Visualization of changes in relationships among traits over time – example in conformation (type) traits

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Genetic parameters change over time

J. Dairy Sci. 88:1156–1165

Changing Definition of Productive Life in US Holsteins: Effect on Genetic Correlations

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J. Dairy Sci. 87:1457–1468

Genetic Correlations Among Production, Body Size, Udder, and Productive Life Traits Over Time in Holsteins

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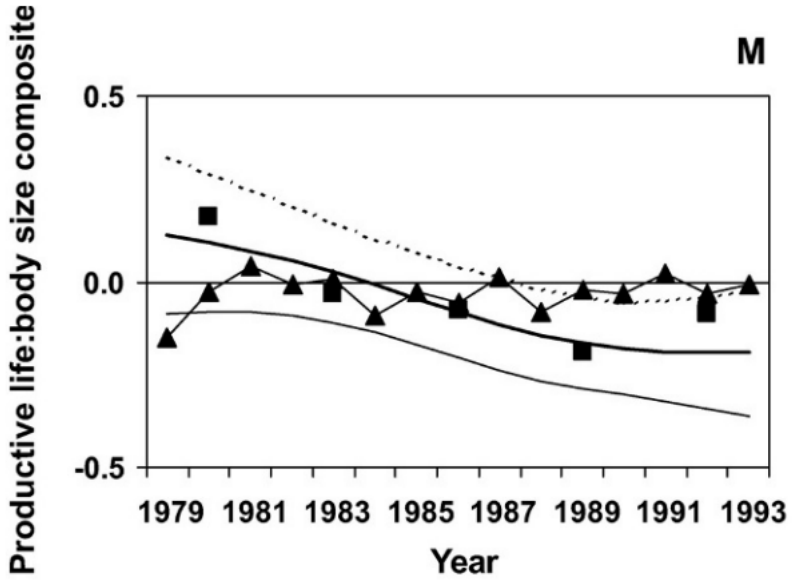

Purpose

Potential for change to accelerate with improvements in genomics

Changed parameters affect estimation and selection index

Need complete informative genomic info

Existing methods for estimation (REML, Gibbs sampler) too expensive with complete data

How to estimate parameters in time slices with complete commercial data?

How to visualize the changes?

Heritabilities by predictivity (GPP)

Misztal and Gowane (2025)

Predictivity: c
$= corr(y - Xb, \hat{u})$

$$\widehat{h^2} = \frac{c^2 + \sqrt{c^4 + 4c^2 M_e / N_{ref}}}{2}$$

N_{ref} – animals in reference population
Me – effective chromosome segments, ~5k in pigs and chicken, ~15k in cattle
N_{val} – number of animals in validation population

Genetic correlations by predictivity (GPP)

$\hat{u}_i = \text{GEBV}$ $\quad y_i - X\hat{\beta}_i$

$\hat{u}_j = \text{GEBV}$ $\quad y_j - X\hat{\beta}_j$

$$corr_{ij} = \frac{corr\left(y_i - Xb_i, \hat{u}_j\right)}{h_i \; acc_j}$$

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Genomic Prediction

OXFORD GENETICS

Estimation of heritabilities and genetic correlations by time slices using predictivity in large genomic models

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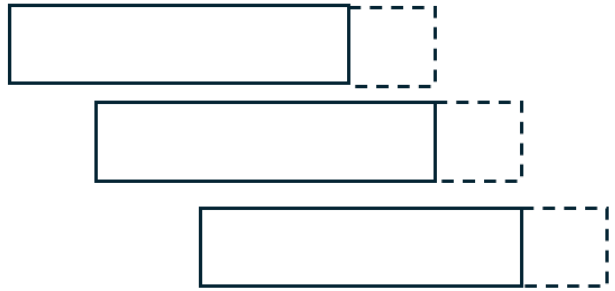


Type traits and initial heritabilities used for ssGBLUP

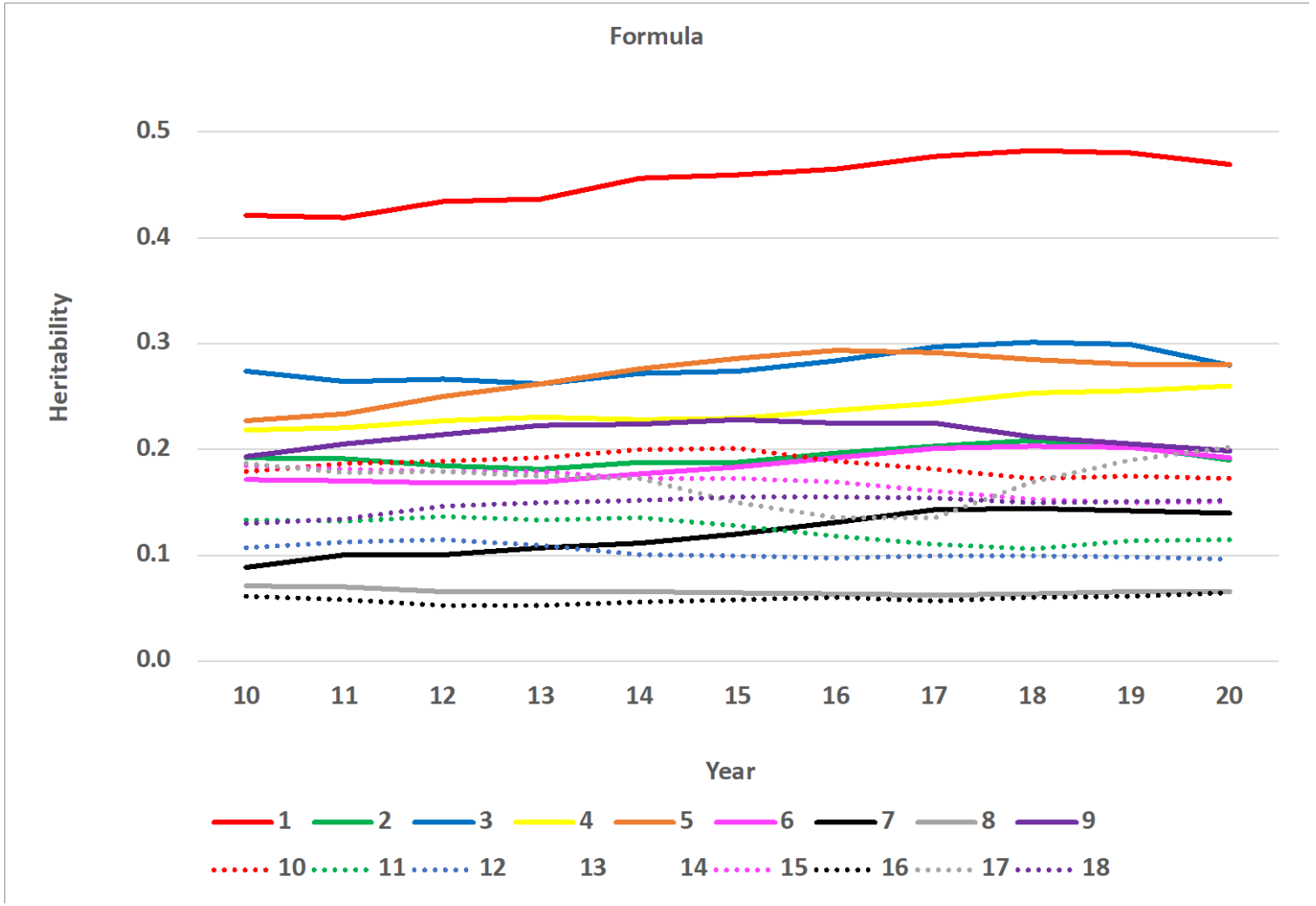
No	Traits	h^2	No.	Traits	h^2
1	Stature	0.456	10	Rear Udder Height	0.214
2	Strength	0.270	11	Rear Udder Width	0.172
3	Body Depth	0.337	12	Udder Cleft	0.178
4	Dairy Form	0.298	13	Udder Depth	0.332
5	Rump Angle	0.341	14	Front Teat Placement	0.267
6	Rump Width	0.248	15	Teat Length	0.254
7	Rear Legs - Side View	0.173	16	Rear Legs - Rear View	0.106
8	Foot Angle	0.110	17	Feet & Legs Score	0.182
9	Fore Attachment	0.230	18	Rear Teat Placement	0.213

Tsuruta et al. (2024)

Details of validation and reference data for the 11 time periods

Validation ('000s)				Reference ('000s)		
Year of birth	# genotyped animals	# records	# animals with records	Year of birth	# records	# genotyped animals
2009-2011	33	685	515	2001-2008	2,725	367
2010-2012	47	674	513	2001-2009	2,956	375
2011-2013	65	647	499	2001-2010	3,188	385
2012-2014	83	609	476	2001-2011	3,411	400
2013-2015	96	565	445	2001-2012	3,630	422
2014-2016	102	522	409	2001-2013	3,834	450
2015-2017	105	494	388	2001-2014	4,019	483
2016-2018	108	466	371	2001-2015	4,195	518
2017-2019	112	429	360	2001-2016	4,356	551
2018-2020	103	348	310	2001-2017	4,514	589
2019-2021	67	203	191	2001-2018	4,661	625

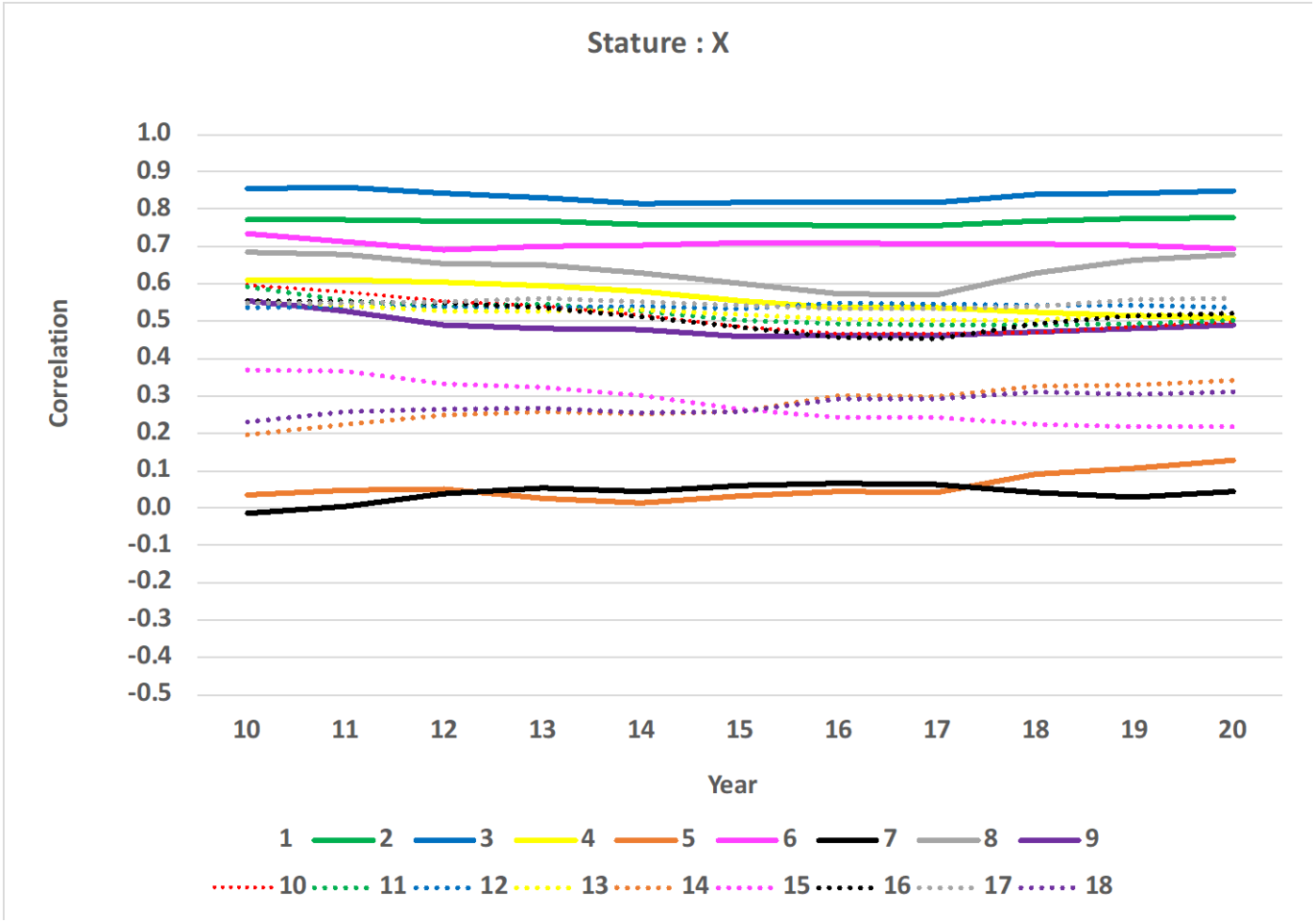
Heritability over time by GPP



Tsuruta et al. (2024)

Genetic correlations of stature with other traits

Tsuruta et al. (2024)



How to visualize changes over time?

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2020	1	1	0.779	0.848	0.509	0.129	0.693	0.044	0.678	0.489	0.497	0.501	0.537	0.516	0.342	0.217	0.52	0.562	0.311
2020	2	0.779	1	0.851	0.137	-0.07	0.609	-0.097	0.583	0.328	0.24	0.41	0.316	0.169	0.176	0.294	0.488	0.4	0.17
2020	3	0.848	0.851	1	0.612	-0.02	0.688	0.124	0.535	0.299	0.376	0.575	0.468	0.115	0.288	0.314	0.474	0.508	0.287
2020	4	0.509	0.137	0.612	1	0.069	0.406	0.382	0.098	0.064	0.416	0.611	0.406	-0.09	0.312	0.084	0.154	0.313	0.33
2020	5	0.129	-0.07	-0.02	0.069	1	-0.005	-0.102	-0.1	-0.092	0.028	-0.024	-0.02	0.019	0.074	-0.118	-0.136	-0.15	0.065
2020	6	0.693	0.609	0.688	0.406	-0.005	1	0.21	0.346	0.324	0.382	0.532	0.453	0.221	0.276	0.135	0.33	0.378	0.287
2020	7	0.044	-0.097	0.124	0.382	-0.102	0.21	1	-0.396	-0.053	-0.035	0.08	0.153	-0.085	0.148	0.031	-0.253	0.03	0.145
2020	8	0.678	0.583	0.535	0.098	-0.1	0.346	-0.396	1	0.468	0.36	0.279	0.256	0.415	0.183	0.139	0.769	0.607	0.142
2020	9	0.489	0.328	0.299	0.064	-0.092	0.324	-0.053	0.468	1	0.695	0.424	0.324	0.818	0.352	-0.02	0.462	0.509	0.225
2020	10	0.497	0.24	0.376	0.416	0.028	0.382	-0.035	0.36	0.695	1	0.778	0.413	0.429	0.268	0.086	0.428	0.497	0.252
2020	11	0.501	0.41	0.575	0.611	-0.024	0.532	0.08	0.279	0.424	0.778	1	0.521	-0.025	0.373	0.102	0.389	0.428	0.404
2020	12	0.537	0.316	0.468	0.406	-0.02	0.453	0.153	0.256	0.324	0.413	0.521	1	0.281	0.719	0.003	0.27	0.359	0.827
2020	13	0.516	0.169	0.115	-0.09	0.019	0.221	-0.085	0.415	0.818	0.429	-0.025	0.281	1	0.351	-0.135	0.371	0.412	0.241
2020	14	0.342	0.176	0.288	0.312	0.074	0.276	0.148	0.183	0.352	0.268	0.373	0.719	0.351	1	-0.317	0.253	0.318	0.936
2020	15	0.217	0.294	0.314	0.084	-0.118	0.135	0.031	0.139	-0.02	0.086	0.102	0.003	-0.135	-0.317	1	0.07	0.05	-0.208
2020	16	0.52	0.488	0.474	0.154	-0.136	0.33	-0.253	0.769	0.462	0.428	0.389	0.27	0.371	0.253	0.07	1	0.704	0.09
2020	17	0.562	0.4	0.508	0.313	-0.15	0.378	0.03	0.607	0.509	0.497	0.428	0.359	0.412	0.318	0.05	0.704	1	0.268
2020	18	0.311	0.17	0.287	0.33	0.065	0.287	0.145	0.142	0.225	0.252	0.404	0.827	0.241	0.936	-0.208	0.09	0.268	1

Methodology

11 18x18 matrices

Changes in individual traits and relationships among traits

How to characterize changes in conformation traits over time?

How to illustrate collinearities among type traits?

Select target trait and use every combination of 2-, 3-, and 4- predictor traits from remaining 17

Choose combination of predictor traits with the highest explained variance in 2020

Use these combinations to graph all 11 time slices

Example – prediction of Rear Udder Width by 3 other traits

- Predict Rear Udder, Width (UW) by all combinations of 3 traits from remaining traits
- Select one with highest explained variance

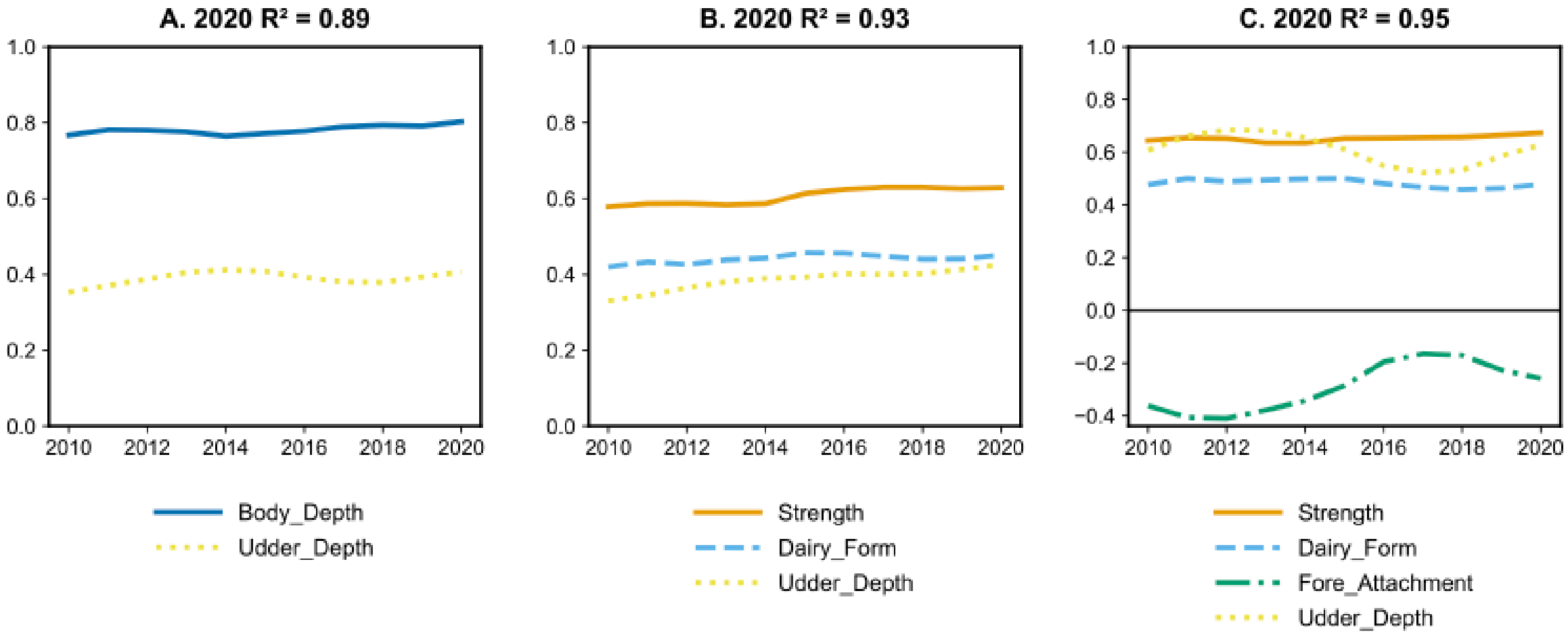
$$E(BV_{UW}) = Corr_{UW,[t1,t2,t3]} Corr^{-1}_{[t1,t2,t3]} \begin{bmatrix} BV_{t1} \\ BV_{t2} \\ BV_{t3} \end{bmatrix}$$

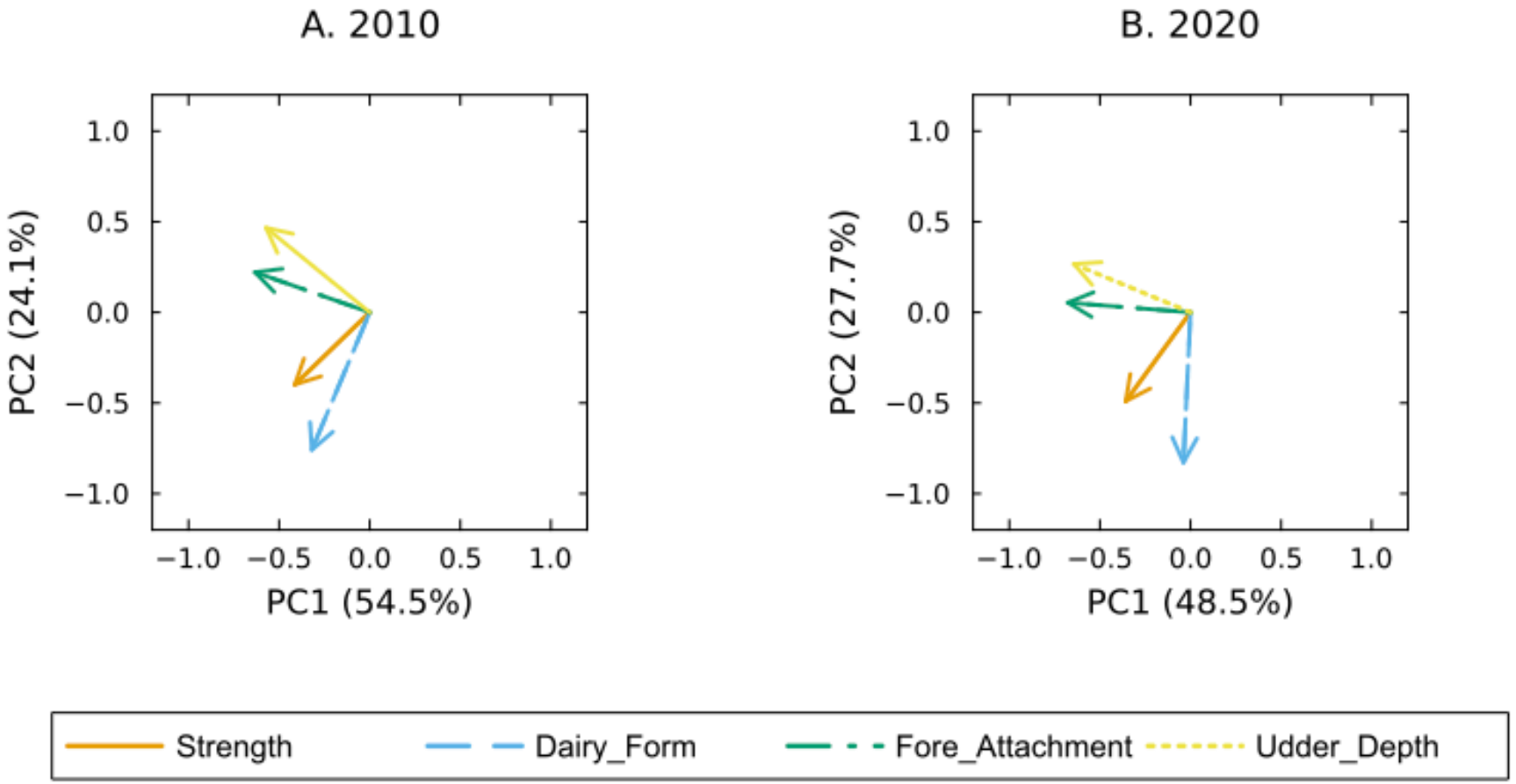
UW = 0.89 UH - 0.50 UD + 0.31 TP R^2=0.821
UW = 0.82 UH - 0.39 UD + 0.30 BD R^2=0.820
UW = 0.83 UH - 0.43 UD + 0.30 RW R^2=0.817
....
UW = 0.01 RA + 0.27 FA + 0.06 TL R^2=0.082

UH = Rear Udder Height; UD = Udder Depth; TP = Front Teat Placement;
BD = Body Depth; RW = Rump Width; RA = Rump Angle, FA = Foot Angle; TL = Teat Length

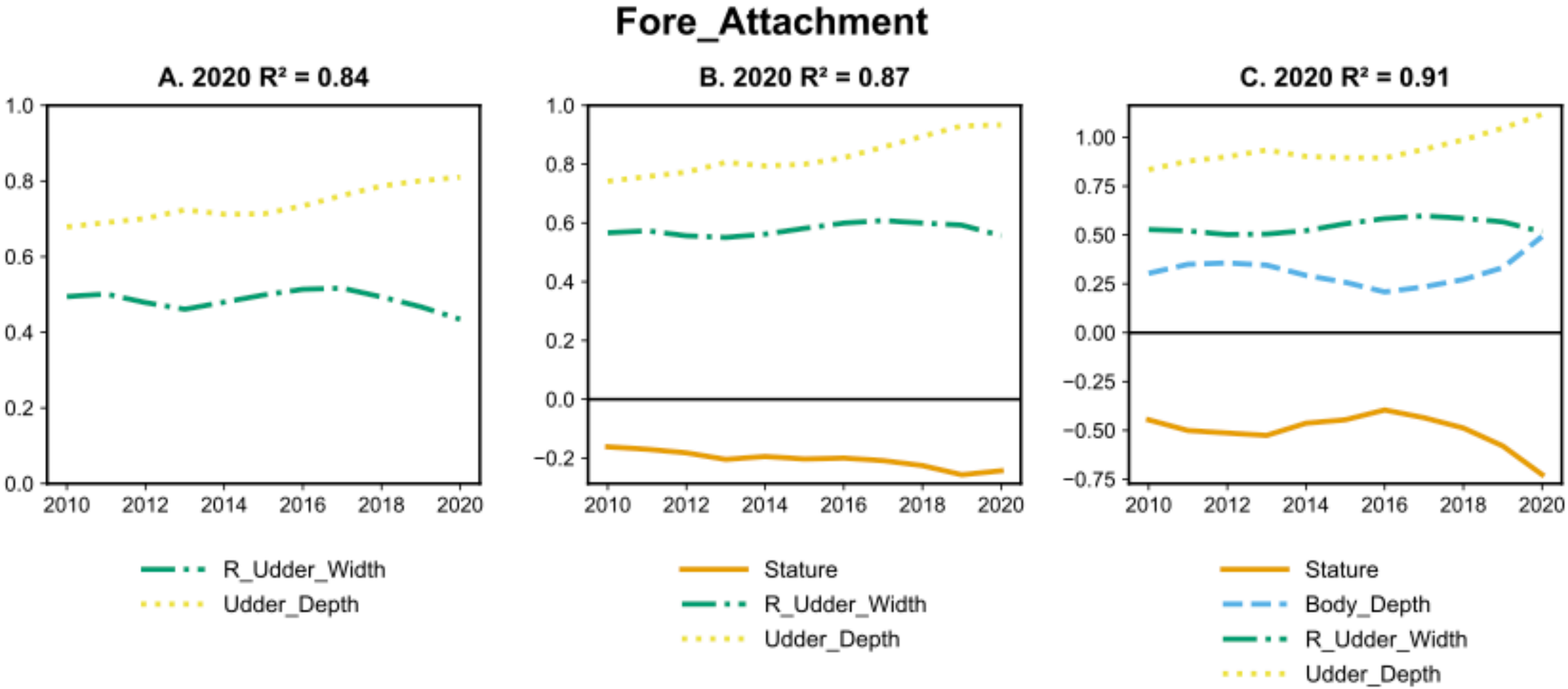
[1]Target trait	2-predictor model[1]	R^2 (%)	3-predictor model	R^2 (%)	4-predictor model	R^2 (%)
BD	SR (78), DF (50)	96	SR (81), DF (56), UW (-10)	97	SR (79), DF (55), UW (-12), FLS (7)	97
SR	BD (122), DF (-60)	95	BD (117), DF (-66), UW (15)	96	ST (37), BD (94), DF (-63), UD (-17)	97
RT	UC (32), TP (71)	92	UC (35), TP (73), RL (-18)	95	FA (14), UC (33), TP (74), RL (-29)	96
TP	RL (17), RT (91)	90	UC (-28), RL (22), RT (114)	92	FA (-17), UC (-28), RL (35), RT (115)	93
ST	BD (80), UD (41)	89	SR (63), DF (45), UD (43)	93	SR (67), DF (48), FU (-26), UD (63)	95
DF	SR (-133), BD (174)	88	SR (-127), BD (154), UW (25)	92	SR (-122), BD (151), FU (-12), UW (30)	93
FU	UW (43), UD (81)	84	ST (-24), UW (56), UD (93)	87	ST (-73), BD (49), UW (52), UD (112)	91
UD	FU (99), UW (-43)	81	ST (34), FU (87), UW (-55)	89	ST (76), BD (-52), FU (76), UW (-41)	95
UH	UW (78), UD (44)	79	UW (88), UD (53), TP (-25)	84	SR (-21), UW (97), UD (57), TP (-26)	88
UC	ST (30), RT (73)	76	ST (32), TP (-45), RT (114)	78	ST (22), TP (-67), RL (20), RT (136)	81
UW	UH (96), UD (-42)	75	UH (91), UD (-51), TP (31)	84	SR (25), UH (87), UD (-53), TP (29)	89
FA	ST (36), RL (58)	69	ST (43), LS (-30), RL (46)	76	ST (48), RA (-14), LS (-32), RL (42)	78
RL	FA (54), FLS (38)	68	FA (71), TP (96), RT (-90)	71	FA (52), TP (86), FLS (35), RT (-87)	78
FLS	ST (26), RL (57)	54	DF (21), FU (23), RL (56)	58	LS (27), FA (28), UH (21), RL (47)	61
RW	ST (56), UW (26)	52	ST (56), LS (17), UW (24)	55	ST (38), SR (24), LS (20), UW (23)	57
LS	DF (43), FA (-44)	34	ST (64), RA (-27), FA (-85)	39	ST (43), DF (25), RA (-25), FA (-73)	43
TL	BD (44), TP (-44)	28	BD (43), TP (-99), RT (59)	33	BD (38), TP (-112), RL (11), RT (71)	33
RA	ST (30), FLS (-32)	9	ST (54), LS (-36), FA (-61)	17	ST (84), SR (-41), LS (-41), FA (-58)	23

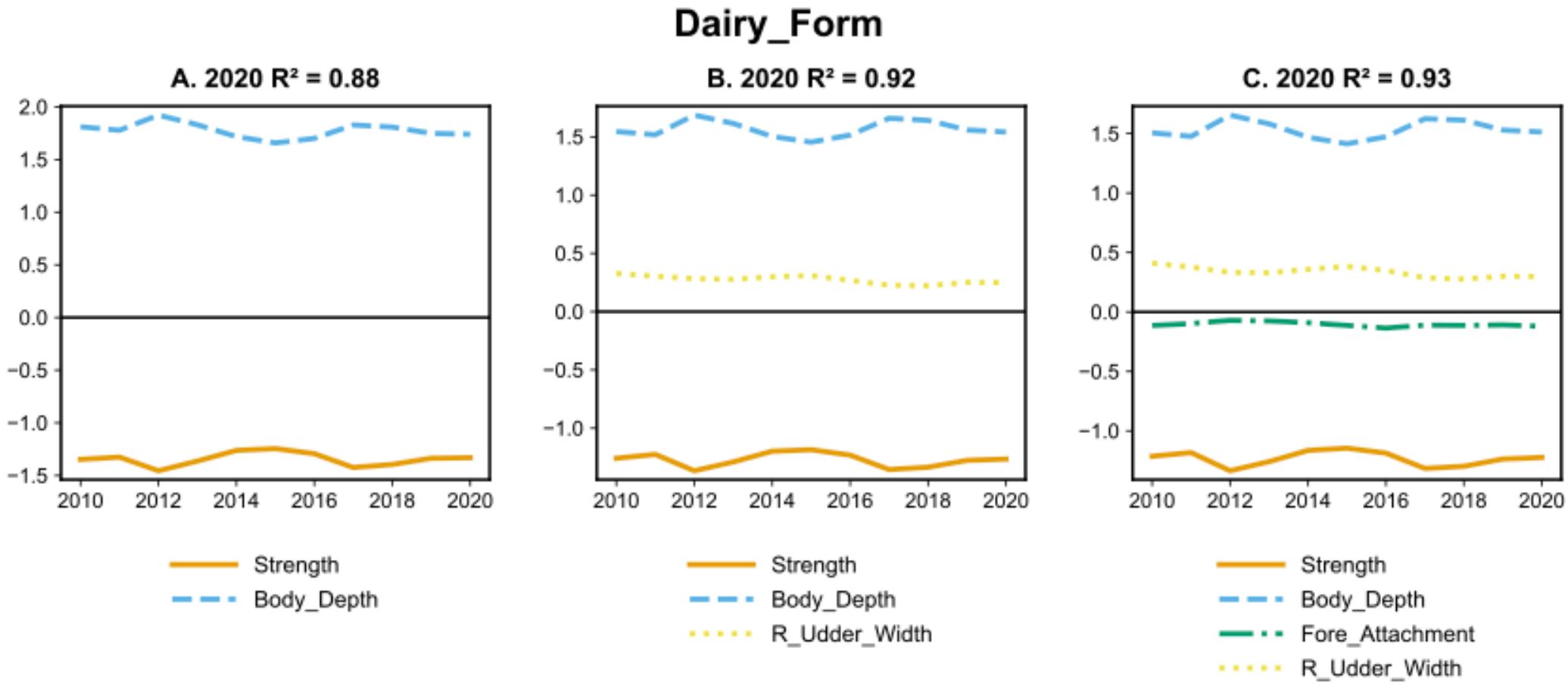
Stature

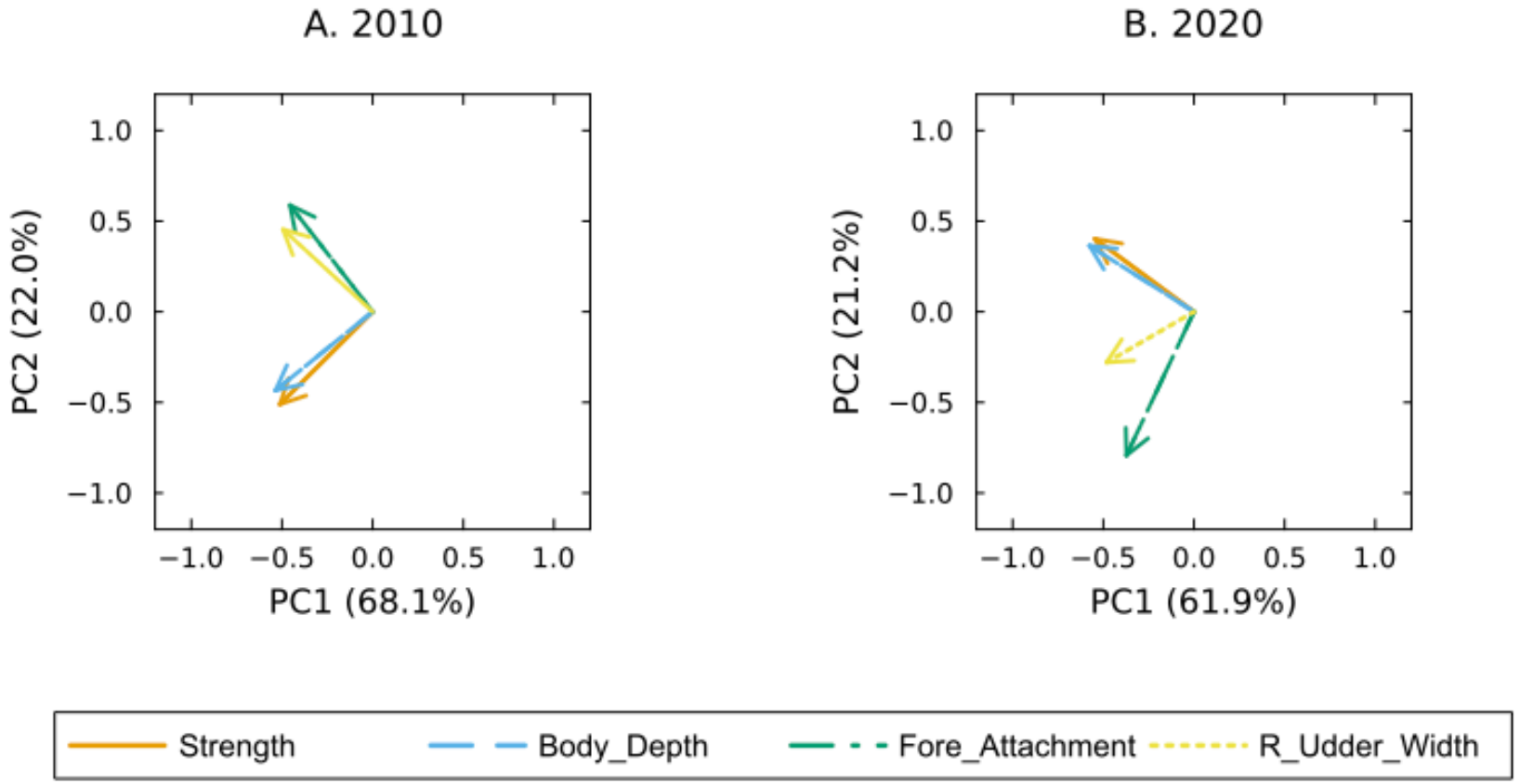

A. 2020 R² = 0.89
B. 2020 R² = 0.93
C. 2020 R² = 0.95
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
2010
2012
2014
2016
2018
2020
Body_Depth
Udder_Depth
Strength
Dairy_Form
Udder_Depth
Strength
Dairy_Form
Fore_Attachment
Udder_Depth



2010 Eigenvalues: [2.18, 0.96, 0.72, 0.14] 2020 Eigenvalues: [1.94, 1.11, 0.78, 0.17]

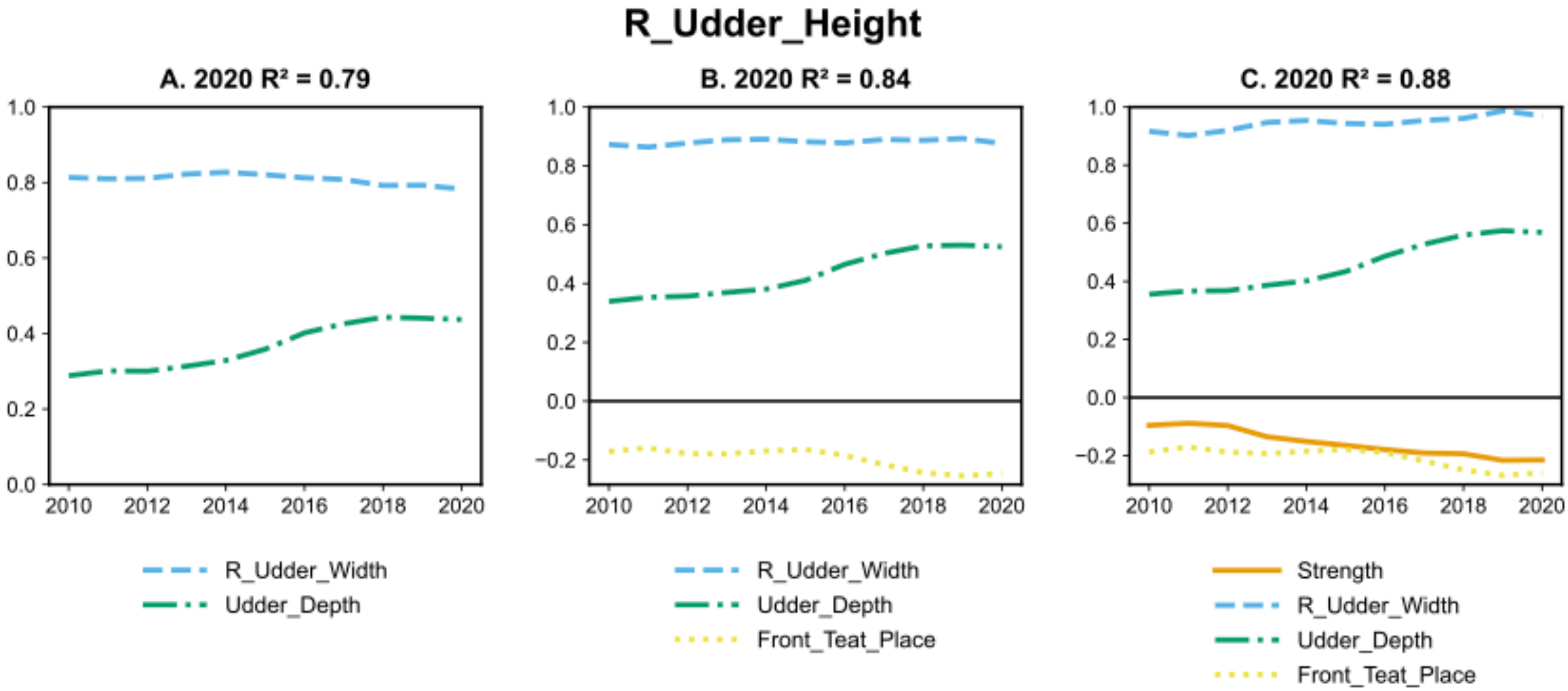

Fore_Attachment
A. 2020 R² = 0.84
B. 2020 R² = 0.87
C. 2020 R² = 0.91
R_Udder_Width
Udder_Depth
Stature
R_Udder_Width
Udder_Depth
Stature
Body_Depth
R_Udder_Width
Udder_Depth

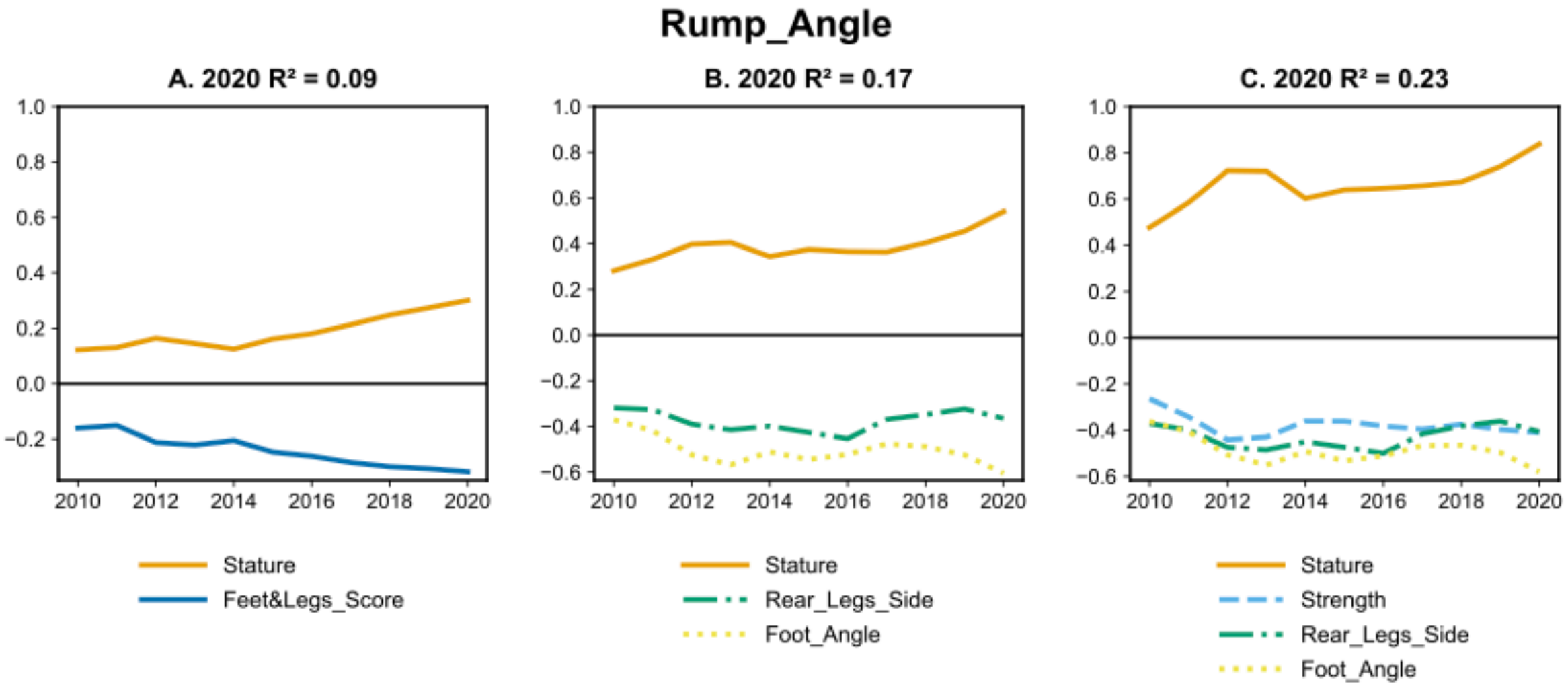

Dairy_Form
A. 2020 R² = 0.88
B. 2020 R² = 0.92
C. 2020 R² = 0.93
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
2010
2012
2014
2016
2018
2020
Strength
Body_Depth
R_Udder_Width
Fore_Attachment



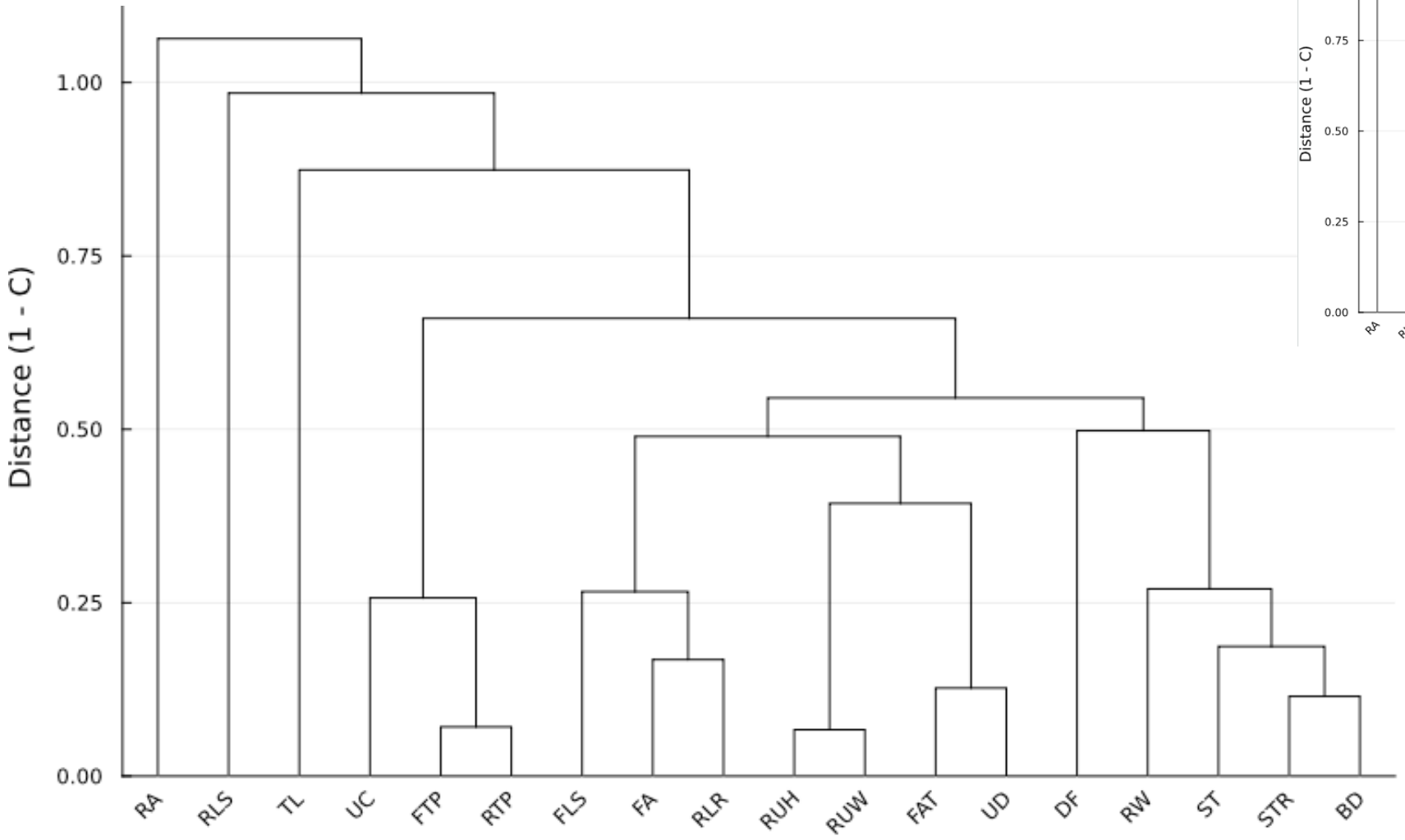
2010 Eigenvalues: [2.72, 0.88, 0.3, 0.09]

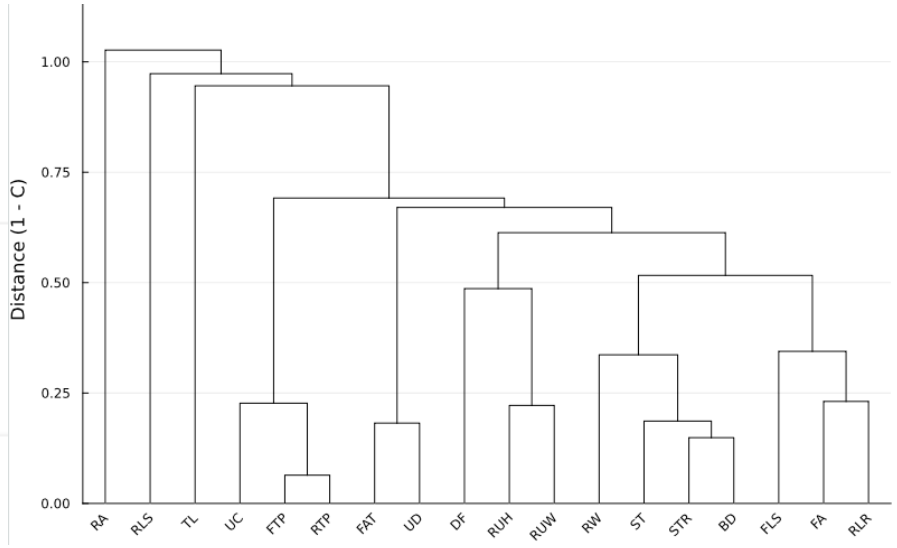
2020 Eigenvalues: [2.48, 0.85, 0.55, 0.12]


R_Udder_Height
A. 2020 R² = 0.79
B. 2020 R² = 0.84
C. 2020 R² = 0.88
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
2010
2012
2014
2016
2018
2020
R_Udder_Width
Udder_Depth
Front_Teat_Place
Strength


Rump_Angle
A. 2020 R² = 0.09
B. 2020 R² = 0.17
C. 2020 R² = 0.23
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
2010
2012
2014
2016
2018
2020
Stature
Feet&Legs_Score
Stature
Rear_Legs_Side
Foot_Angle
Stature
Strength
Rear_Legs_Side
Foot_Angle

2020


Distance (1 - C)
1.00
0.75
0.50
0.25
0.00
RA
RLS
TL
UC
FTP
RTP
FLS
FA
RLR
RUH
RUW
FAT
UD
DF
RW
ST
STR
BD


Distance (1 - C)
1.00
0.75
0.50
0.25
0.00
RA
RLS
TL
UC
FTP
RTP
FAT
UD
DF
RUH
RUW
RW
ST
STR
BD
FLS
FA
RLR

2010

Conclusions

Yearly estimating of genomic parameters with complete commercial data possible with GPP

Informative visualization of relationships among traits

Many conformation traits strongly related

Good fit of prediction with 2 or 3 other conformation traits

Examples of changes over time:

Udder Depth increasing coefficient on Fore Udder Attachment

Udder Height increasing coefficient on Udder Depth

Further Observations

Dendrograms show that DF had the most significant change

Correlated with Read Udder height and Rear Udder Width in 2010

More closely correlated with Rump Width, Strength, and Body Depth in 2020

Rump Angle, Rear Legs- Side View, Dairy Form most independent

Strength, Body Depth, and Dairy Form strongly associated

Rear Udder Width, Rear Udder Height and Rear Udder Depth strongly associated

Front Teat Placement and Rear Teat Placement

Animal Breeding and Genetics Group

College of Agricultural & Environmental Sciences

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