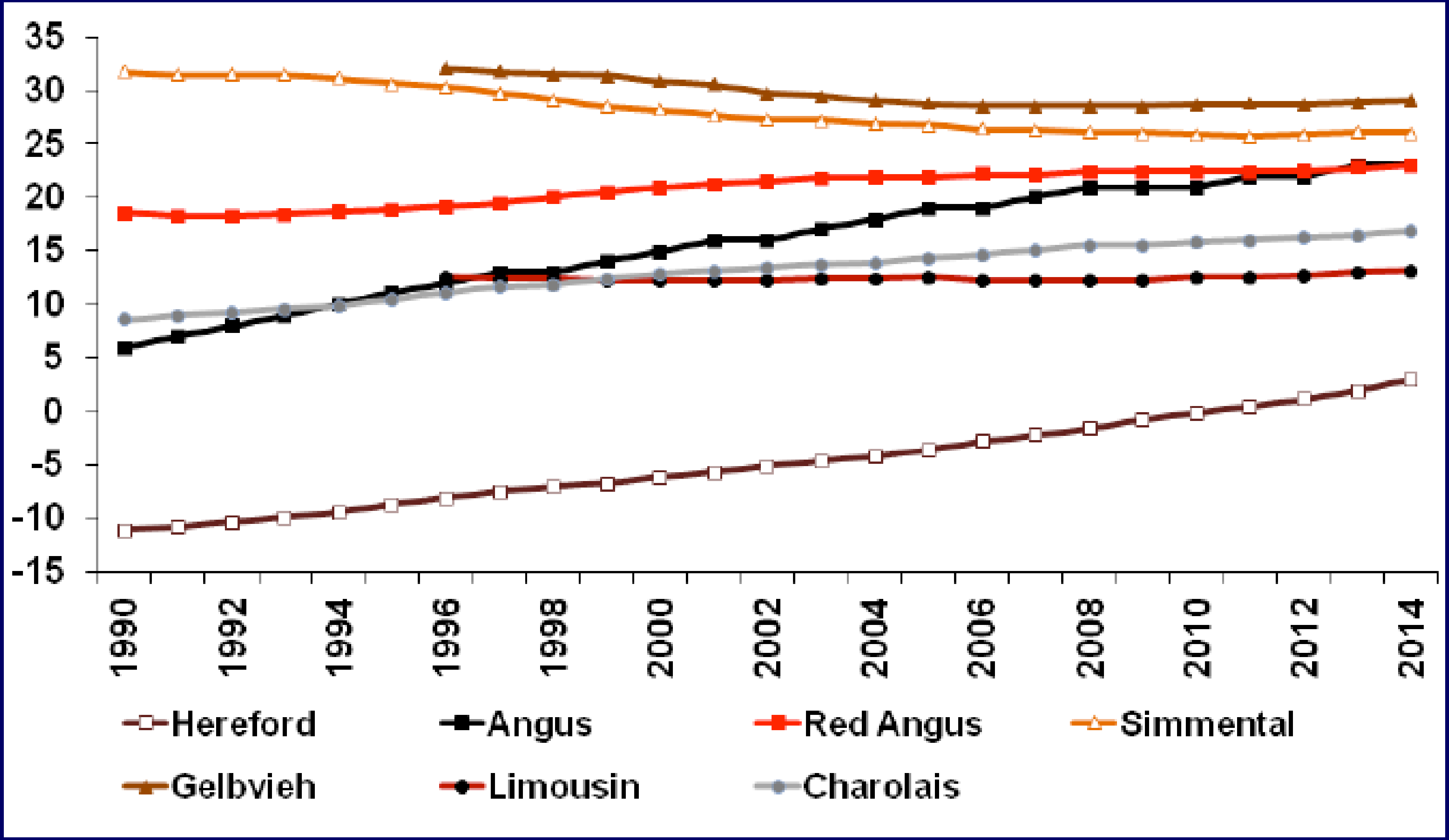


BIF Proceedings 2016

Maternal

- Milk
- Reproduction
  - Heifer Pregnancy
  - 30-Month Pregnancy
  - Stayability
  - Sustained Cow Fertility

Milk Trends



BIF Proceedings 2016

When making selection decisions to improve fertility – which group of cattle should selection focus upon?

1. Bulls
2. Cows
3. Heifers

Genetic composition of the herd:

87% of genetic composition of calf crop is determined by the sires used over the last 3 generations

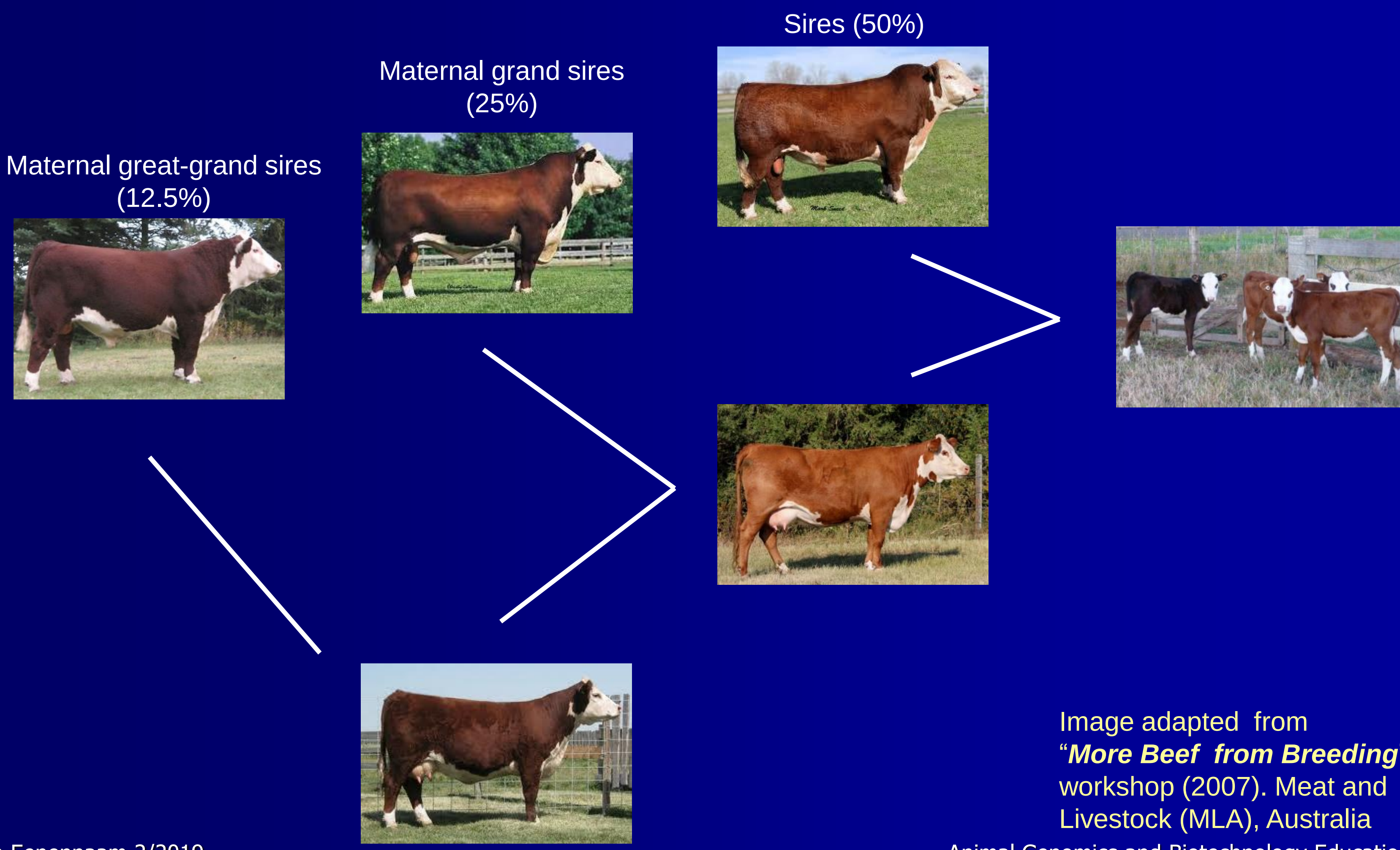


Image adapted from "***More Beef from Breeding***" workshop (2007). Meat and Livestock (MLA), Australia

Carcass

- Carcass Wt EPD
- Quality Factors
  - Marbling EPD
  - % IMF EPD
- Yield Factors
  - Fat EPD
  - Ribeye Area EPD

Other

- Disposition
  - Docility EPD
- Scrotal Circumference
  - SC EPD
  - Actual Measurement
- Color/Horned-Polled
  - Homozygous vs Double bred
  - Carrier

30

PVF Insight 12

NB Magic Sugar

S A V Brilliance

PVF Missie

Triple C Majic Man

NB Sugar & Spice

CE	BW	WW	YW	MCE	Milk	MWW	Marb	REA	API
14	-0.6	62	104	8	30	61	0.27	1.2	131

2018 Purebred Simmental Percentile Table

- Purebred
- Fullblood
- Simbrah
- Hybrid
- Top Fifty Sires
- Possible Change

%	API	TI	CE	BW	WW	ADG	YW	MCE	MLK	MWW	STY	DOC	CWT	YG	MRB	BF	REA	SF
1	163.73	86.19	18.4	-2.4	85.8	0.30	131.1	15.7	32.7	68.5	19.3	15.2	53.8	-0.49	0.49	-0.100	1.17	-0.51
2	159.11	84.28	17.4	-1.9	83.3	0.29	126.8	14.9	31.4	66.8	18.5	14.7	50.9	-0.46	0.45	-0.094	1.12	-0.48
3	156.19	83.07	16.8	-1.6	81.7	0.28	124.1	14.3	30.5	65.6	17.9	14.4	49.0	-0.45	0.42	-0.091	1.09	-0.47
4	153.99	82.16	16.3	-1.4	80.5	0.27	122.1	13.9	29.9	64.8	17.5	14.2	47.6	-0.44	0.40	-0.088	1.07	-0.46
5	152.20	81.42	[illegible]	-1.2	79.5	0.27	120.4	13.6	29.4	64.1	17.2	14.0	46.5	-0.43	0.39	-0.086	1.05	-0.45
10	146.07	78.87	14.5	-0.5	76.2	0.25	114.7	12.4	27.6	61.7	16.0	13.3	42.5	-0.40	0.33	-0.079	0.98	-0.42
15	141.93	77.16	13.6	-0.1	73.9	0.24	110.9	11.6	26.4	60.1	15.2	12.9	39.9	-0.38	0.30	-0.074	0.94	-0.40
20	138.63	75.79	12.9	0.3	72.1	0.23	107.8	11.0	25.4	58.9	14.6	12.5	37.8	-0.37	0.27	-0.070	0.90	-0.39
25	135.81	74.63	12.3	0.6	70.6	0.22	105.2	10.5	24.6	57.8	14.1	12.2	36.0	-0.35	0.24	-0.067	0.87	-0.37
30	133.26	73.57	11.7	0.9	69.2	0.22	102.8	10.0	23.9	56.8	13.6	11.9	34.4	-0.34	0.22	-0.063	0.84	-0.36
35	130.92	72.60	11.2	1.1	68.0	0.21	100.7	9.5	23.2	55.9	13.1	11.7	32.9	-0.33	0.20	-0.061	0.82	-0.35
40	128.68	71.67	10.7	1.3	66.7	0.20	98.6	9.1	22.5	55.0	12.7	11.5	31.4	-0.32	0.18	-0.058	0.80	-0.34
45	126.53	70.78	10.3	1.6	65.6	0.20	96.6	8.7	21.9	54.2	12.3	11.2	30.1	-0.31	0.16	-0.056	0.77	-0.33
50	124.40	69.90	9.8	1.8	64.4	0.19	94.6	8.3	21.3	53.4	11.9	11.0	28.7	-0.30	0.14	-0.053	0.75	-0.32
55	122.27	69.02	9.3	2.0	63.2	0.18	92.6	7.9	20.7	52.6	11.5	10.8	27.3	-0.29	0.12	-0.050	0.73	-0.31
60	120.12	68.13	8.9	2.3	62.1	0.18	90.6	7.5	20.1	51.8	11.1	10.5	26.0	-0.28	0.10	-0.048	0.70	-0.30
65	117.88	67.20	8.4	2.5	60.8	0.17	88.5	7.1	19.4	50.9	10.7	10.3	24.5	-0.27	0.08	-0.045	0.68	-0.29
70	115.54	66.23	7.9	2.7	59.6	0.16	86.4	6.6	18.7	50.0	10.2	10.1	23.0	-0.26	0.06	-0.043	0.66	-0.28
75	112.99	65.18	7.3	3.0	58.2	0.16	84.0	6.1	18.0	49.0	9.7	9.8	21.4	-0.25	0.04	-0.040	0.63	-0.27
80	110.17	64.01	6.7	3.3	56.7	0.15	81.4	5.6	17.2	47.9	9.2	9.5	19.6	-0.23	0.01	-0.036	0.60	-0.25
85	106.87	62.64	6.0	3.7	54.9	0.14	78.3	5.0	16.2	46.7	8.6	9.1	17.5	-0.22	-0.02	-0.032	0.56	-0.24
90	102.73	60.93	5.1	4.1	52.6	0.13	74.5	4.2	15.0	45.1	7.8	8.7	14.9	-0.20	-0.05	-0.027	0.52	-0.22
95	96.60	58.39	3.7	4.8	49.3	0.11	68.8	3.0	13.2	42.7	6.6	8.0	10.9	-0.17	-0.11	-0.020	0.45	-0.19
Avg	124.40	69.90	9.8	1.8	64.4	0.19	94.6	8.3	21.3	53.4	11.9	11.0	28.7	-0.30	0.14	-0.053	0.75	-0.32

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Production									Maternal						
CED Acc	BW Acc	WW Acc	YW Acc	RADG Acc	DMI Acc	YH Acc	SC Acc	DOC Acc	HP Acc	CEM Acc	Milk Acc	MkH MkD	MW Acc	MH Acc	EN$
+19 .75	-3.6 .85	+53 .79	+98 .64	+.22 .46	+.19 .46	+.6 .64	+.50 .69	+14 .55	+13.4 .29	+18 .22	+28 .28	5 5	+14 .47	+0 .23	-9.09

Carcass					Usnd	$Values					
CW Acc	Marb Acc	RE Acc	Fat Acc	Grp Prog	UGrp UProg	Wean	Feedlot	Grid	$QG	$YG	Beef
+32 .50	-.04 .54	+.55 .52	+.085 .49	5 12	13 34	62.55	60.09	-1.35	2.6	-3.95	77.15

	Production								Maternal					Carcass			
Accuracy	CED	BW	WW	YW	RADG	DMI	YH	SC	Doc	HP	CEM	Milk	MW	MH	CW	Marb	RE	Fat
.05	9.7	2.55	14.9	24.3	.092	.730	.42	.76	16.7	7.7	10.4	9.5	38	.54	20	.29	.30	.041
.10	9.2	2.42	14.1	23.0	.087	.691	.40	.72	15.8	7.3	9.9	9.0	36	.51	19	.28	.28	.039
.15	8.7	2.28	13.3	21.7	.082	.653	.38	.68	14.9	6.9	9.3	8.5	34	.49	18	.26	.27	.037
.20	8.2	2.15	12.6	20.5	.077	.614	.35	.64	14.0	6.5	8.8	8.0	32	.46	17	.25	.25	.034
.25	7.7	2.02	11.8	19.2	.073	.577	.33	.60	13.2	6.1	8.2	7.5	30	.43	16	.23	.23	.032
.30	7.2	1.88	11.0	17.9	.068	.538	.31	.56	12.3	5.7	7.7	7.0	28	.40	15	.22	.22	.030
.35	6.7	1.75	10.2	16.6	.063	.500	.29	.52	11.4	5.3	7.1	6.5	26	.37	14	.20	.20	.028
.40	6.2	1.61	9.4	15.4	.058	.462	.26	.48	10.5	4.9	6.6	6.0	24	.34	13	.18	.19	.026
.45	5.6	1.48	8.6	14.1	.053	.423	.24	.44	9.7	4.5	6.0	5.5	22	.31	12	.17	.17	.024
.50	5.1	1.34	7.9	12.8	.048	.385	.22	.40	8.8	4.1	5.5	5.0	20	.29	11	.15	.16	.022
.55	4.6	1.21	7.1	11.5	.044	.346	.20	.36	7.9	3.7	4.9	4.5	18	.26	10	.14	.14	.019
.60	4.1	1.08	6.3	10.2	.039	.308	.18	.32	7.0	3.3	4.4	4.0	16	.23	9	.12	.12	.017
.65	3.6	.94	5.5	9.0	.034	.269	.15	.28	6.1	2.9	3.8	3.5	14	.20	7	.11	.11	.015
.70	3.1	.81	4.7	7.7	.029	.231	.13	.24	5.3	2.4	3.3	3.0	12	.17	6	.09	.09	.013
.75	2.6	.67	3.9	6.4	.024	.192	.11	.20	4.4	2.0	2.7	2.5	10	.14	5	.08	.08	.011
.80	2.1	.54	3.1	5.1	.019	.154	.09	.16	3.5	1.6	2.2	2.0	8	.11	4	.06	.06	.009
.85	1.5	.40	2.4	3.8	.015	.115	.07	.12	2.6	1.2	1.6	1.5	6	.09	3	.05	.05	.006
.90	1.0	.27	1.6	2.6	.010	.077	.04	.08	1.8	.8	1.1	1.0	4	.06	2	.03	.03	.004
.95	.5	.13	.8	1.3	.005	.038	.02	.04	.9	.4	.5	.5	2	.03	1	.02	.02	.002

Historically not all cattle breeding objectives have been economic

Photo taken in 1949 at Red Bluff Bull Sale, CA.
Kindly provided by Cathy Maas from Crowe Hereford Ranch, Millville, CA.

Selection Index

- Allows comparison on single value
- Weights traits according to economic importance
- Selection index

$$= a_1EPD_1 + a_2EPD_2 + \ .\ \ .\ \ .\ + a_kEPD_k$$

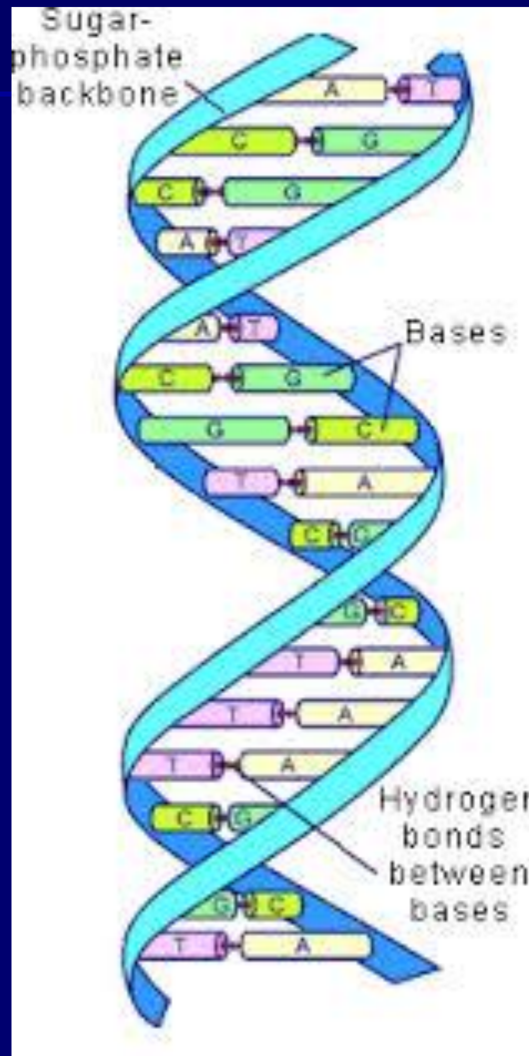
Selection Index

- Easy to use, selection based on one value
- Should be aware of EPD in index that is not of value to your beef operation
- If missing relevant EPDs, use SI in tandem with those EPDs

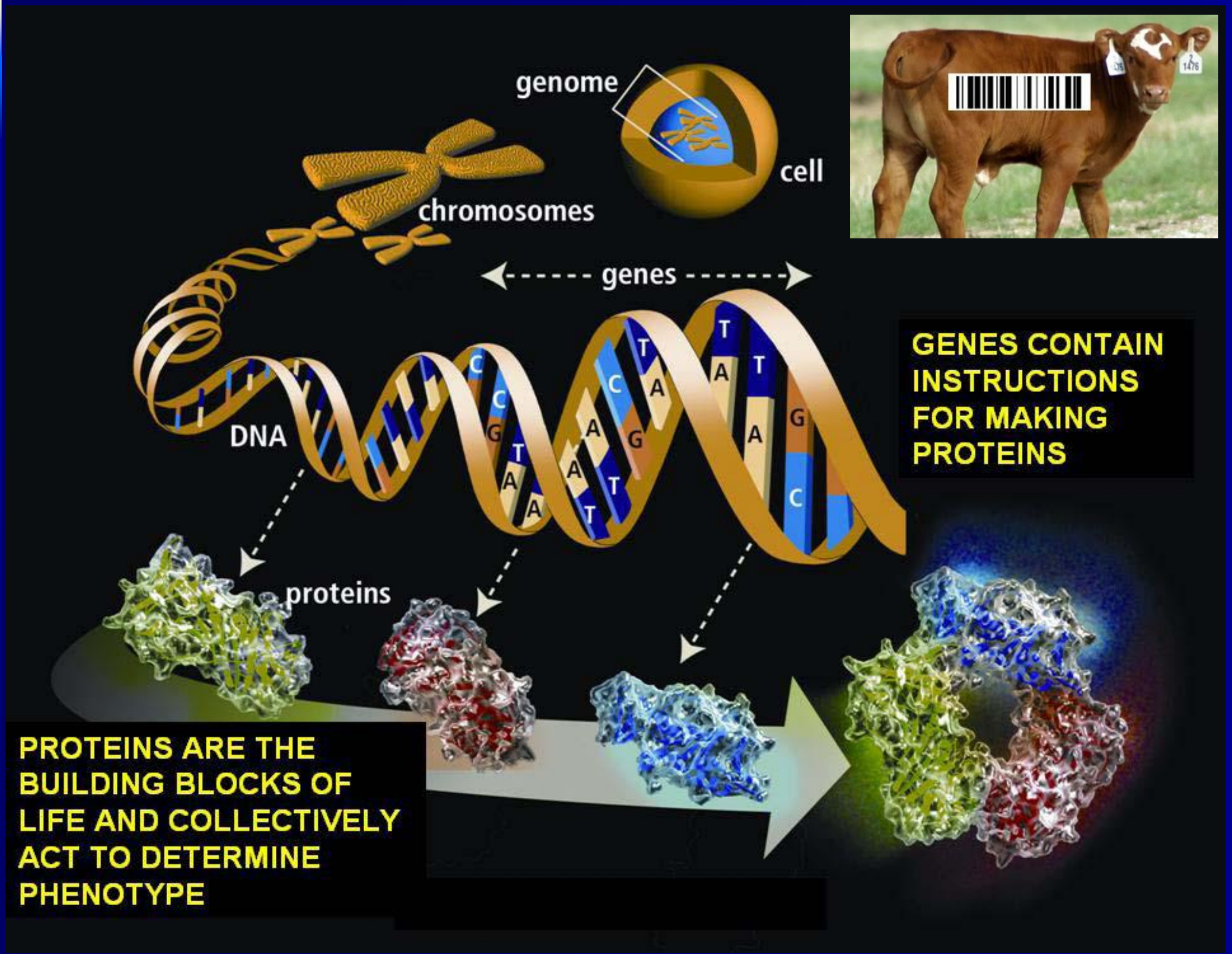
Many beef breeds have indexes which combine EPDs according to economics

TERMINAL	MATERNAL
$B, $F, $G (Angus)	$W, $EN (Angus)
TI (Simmental)	API (Simmental)
CHB$ (Hereford)	BMI$, BII$, CEZ$ (Hereford)
MTI (Limousin)	HerdBuilder (Red Angus)
EPI and FPI (Gelbvieh)	$Cow (Gelbvieh)
Charolais	$M (Beefmaster)
GridMaster (Red Angus)	
$T (Beefmaster)	$Profit (Topline-Leachman Bulls)

Genomics


Sugar-
phosphate
backbone
Bases
Hydrogen
bonds
between
bases

The bovine genome is similar in size to the genomes of humans, with an estimated size of 3 billion base pairs.



Human & cattle genomes are 83% identical

1000 Bull Genomes Run 6

2703 Sequenced Animals, 11x

~55 Breeds: Dairy, Beef, Dual Purpose, Crosses, Composites

2703 x 11 x 3 billion= 90,000,000,000,000

Slide courtesy Ben Hayes, QAAFI

1000 Bull Genomes Run 6

86.5 million single-nucleotide polymorphisms (SNPs) and 2.5 million small insertion deletions

Run 6 – Taurus only

44.7 million filtered variants

43 million SNP, 1.7 million Indel

Run 6 – Taurus Indicus

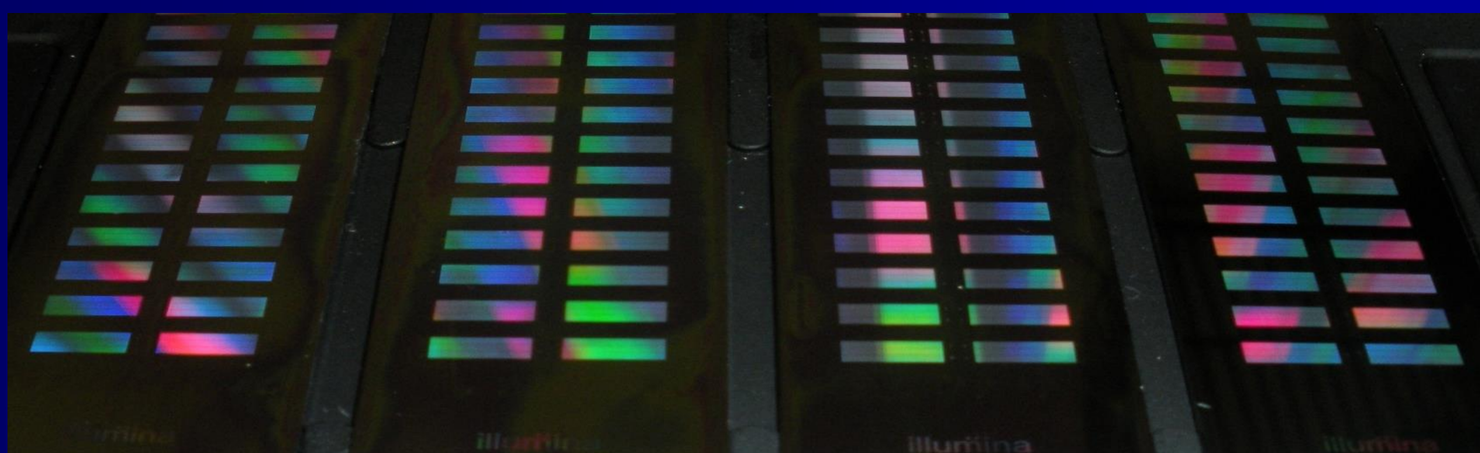
86.5 million filtered variants

84 million SNP, 2.5 million Indel

Hayes, B. J. & Daetwyler, H. D. 1000 Bull Genomes Project to Map Simple and Complex Genetic Traits in Cattle: Applications and Outcomes. *Annual review of animal biosciences*, doi:10.1146/annurev-animal-020518-115024 (2018).

High-throughput genotyping technology enabled the development of high density "SNP chips"

The 2009 sequencing of the bovine genome allowed for the development of a 50,000 SNP chip, also known as the "50K"



We can use these SNPs for “genomic” selection?

TRAINING POPULATION

1,000s animals
- Phenotypes
- Genotypes

Training = estimate the value of every chromosome fragment contributing variation in a population with phenotypic observations

Prediction = the results of training can then be used to develop prediction equations to predict the merit of new animals (e.g. young bulls)

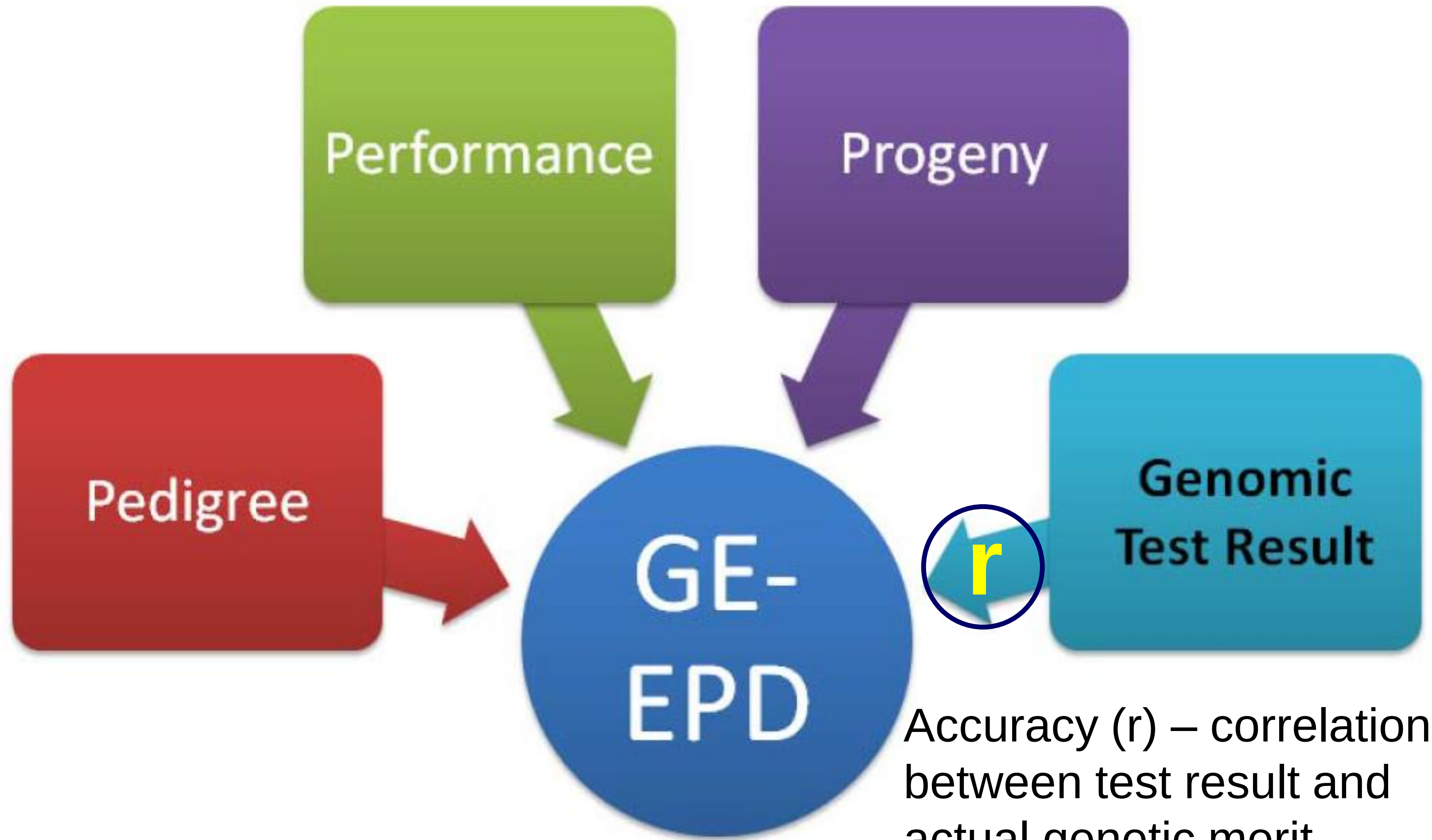
Angus: Current implementation size

- 7.7M birth weights
- 8.4M weaning weights
- 4.1M post-weaning gain records
- 1.5M heifer calving ease scores
- 112K carcass records
- 1.8M ultrasound records
- 19K individual intake records
- 237K docility scores
- 57K heifer pregnancy observations
- 199K mature cow weights

Slide courtesy of Steve Miller 5/9/2017

AGI

Information sources for EPDs – DNA just one source of data for GE-EPD



Accuracy (r) – correlation between test result and actual genetic merit

Genomic-Enhanced EPDs (GE-EPD)

Genomics in National Cattle Evaluation (NCE)

- Currently several breeds are using genomic information in their national cattle evaluation programs
  - Angus
  - Red Angus
  - Limousin
  - Simmental
  - Beefmaster
  - Hereford
  - Gelbvieh
  - Charolais
  - Santa Gertrudis
  - Brangus
- Other breeds are trying to incorporate genomic information
- Virtually only National Cattle Evaluation traits – only traits with enough data

How much do genetic tests cost?

- ~ $13-20 for parentage testing
- ~$20-$30 per animal for a single mutation test for a disease or trait
- $75-90 for the high-density SNP chips for genomic-enhanced EPDs.
- $45-50 for the low-density imputation chips.

Breed associations work to include that genomic information to provide genomic-enhanced EPDs (GE-EPD) that have improved accuracy due to the inclusion of the genomic information in the EPD calculations.

If multiple tests can be performed on a single DNA sample or a large volume of samples is tested then the cost per test is reduced.

Additional costs can include the cost of DNA cards, sample collection, sample storage and shipping and sample processing, again depending on sample type, test and application.

There are several tests that are being marketed for use on commercial cattle that are not directly part of a breed association genetic evaluation program.

- **GeneMax Advantage** ($39) and **GeneMax Focus** ($17). Distributed by Angus Genetics Inc. (AGI) and marketed by Zoetis® for cattle that are at least 75% Angus.
- **PredicGEN** ($19.50) is a test marketed by Zoetis® as "a heifer selection tool for straight-bred or crossbred British/Continental animals"
- **The Igenity Beef Profile** ($29) marketed by Neogen® as "DNA profiles for crossbred and purebred cattle." Predictions for weaning weight, yearling weight and hot carcass weight for a total of 16 traits scored on a 1–10 scale, plus two new selection indexes."The Igenity profile was designed and validated for crossbred or straightbred cattle with backgrounds **of Angus, Red Angus, Simmental, Hereford, Limousin and Gelbvieh**
- **There aren't yet any independent, peer-reviewed papers documenting the field performance of these tests for commercial cattle.**

Crossbreeding

- Should always be a consideration for commercial cattle producers
- Greatest benefit to reproduction and longevity
- Rule of thumb – no females with >75% one breed!

Website: eBEEF.org
YouTube: eBEEF
Twitter : @eBEEForg

USDA NIFA
United States Department of Agriculture
National Institute of Food and Agriculture

eBEEF was developed as part of USDA NIFA grants
2013-68004-20364
#2011-68004-30367
#2011-68004-30214

Take Homes

- DNA testing can be used it identify parentage, genetic defects, and to improve the accuracy of breed EPDs
- Tests have not been shown to work well in predicting genetic merit of crossbreds
- Economics of testing commercial cattle needs to be carefully considered – will depend on a number of factors – return greater on males than females

Thanks for inviting me!

UC DAVIS ANIMAL SCIENCE

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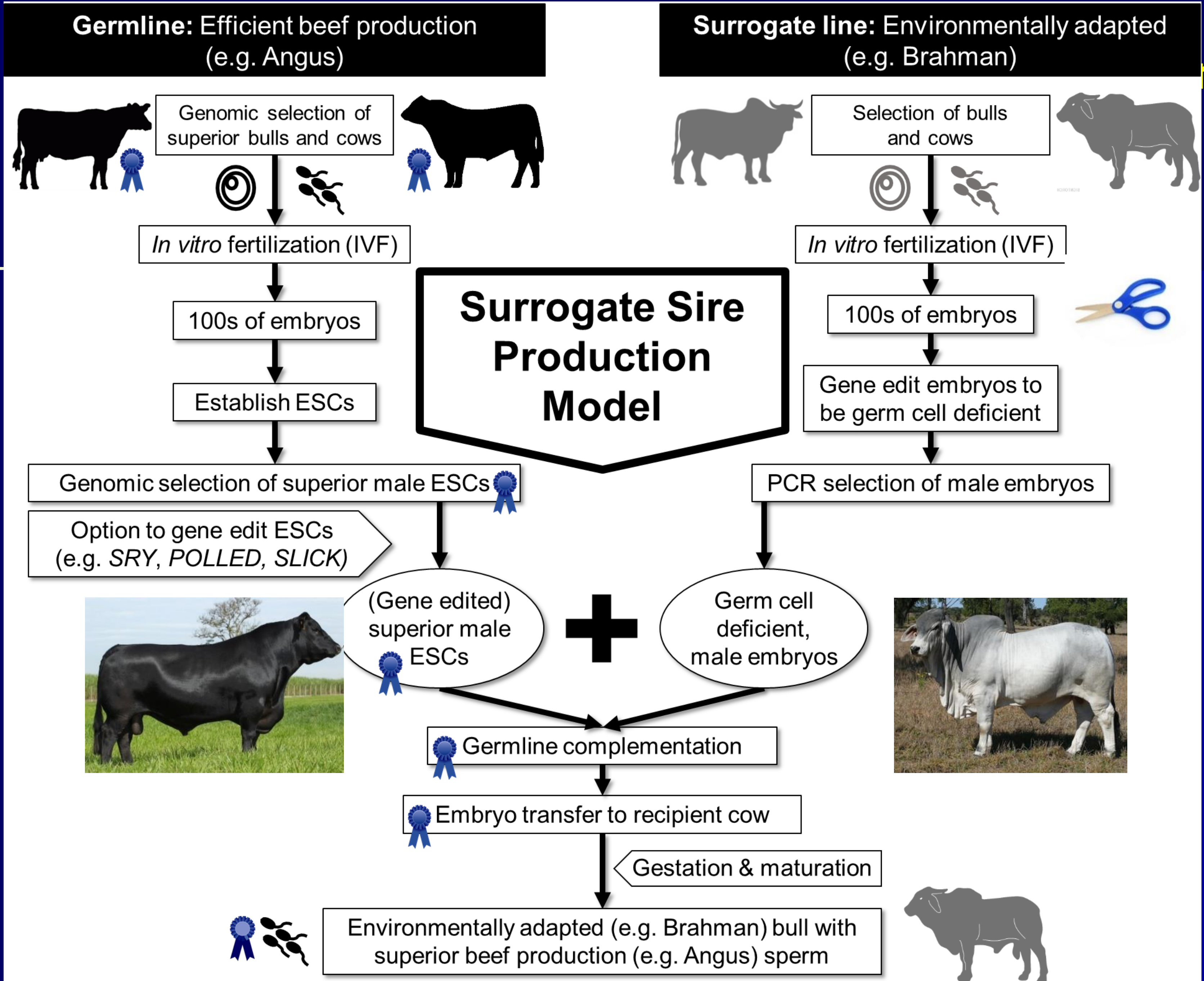
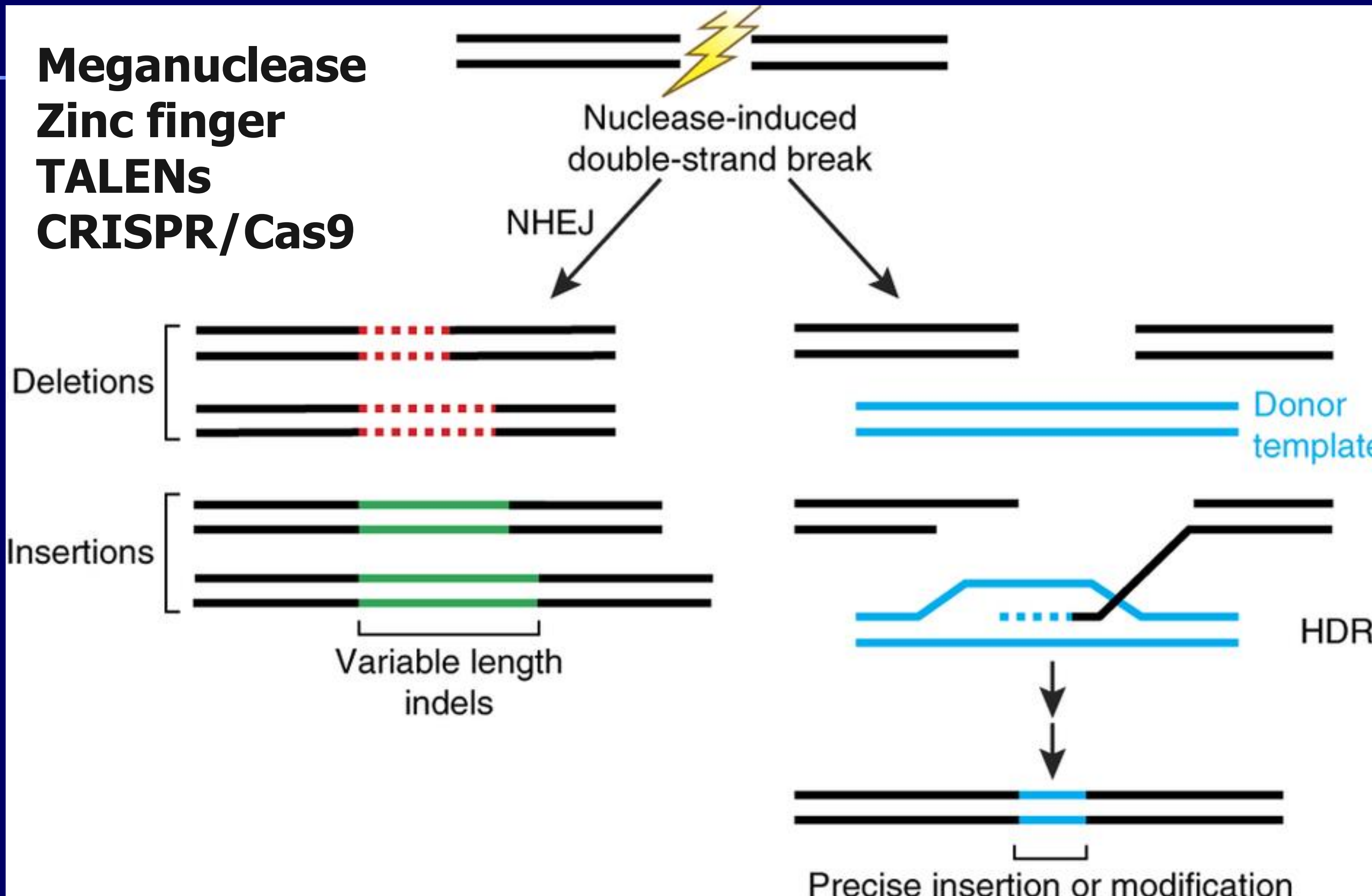
USDA United States Department of Agriculture — National Institute of Food and Agriculture


Germline: Efficient beef production (e.g. Angus)
Surrogate line: Environmentally adapted (e.g. Brahman)
Genomic selection of superior bulls and cows
In vitro fertilization (IVF)
100s of embryos
Establish ESCs
Genomic selection of superior male ESCs
Option to gene edit ESCs (e.g. SRY, POLLED, SLICK)
(Gene edited) superior male ESCs
Selection of bulls and cows
In vitro fertilization (IVF)
100s of embryos
Gene edit embryos to be germ cell deficient
PCR selection of male embryos
Germ cell deficient, male embryos
Surrogate Sire Production Model
Germline complementation
Embryo transfer to recipient cow
Gestation & maturation
Environmentally adapted (e.g. Brahman) bull with superior beef production (e.g. Angus) sperm

Will gene editing allow an additional inflection point in rate of livestock genetic gain?

Meganuclease
Zinc finger
TALENs
CRISPR/Cas9



Sander JD, Joung JK. CRISPR-Cas systems for editing, regulating and targeting genomes. *Nat Biotech* 2014;32:347-355.

Gene Edited Polled Calves

Naturally-occurring bovine allele at polled locus

recombinetics

Carlson DF, Lancto CA, Zang B, Kim E-S, Walton M, et al. 2016. **Production of hornless dairy cattle from genome-edited cell lines**. Nat Biotech 34: 479-81

Animal Biotechnology and Genomics Education

Precision Breeding Offers New Alternative to Dehorning Cattle

https://www.youtube.com/watch?v=-Qks_LMmodw

Editing is the Cherry on Top of Breeding Sundae

It will be able to introduce useful alleles, and potentially bring in useful novel genetic variation to improve livestock rapidly, without "linkage" drag

Genome Editing

Somatic cell nuclear transfer cloning

Genomic Selection

Embryo Transfer

Artificial insemination

Progeny testing

Performance recording

Development of breeding goals

Association of like minded breeders

Cracking the genetic code for complex traits in cattle

20 February 2018

A massive global study involving 58,000 cattle has pinpointed the genes that influence the complex genetic trait of height in cattle, opening the door for researchers to use the same approach to map high-value traits including those important for beef and milk production.

The University of Queensland's Professor Ben Hayes, who heads the global 1000 Bull Genomes Consortium of 57 researchers from 30 institutes, said it had previously been a major challenge to identify variants in the genome affecting complex traits, due to variations within multiple genes, and behavioural and environmental factors.

"To overcome this issue, the consortium pooled large genomic datasets and phenotypes collected from 58,000 cattle around the world to gain the clearest picture so far of their genetics," Professor Hayes said.

"We needed access to vast resources of data in order to demonstrate that the genes affecting a complex trait like height can be accurately identified.

"By applying the same collaborative big data approach, it may now be possible to identify genes associated with high-value complex traits that are really important to the industry, such as beef and milk production, feed efficiency and reduced methane emissions."

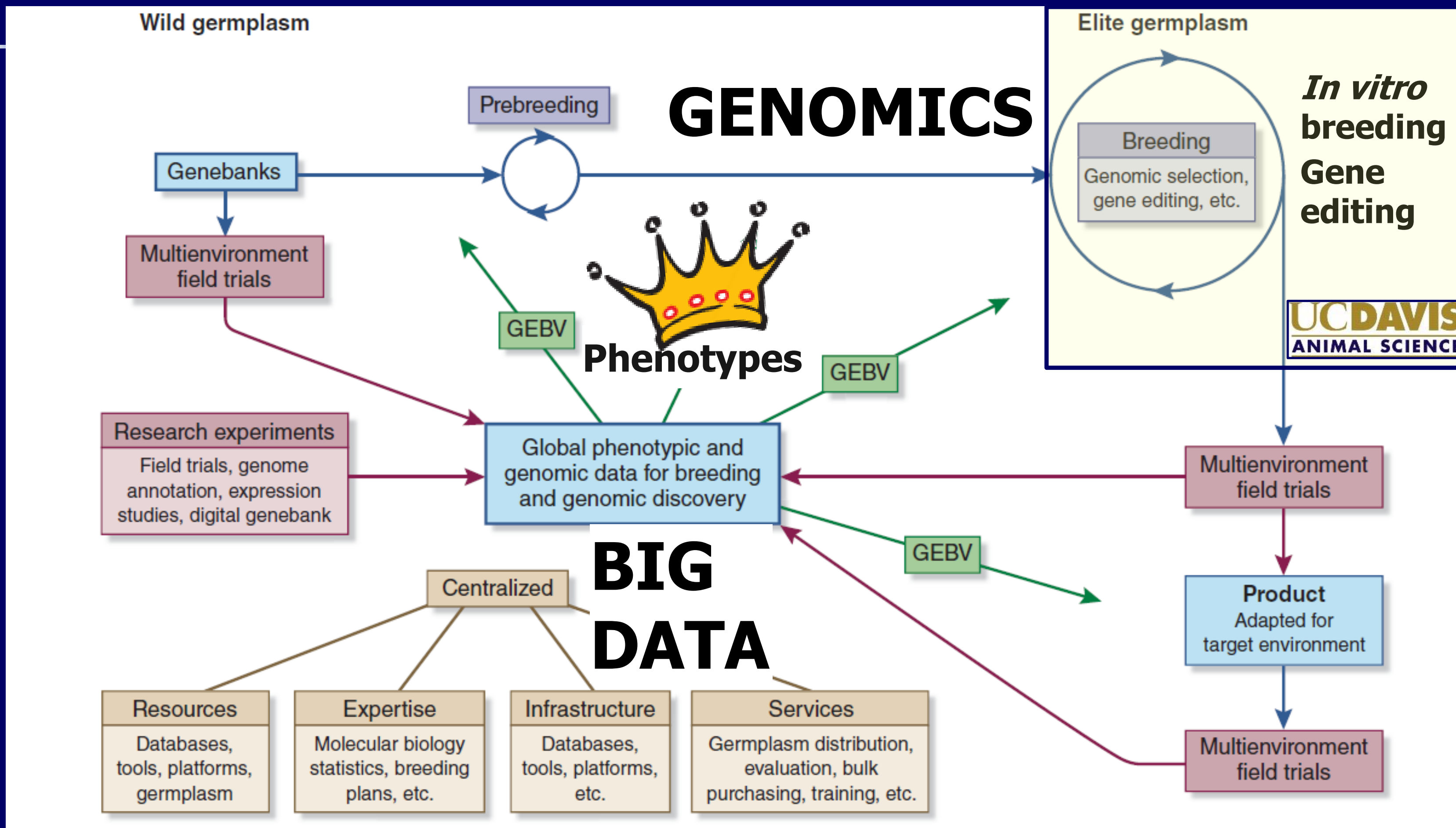
The 1000 Bull Genomes Consortium's findings on height were confirmed by analysing the genetic material of miniature cattle and the DNA sequenced from a 6500-year-old wild auroch bone.

"Aurochs are an extinct species of large wild ox – which were domesticated by ancient humans about 10,000 years ago and bred to be shorter – and are the ancestor to all cattle breeds," Professor Hayes said.

"From analysing the DNA of this animal, we could predict its height, and then verify our prediction with the fossil records of auroch skeletons."

Bouwman AC, et al. 2018. **Meta-analysis of genome-wide association studies for cattle stature identifies common genes that regulate body size in mammals.** Nat Genet. Feb 19. doi: 10.1038/s41588-018-0056-5. [Epub ahead of print] PubMed PMID: 29459679.

Strategy to combine big data and genomic selection as a unifying approach to deliver innovative “step changes” in the rate of genetic gain at scale



Hickey et al., 2017; **Genomic prediction unifies animal and plant breeding programs to form platforms for biological discovery.** Nat Genet. 49:1297-1303.