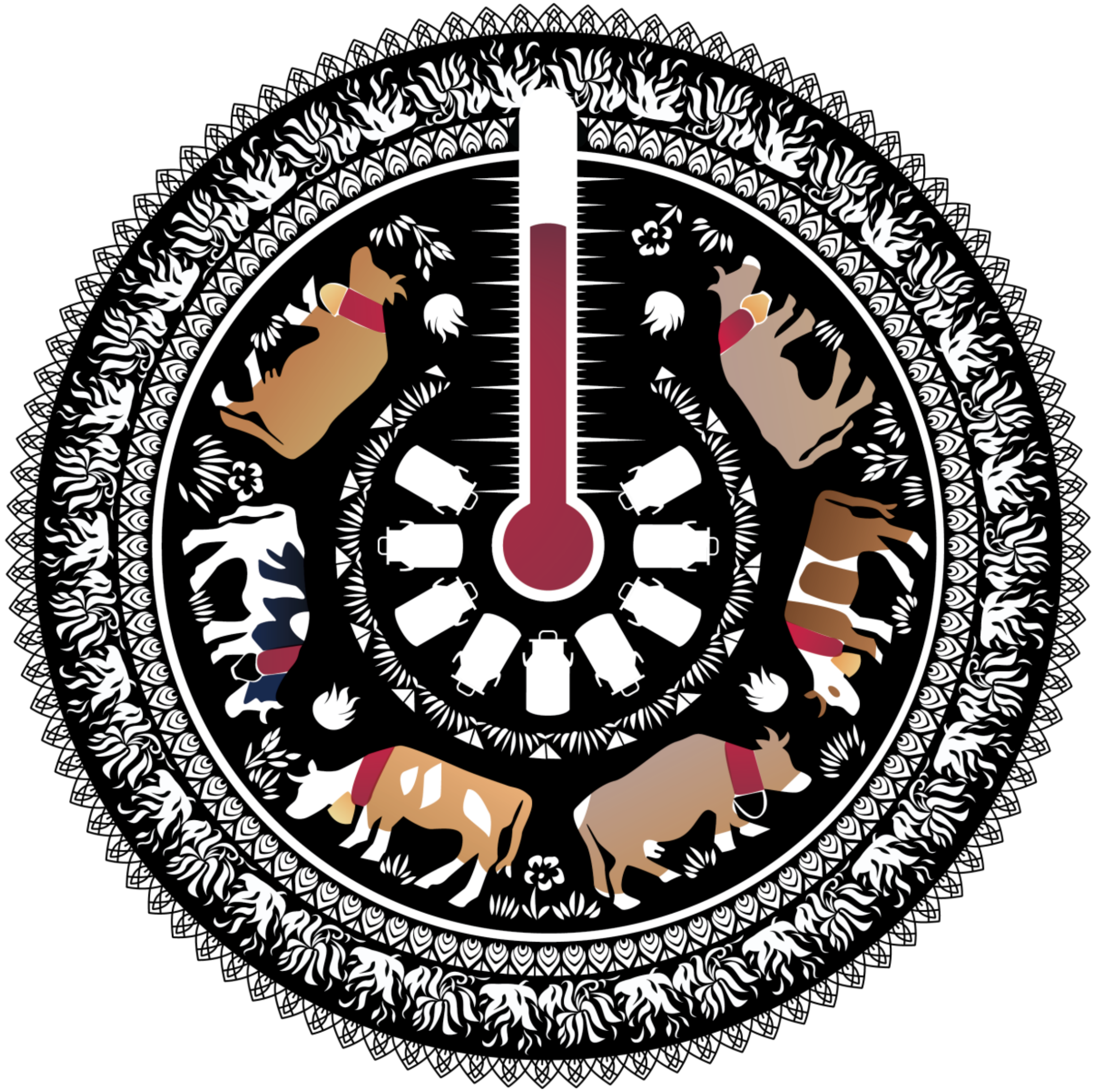


Modelling the Effect of Heat Stress on the Performance of Swiss Dairy Cows

A Big Data Statistical Analysis

Arno Schneuwly

Poll: Which is the most heat-resilient breed in terms of ECM yield?

Brown Swiss

△

Original Braunvieh

+

Holstein

○

Jersey

□

Simmental

◇

Swiss Fleckvieh

×

For which breed is the THI where the ECM yield starts to drop the highest?

Dairy Farming and Climate in Switzerland

Im Tal haben die Kühe Hunger, auf der Alp haben sie Durst: Wie die Hitze das Vieh trifft

Das Wasser wird knapp. Das trifft die Bauernbetriebe besonders hart. Jetzt haben einige Kantone mehr Flächen freigegeben und wollen so dem Futtermangel vorbeugen. Aber nicht überall ist das Futter das Problem.

NZZ (2022)

Agroscope (2023)

Milchbauernhof, Instagram (2022)

Zu hohe Temperaturen für Kühe

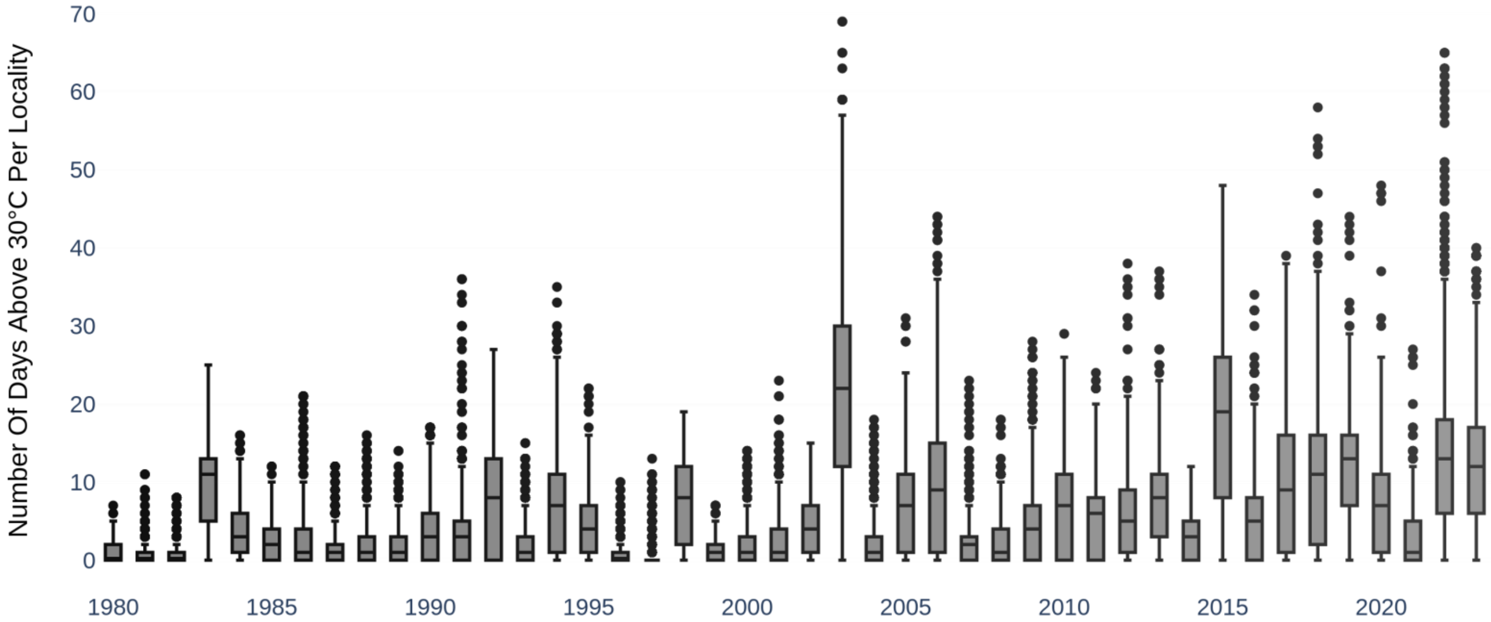
Deshalb leiden Kühe unter Hitzestress

Kühe mögen es kühl und leiden im Sommer deshalb unter Hitzestress. Woran liegt das? Eine Studie bringt neue Erkenntnisse.

Samstag, 22.07.2023, 14:46 Uhr

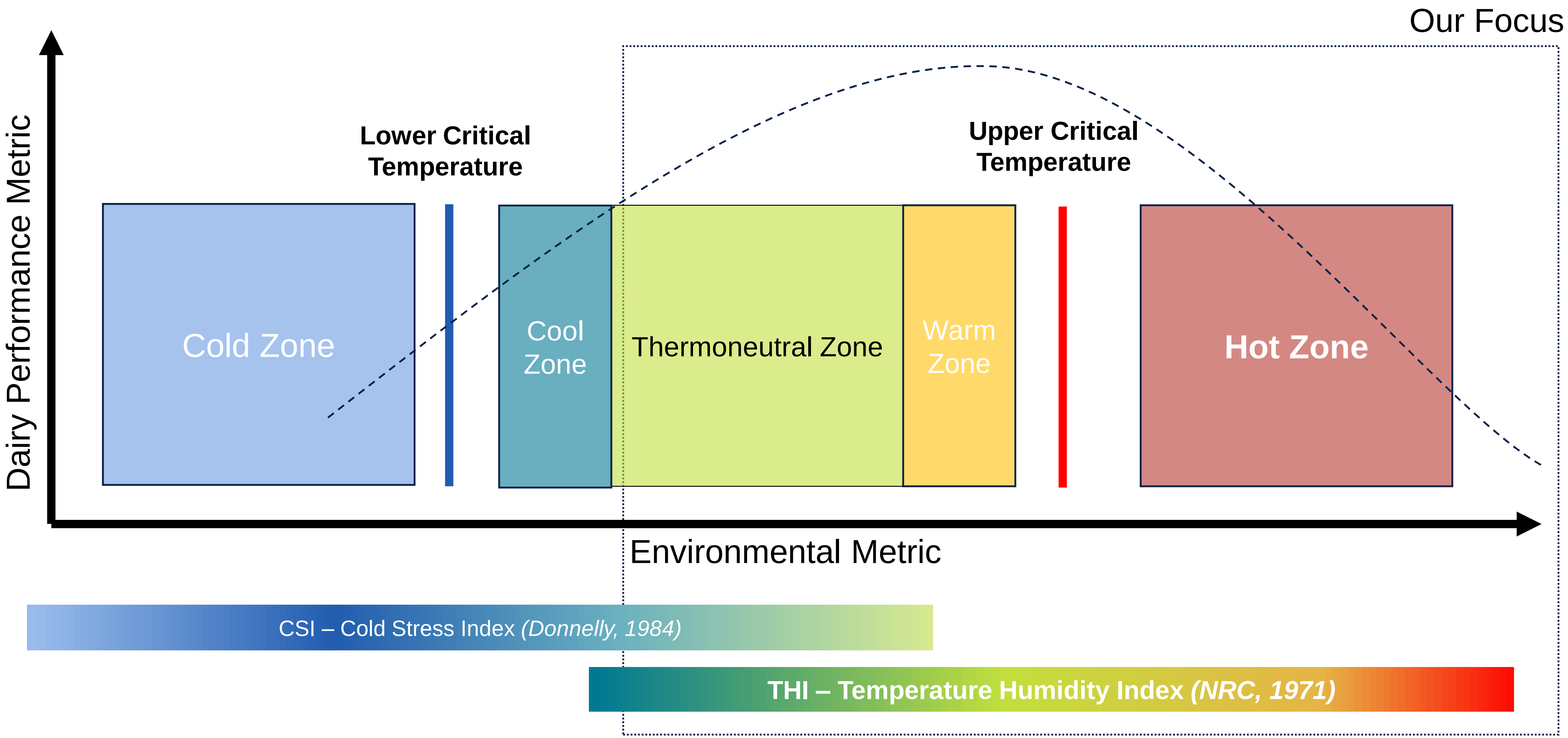
Auch jetzt im Sommer sind die Rinder und Kühe von Bauer Stefan Käser im

SRF (2023)



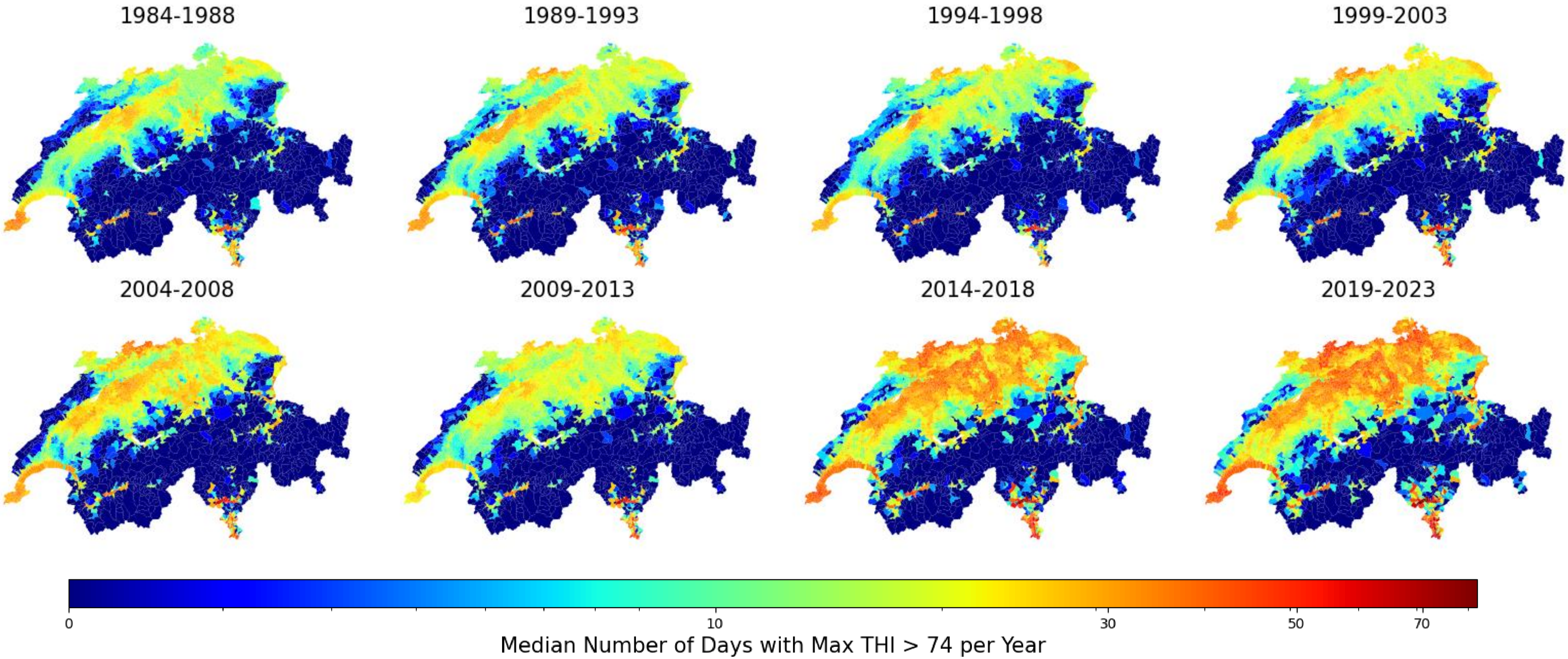
Heat stress appears to be a problem. How big is it? Today, we try to quantify.

Animal Physiology 101 - What is Heat Stress?



THI is the agronomic metric for heat stress.

THI over Time in Switzerland



High-THI exposure is rising. The effect of heat-incurred dairy performance losses is unknown for CH.

Heat Stress on Dairy Cow Performance Across Breeds

Study	Breeds	Records	Farms	Cows	Time	Location	Model
Bryant et al (2007)	3	~ 65 K	~ 0.5 K	> 19 K	1990 – 2002		Mixed
Gantner et al (2017)	2	~ 2.3 M	~ 1.5 K	> 156 K	2005 – 2012		Mixed
Ahmed et al (2022)	4	~ 5 M	~ 1.4 K	?	2016 – 2019		Linear / GAM
Our work	**6**	**> 130 M**	**~ 46 K**	**~ 4.2 M**	**1982 – 2023**		GAM

Heat stress studies of non-experimental production systems across breeds are very scarce.

Research Question & Hypothesis

Can we and at which THI value(s) do we observe a change (increase / decrease) in dairy performance variables for the different dairy cow breeds in Switzerland?

Variable	General Hypothesis	Breed Specific Hypotheses
Milk Yield [kg/day]	Decrease	Different THI thresholds for different breeds – *Kadzere (2002)* Jersey (□) more heat stress resistant than Holstein (○) – *Bryant (2007)* Simmental (◇) more heat resistant than Holstein (○) – *Gantner (2017)*
ECM Yield [kg/day]	Decrease	

well-known

Gap & Contribution

Popular Cow Breeds in Switzerland – 2023 Performance

Brown Swiss

△

Original Braunvieh

+

Holstein

○

Jersey

□

Simmental

◇

Swiss Fleckvieh

×

	Brown Swiss	Original Braunvieh	Holstein	Jersey	Simmental	Swiss Fleckvieh
Purpose	Milk	Milk & Meat	Milk	Milk	Milk & Meat	Milk & Meat
Milk [kg/day]	**23.04** (±7.55)	**19.33** (±6.48)	**27.20** (±8.58)	**18.88** (±6.10)	**19.39** (±6.50)	**22.45** (±7.51)
Protein [%]	3.56 (±0.43)	3.42 (±0.42)	3.42 (±0.42)	3.97 (±0.51)	3.44 (±0.37)	3.46 (±0.42)
Fat [%]	4.13 (±0.61)	4.01 (±0.57)	4.22 (±0.67)	5.30 (±0.94)	4.04 (±0.60)	4.27 (±0.69)
ECM [kg/day]	**25.56** (±8.02)	**20.95** (±6.77)	**30.13** (±8.90)	**24.17** (±7.15)	**21.14** (±6.89)	**25.02** (±7.88)

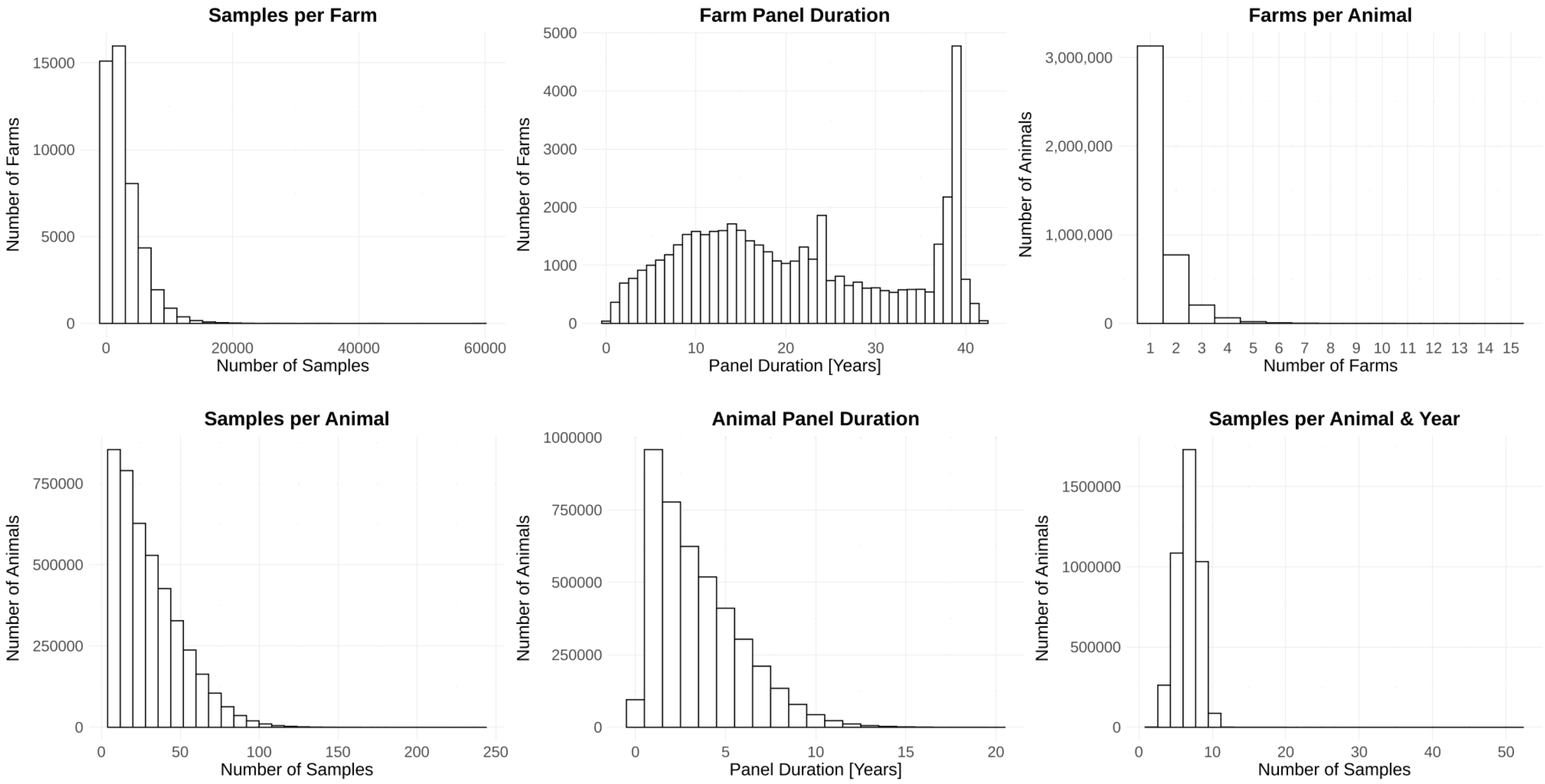
Breeding commonly optimizes for performance. Heat resilience is not explicitly included.

Our Dataset Statistics

	Brown Swiss	Original Braunvieh	Holstein	Jersey	Simmental	Swiss Fleckvieh
						
	△	+	○	□	◇	×
# Samples	56 M	5 M	28 M	700 K	9 M	30 M
# Farms	26 K	18 K	25 K	4 K	19 K	27 K
# Animals	1.7 M	150 K	900 K	24 K	300 K	1 M
Timespan	1982 - 2023	1982 - 2023	1985 - 2023	1998 - 2023	1984 - 2023	1984 - 2023

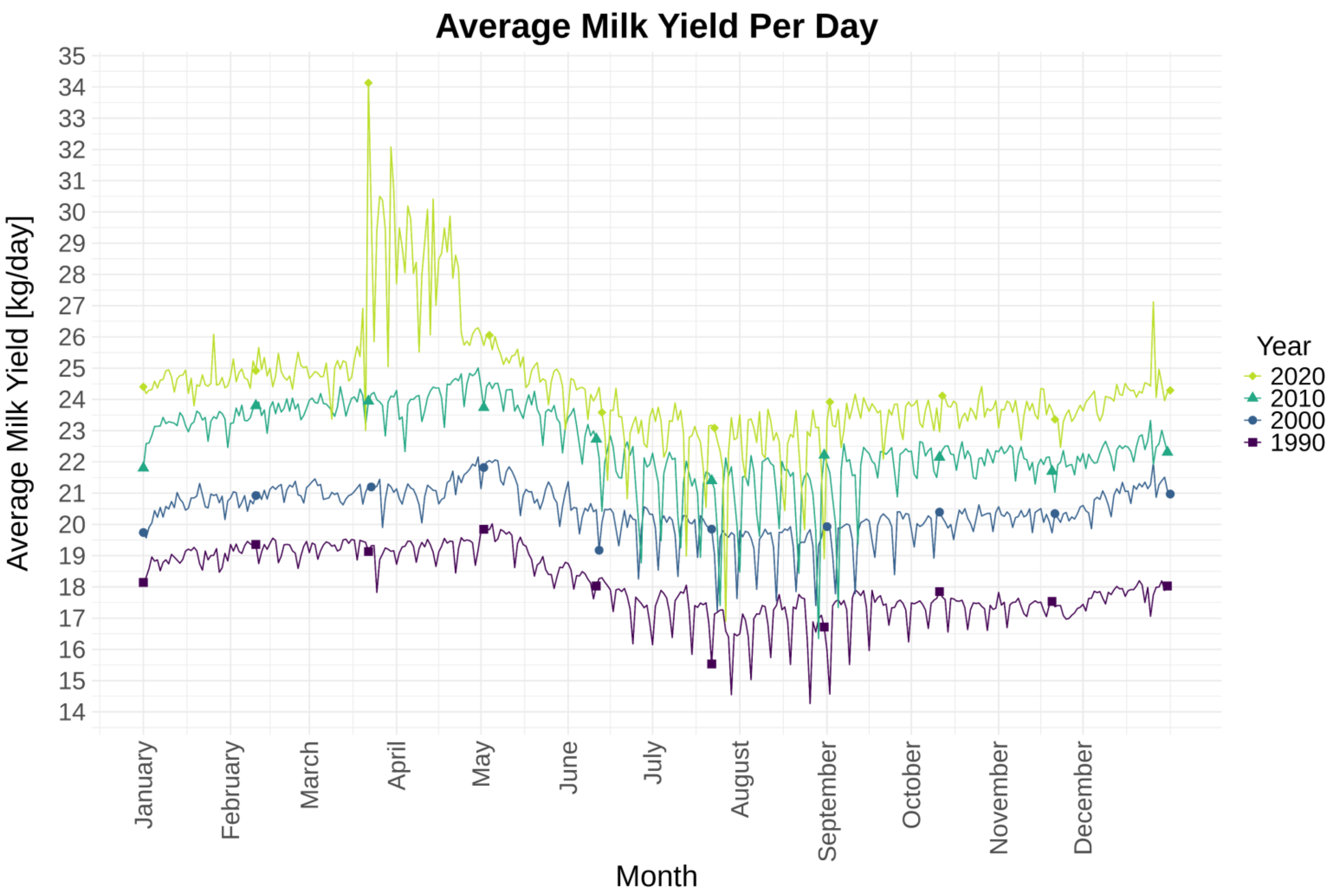
This is real-world data collected in commercial farming over 40 years. No experimental design.

Structure of Our Data – Sparsity & Dynamics



Sparse and hierarchical data. Farms enter and exit. Animals enter, exit and change farms. Irregular sampling frequencies.

Structure of Our Data – Time & Seasonality



Breeding Progress. Policy Changes. Sampling Patterns. Annual Seasonality.

Empirical Strategy

Variable of Interest	=	Weather	+	Controls	+	Unobserved Heterogeneity	+	Error
Milk Yield ECM Yield		3 Day Mean THI		Days in Milk (DIM) Parity Time & Season		Animals Farms		
		non-linear		linear & non-linear		random effects		

Generalized Additive Models – GAMs

Model the non-linearities and derive the threshold values with numerical methods.

Single Breed Model

$Y_{ijkt} = \beta_0$	**Intercept**	
$+ f_{1,1}(\text{THI}_{kt}) \cdot \mathbb{I}(\text{Primiparous}_i)$ $+ f_{1,2}(\text{THI}_{kt}) \cdot (1 - \mathbb{I}(\text{Primiparous}_i))$	**Weather**	$f_1(\text{THI}_{kt})$ is a smooth function of THI on farm k at time t
$+ f_{2,1}(\text{DIM}_{it}) \cdot \mathbb{I}(\text{Primiparous}_i)$ $+ f_{2,2}(\text{DIM}_{it}) \cdot (1 - \mathbb{I}(\text{Primiparous}_i))$ $+ \beta_1 \cdot \mathbb{I}(\text{Primiparous}_i)$	**Controls**	$f_2(\text{THI}_{it})$ is a smooth function of DIM of sample i at time t primiparous vs multiparous
$+ \sum_{m=1}^{M-1} \beta_{2m} \cdot \mathbb{I}(\text{Year}_t = m)$	**Time**	dummy for each year
$+ u_{kt}$	**Seasonality**	RE of zip code of farm k and month of t
$+ v_k$	**Farms**	RE of farm k
$+ w_i$	**Animals**	RE of for animal i
$+ \epsilon_{ijkt}$	**Error**	

GAMs are the state-of-the-art statistical framework to fit our model.

An Unforeseen Challenge… The Sparsity of our Data…

GAM $$g(E(y_i)) = \beta_0 + \sum_{j=1}^{p} f_j(X_{ij}) + \sum_{k=1}^{q} Z_{ik} b_k + \epsilon_i$$

Equivalence
Wood, S.N. (2004)

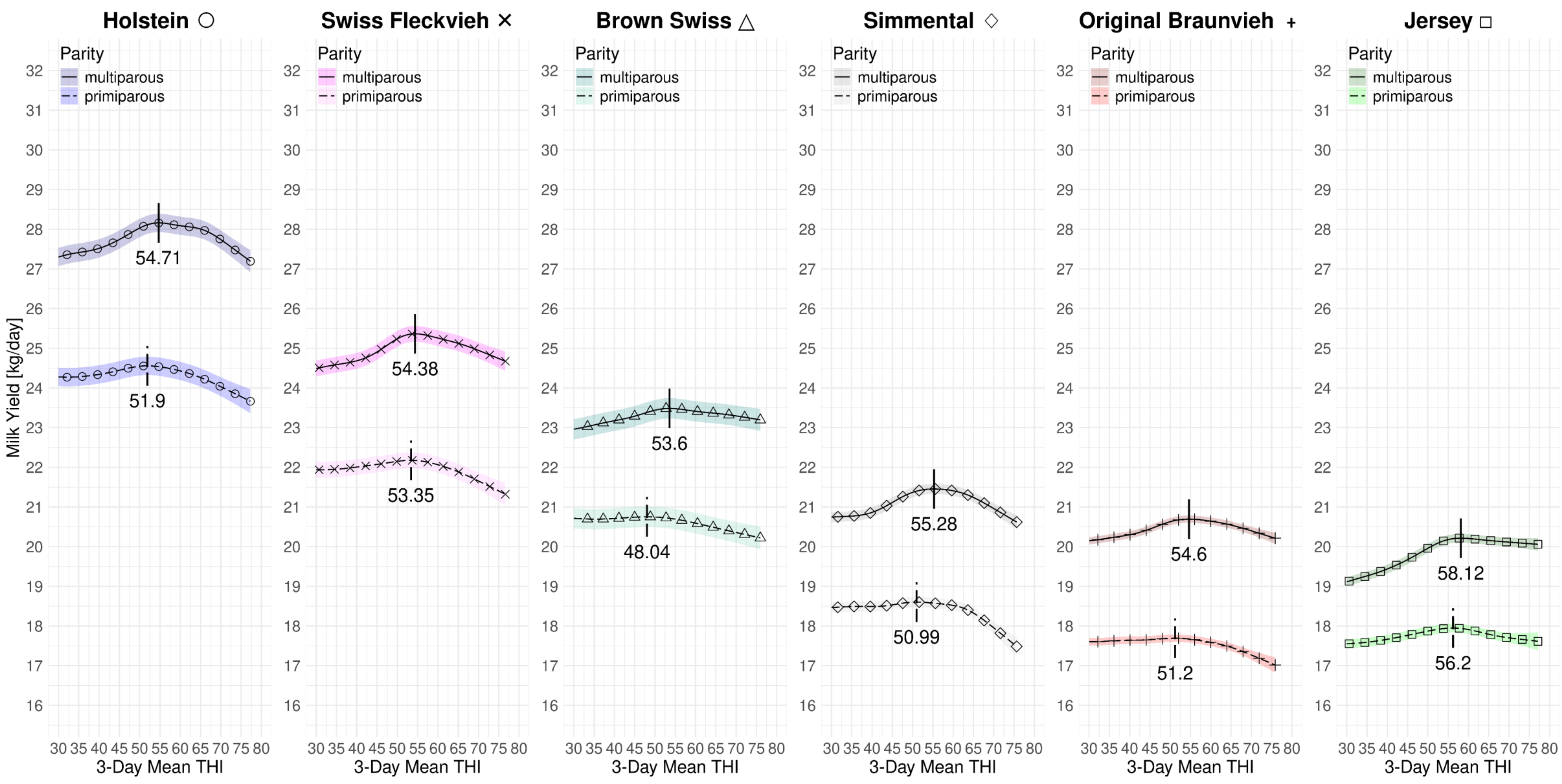
Mixed Model $$y = X\beta + Zb + \epsilon$$

Package		Factor Levels
MGCV Wood (2017)	R	hundreds
gamm4 Wood, Scheipl (2020)	R	thousands
gamm4b	R, Python	tens of thousands
gammJ	R, julia	
~3000% speed-up		

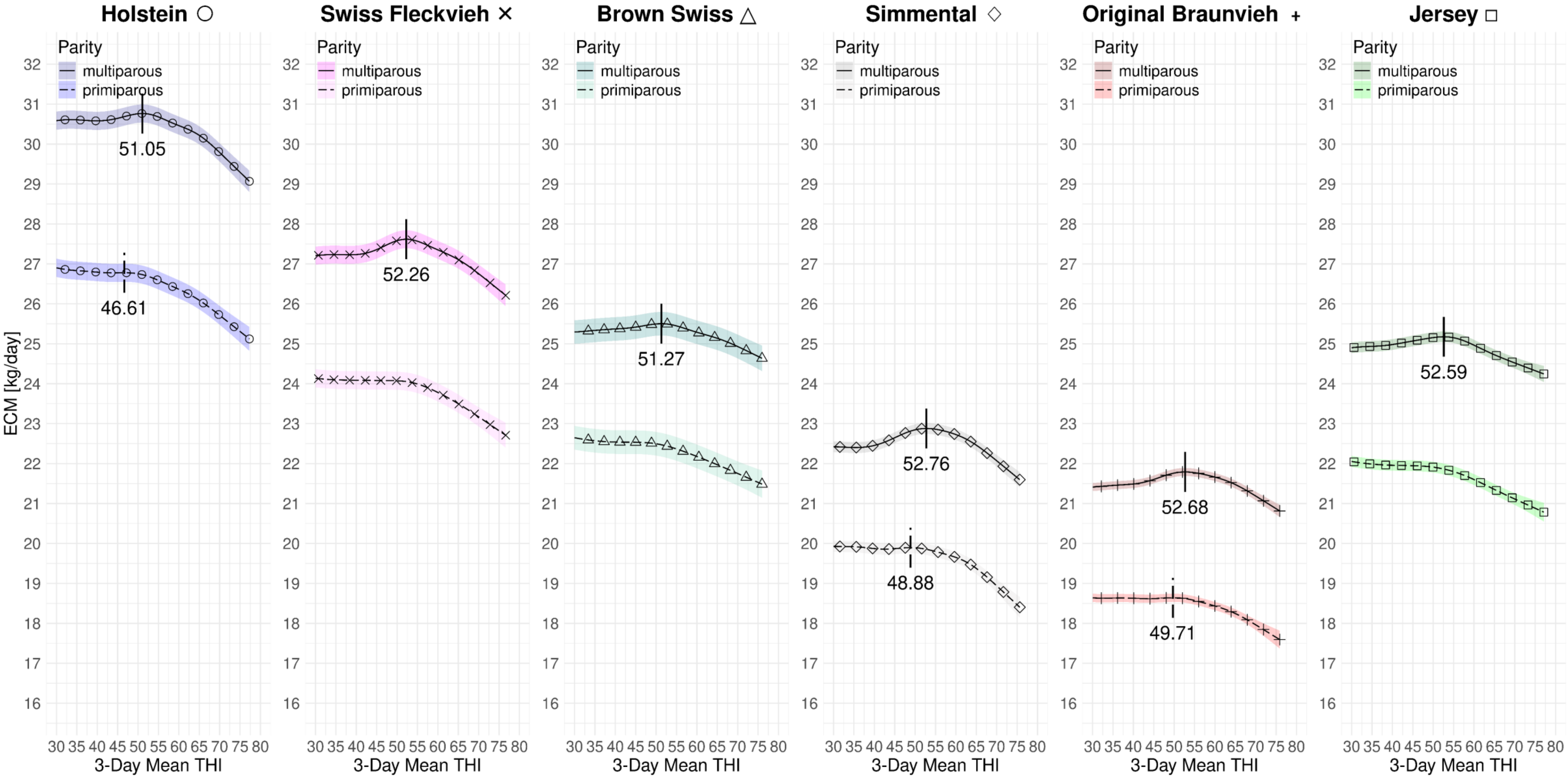
Our contribution → gamm4b, gammJ

We extended libraries to accommodate GAMs with tens of thousands of factor levels.

Results: Milk Yield - THI Effect & Intercepts (Mean + Year 2023)



Results: ECM Yield - THI Effect & Intercepts (Mean + Year 2023)



Discussion

	THI Thresholds Milk Yield [kg/day]					
	HO	SF	BS	SI	OB	JE
Multiparous	54.71	54.38	53.60	55.28	54.60	58.12
Primiparous	51.90	53.35	48.04	50.99	51.20	56.20
	○	×	△	◇	+	□

	THI Thresholds ECM Yield [kg/day]					
	HO	SF	BS	SI	OB	JE
Multiparous	51.05	52.26	51.27	52.76	52.68	52.59
Primiparous	46.61	-	-	48.88	49.71	-
	○	×	△	◇	+	□

Low THI Thresholds: not unseen, but not common - *Ahmed et al (2022), Hill et al (2015), Vinet et al (2023)*

Component drop: Bryant et al (2007), Chen et al (2024)

Lower thresholds for primiparous: similar findings by *Maggiolino et al (2022)* , *J. Castro-Montoy (2019)*

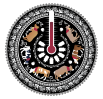
contradicts *Bernabucci et al (2014), West (2004), Aguilar et al (2010)*

Early component drop weighs out differences in volume drops across breeds!

Limitations & Potential Next Steps

6 Single Breed Models

- Computational limits → multi-breed model
- Subsampling strategies
- Stacking / ensemble techniques



Limited interpretability of p-values (non-experimental design) **p*****

Spatial Autocorrelation & Confounding & Seasonality

- Better modelling than with the *zip* X *month* RE -> longitude, latitude, day of year smooths
- Spatial+ Dupont et al (2020)
- Model selection

Farm as fixed effects (MixedModels.jl such an experiment – sparse FE matrix support)

Other weather effects: precipitation, sunshine duration, radiation, exact lactation numbers

Other performance variables: Somatic Cell Count, lactose, (rotein, fat separately - included in ECM)

Contributions

Agronomy / Animal Science

performance critical **THI thresholds** for 6 breeds

non-linear marginal effects of THI for 6 breeds

unprecedented **granularity** and **scale** of data, even if we subsampled

---

Statistics / Computational Science

Identified a **bottleneck** in MGCV for random effects with a high number of factor levels

Fixed gamm4 bugs, introduced an improved version **gamm4b**

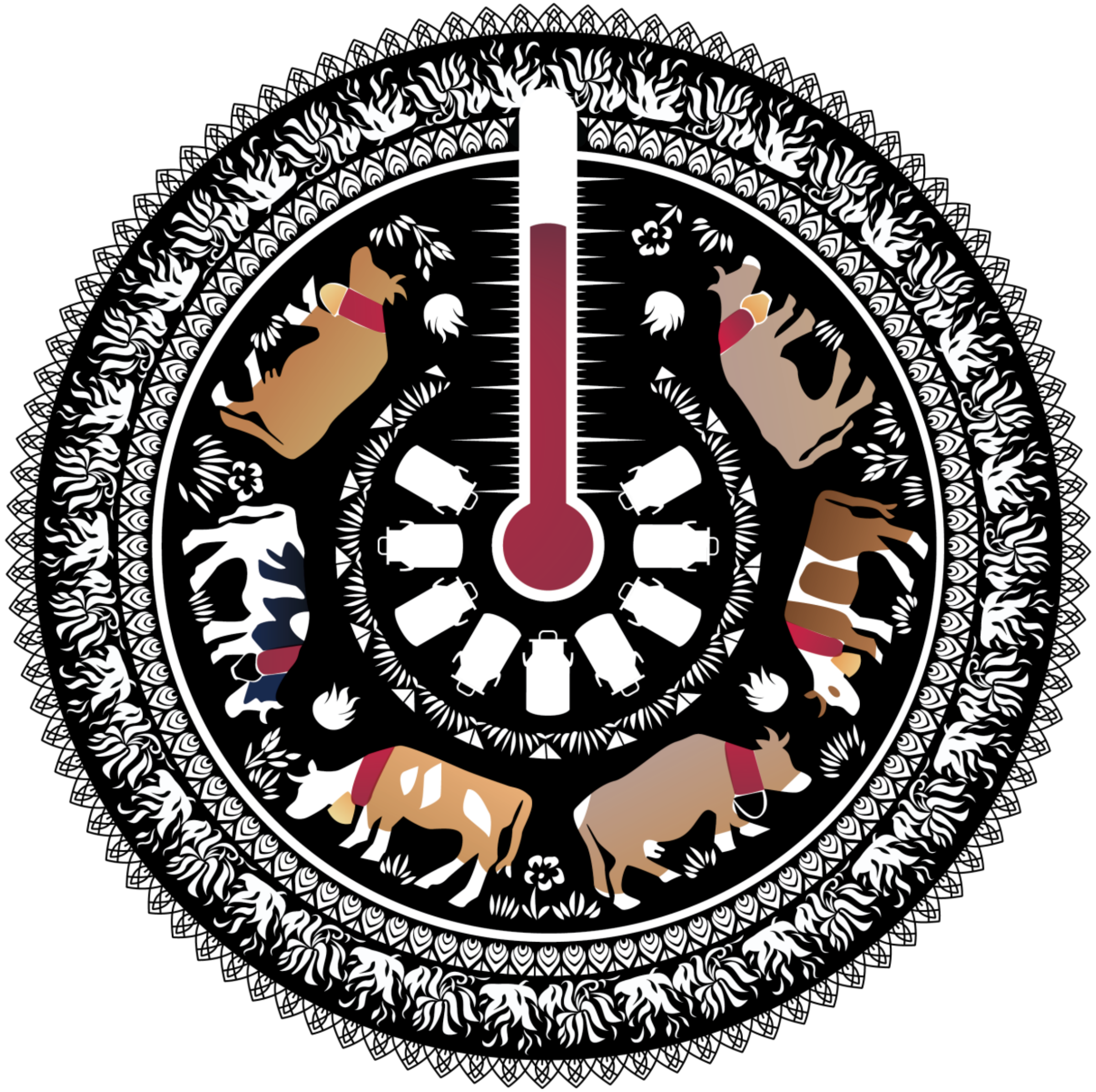
gammJ: modified gamm4 with a bridge to MixedModels.jl to support GAMs

Poll: Which is the most heat-resilient breed in terms of ECM yield?

Brown Swiss	Original Braunvieh	Holstein	Jersey	Simmental	Swiss Fleckvieh
					
△	+	○	□	◇	×
5	2	6	3	**1**	4

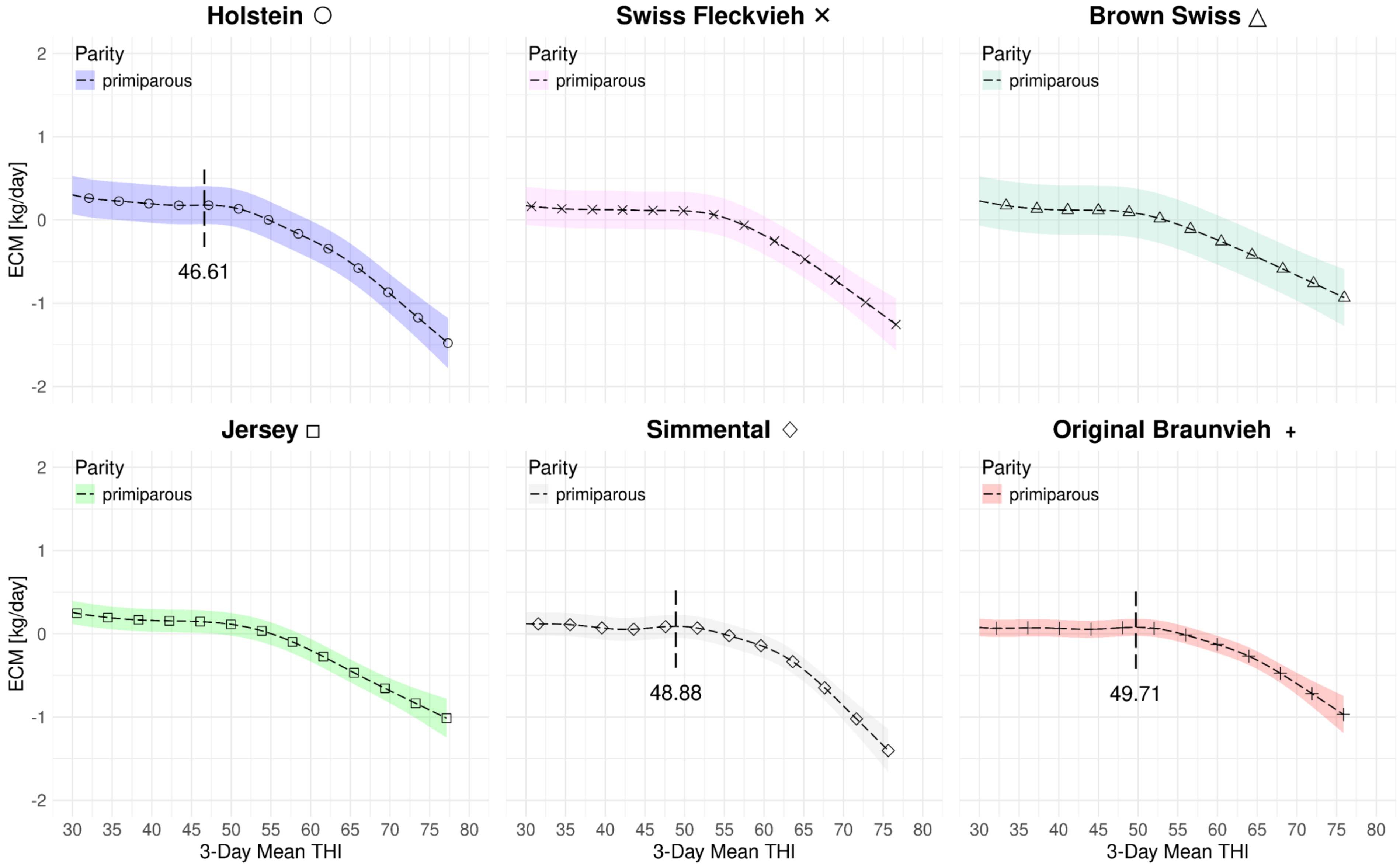
The threshold differences across breeds are minimal for ECM yield! Similar resilience for all breeds.

Appendix

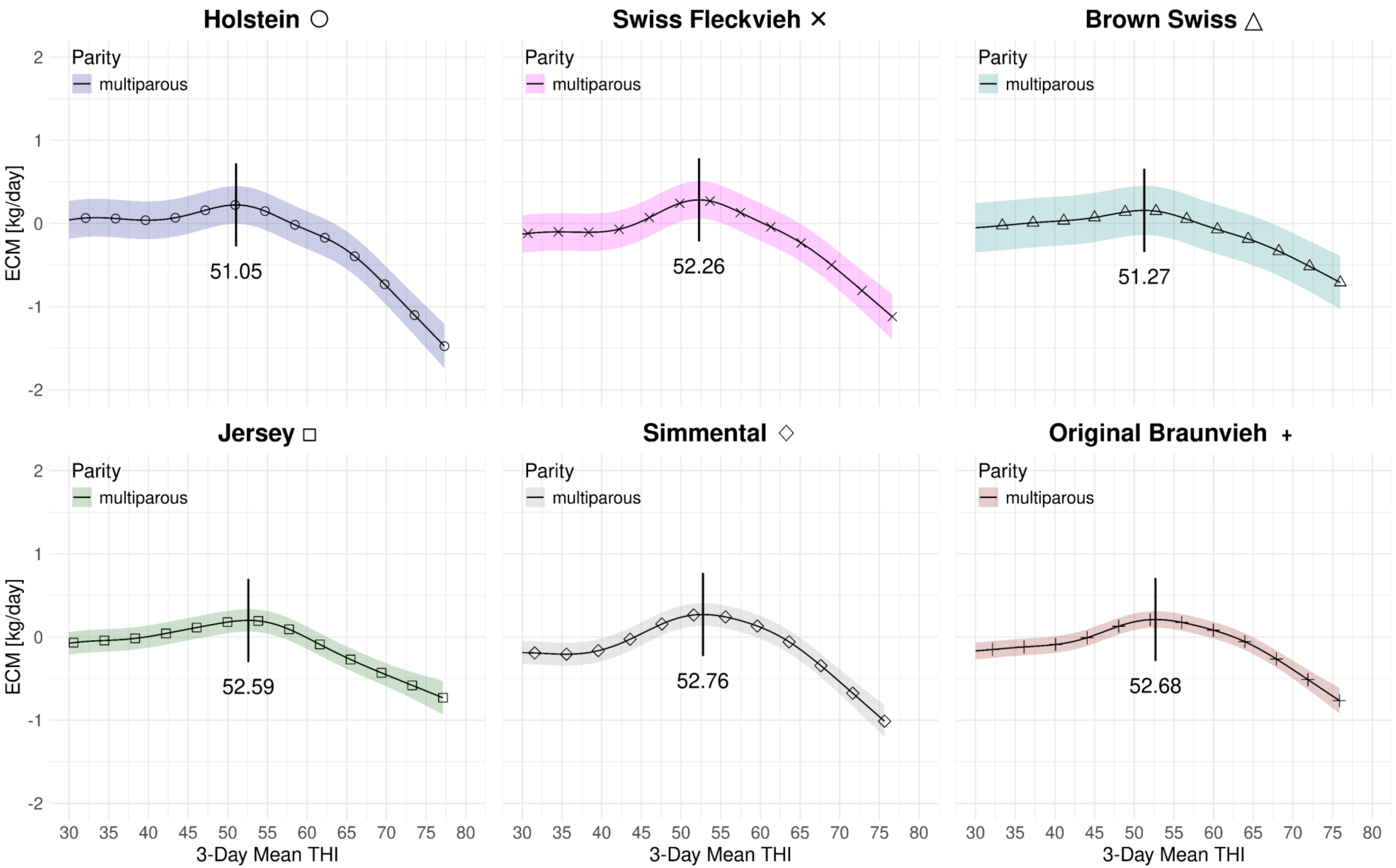


ECM Full Time Range

Results: ECM Yield – Marginal Effects for Primiparous Cows

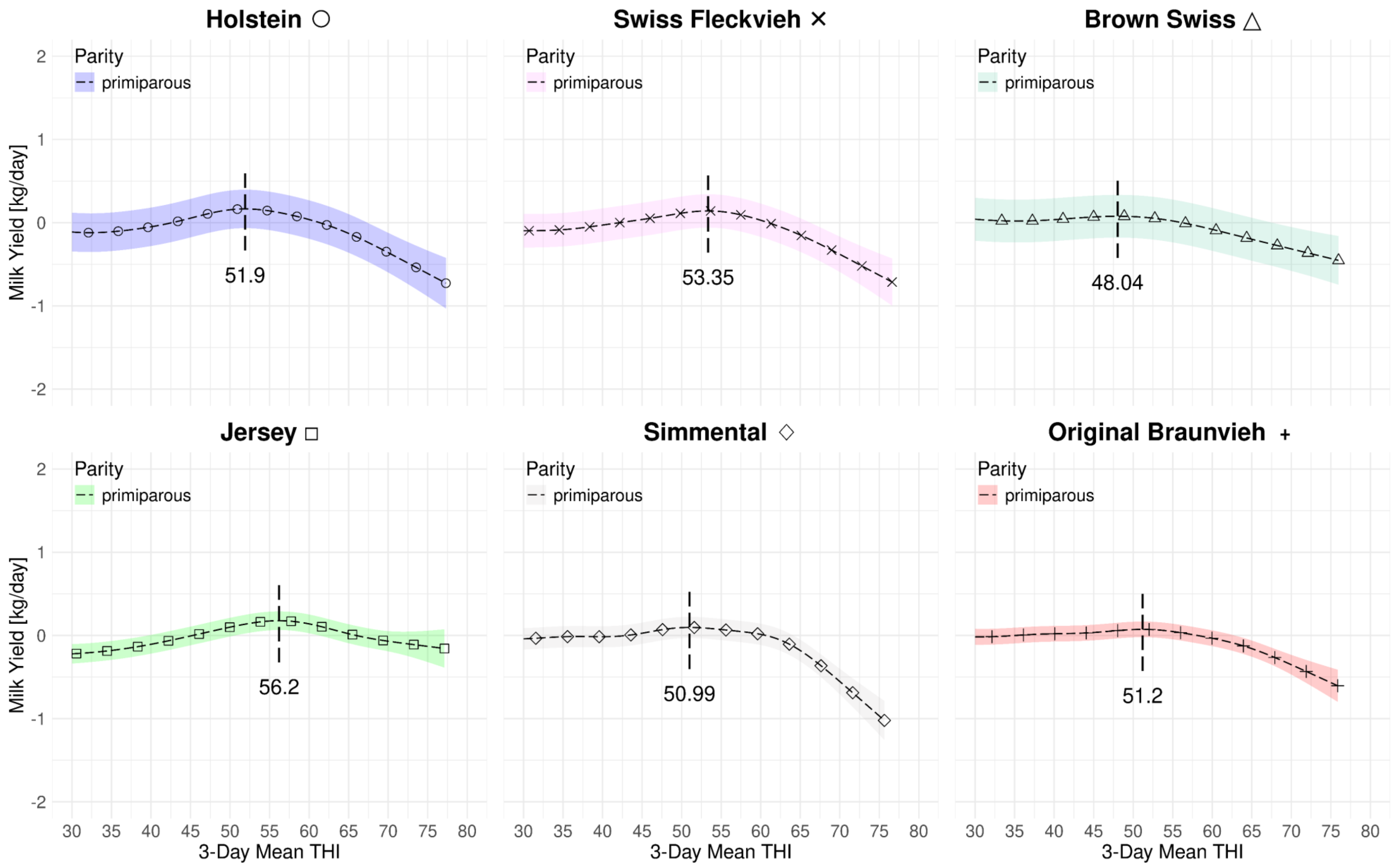


Results: ECM Yield – Marginal Effects for Multiparous Cows

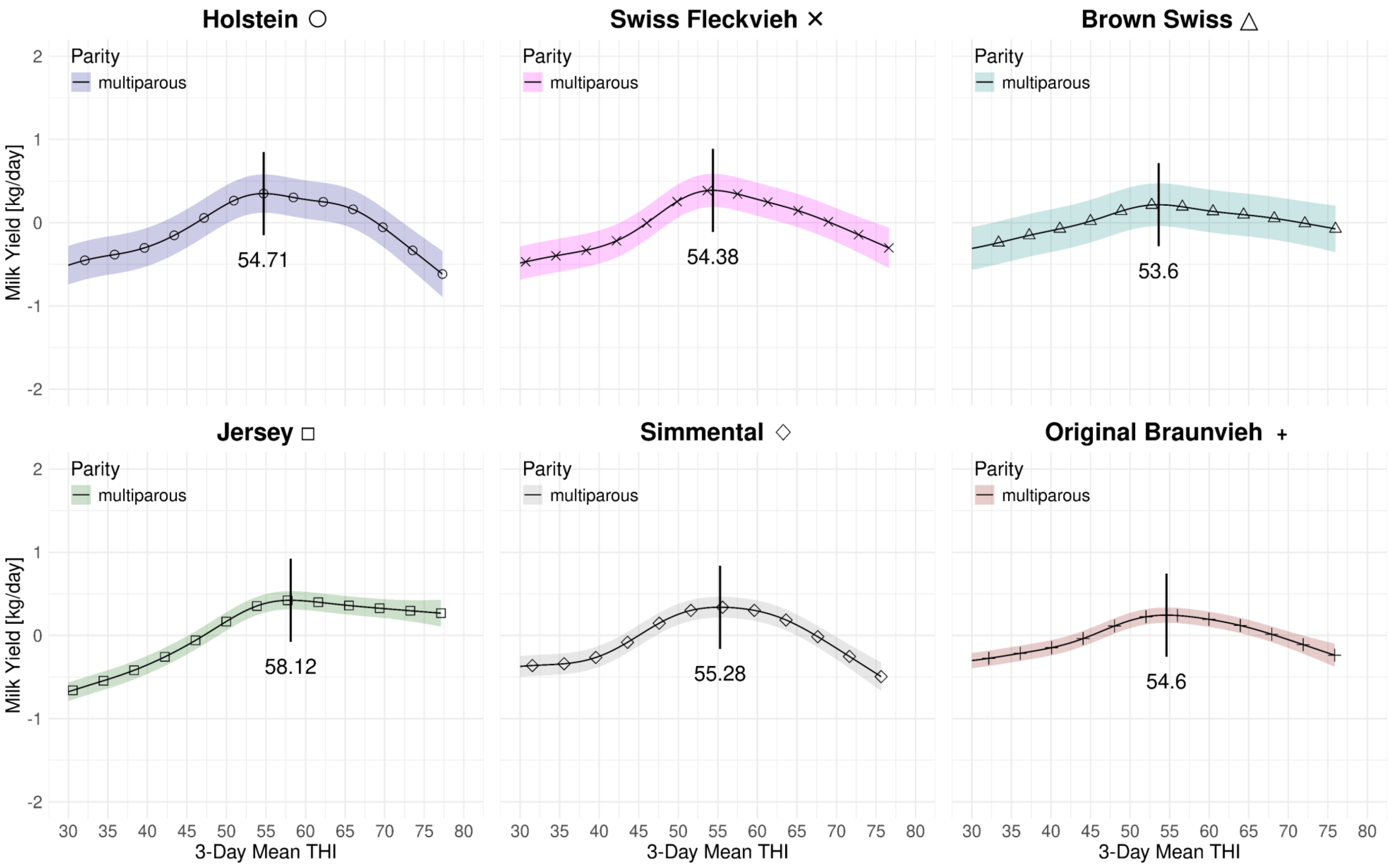


Milk Yield Full Time Range

Results: Milk Yield – Marginal Effects for Primiparous Cows

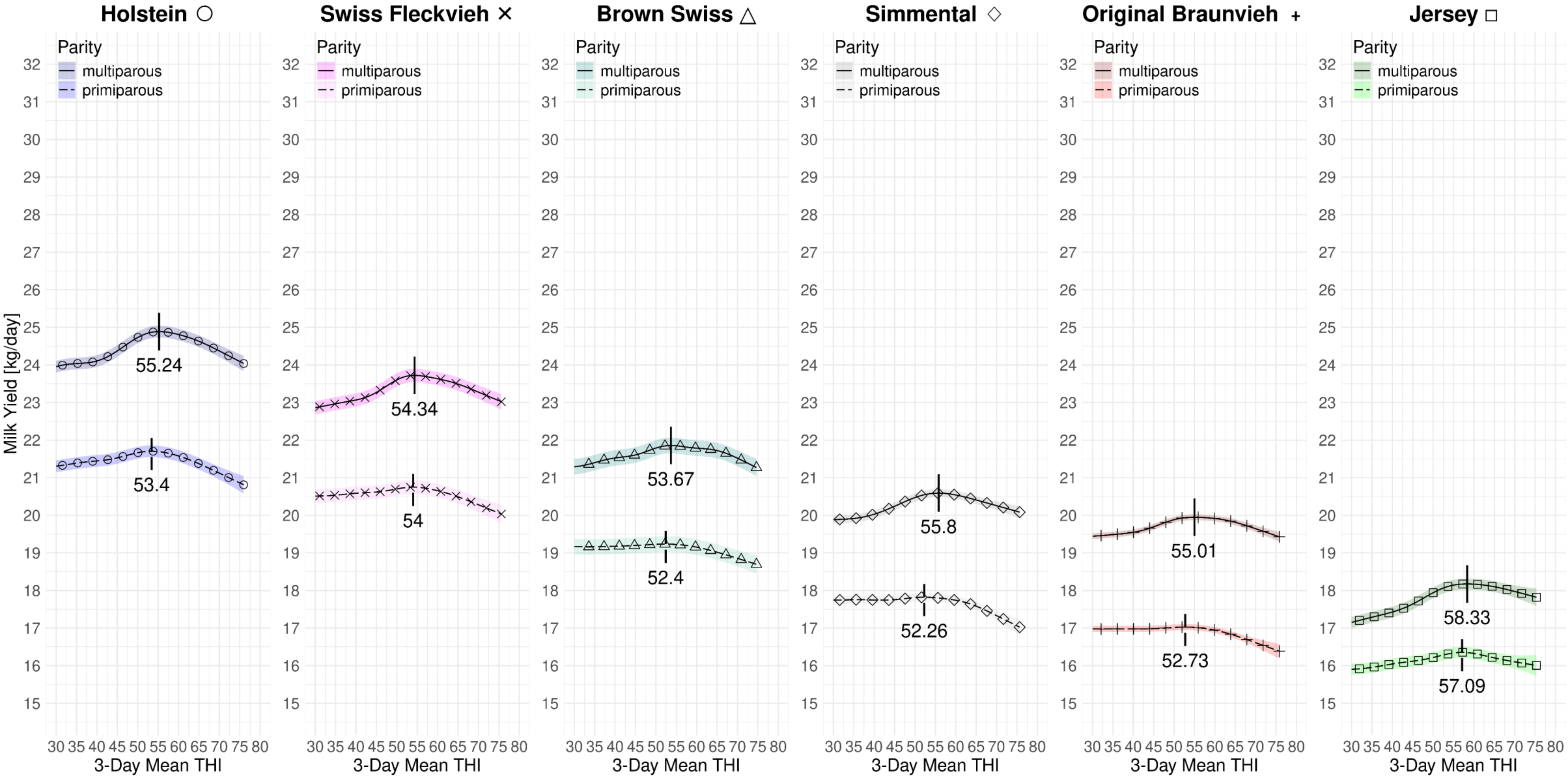


Results: Milk Yield – Marginal Effects for Multiparous Cows

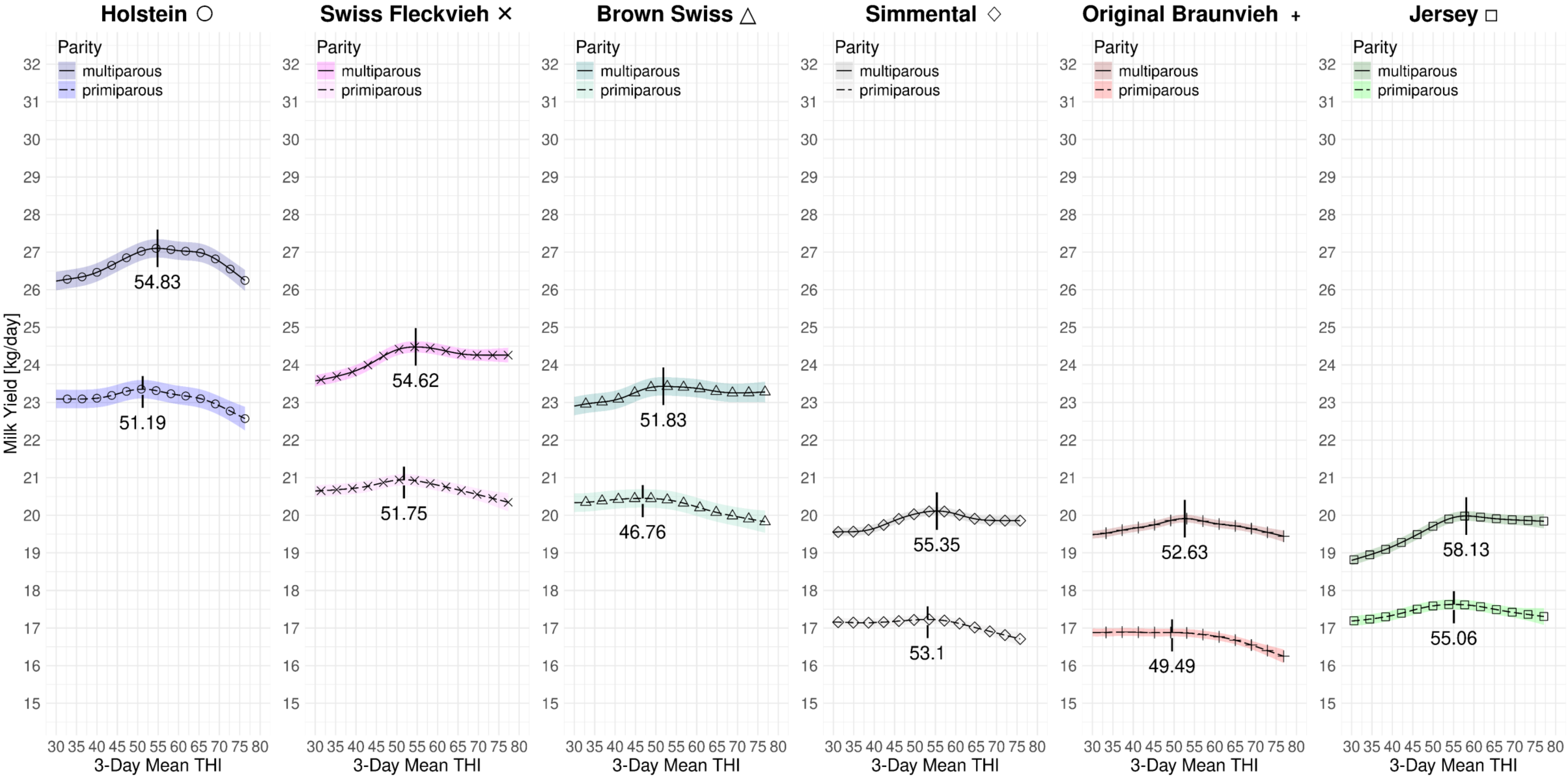


Milk Yield Before & After 2010

Results: Milk Yield – Marginal Effects for Primiparous Cows before 2010

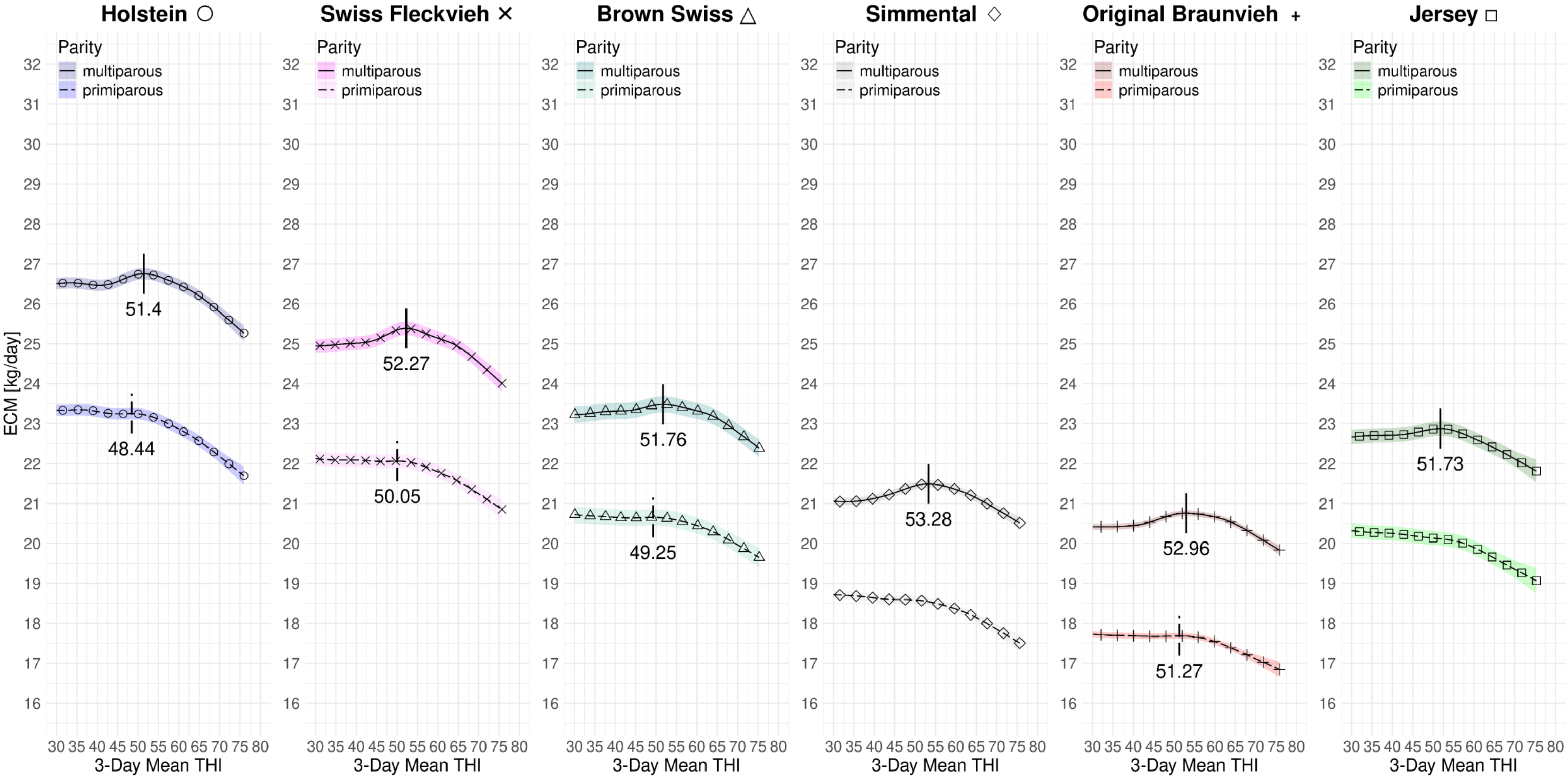


Results: Milk Yield – Marginal Effects for Primiparous Cows after 2010

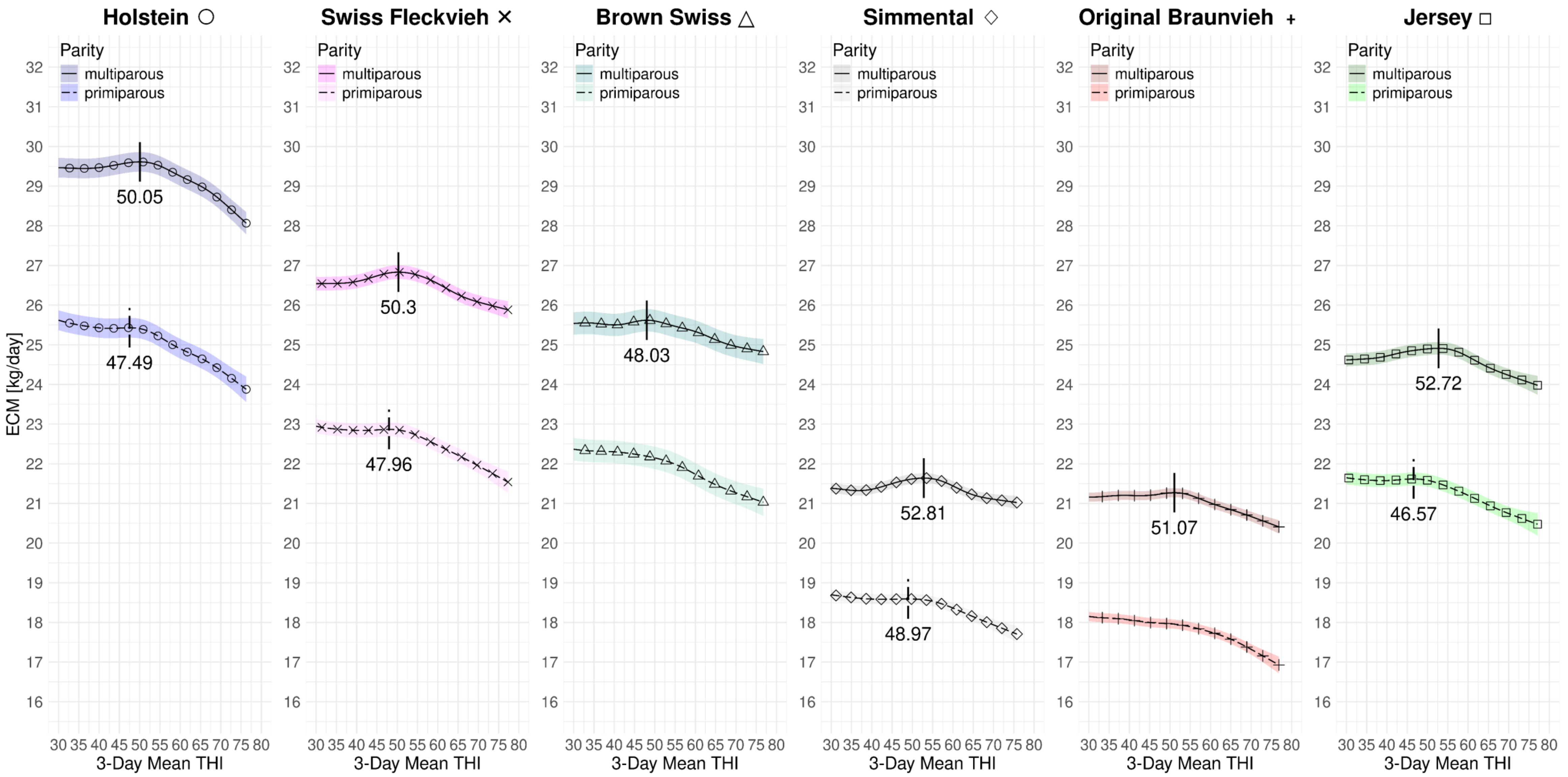


ECM Yield Before & After 2010

Results: ECM Yield – Marginal Effects for Primiparous Cows before 2010

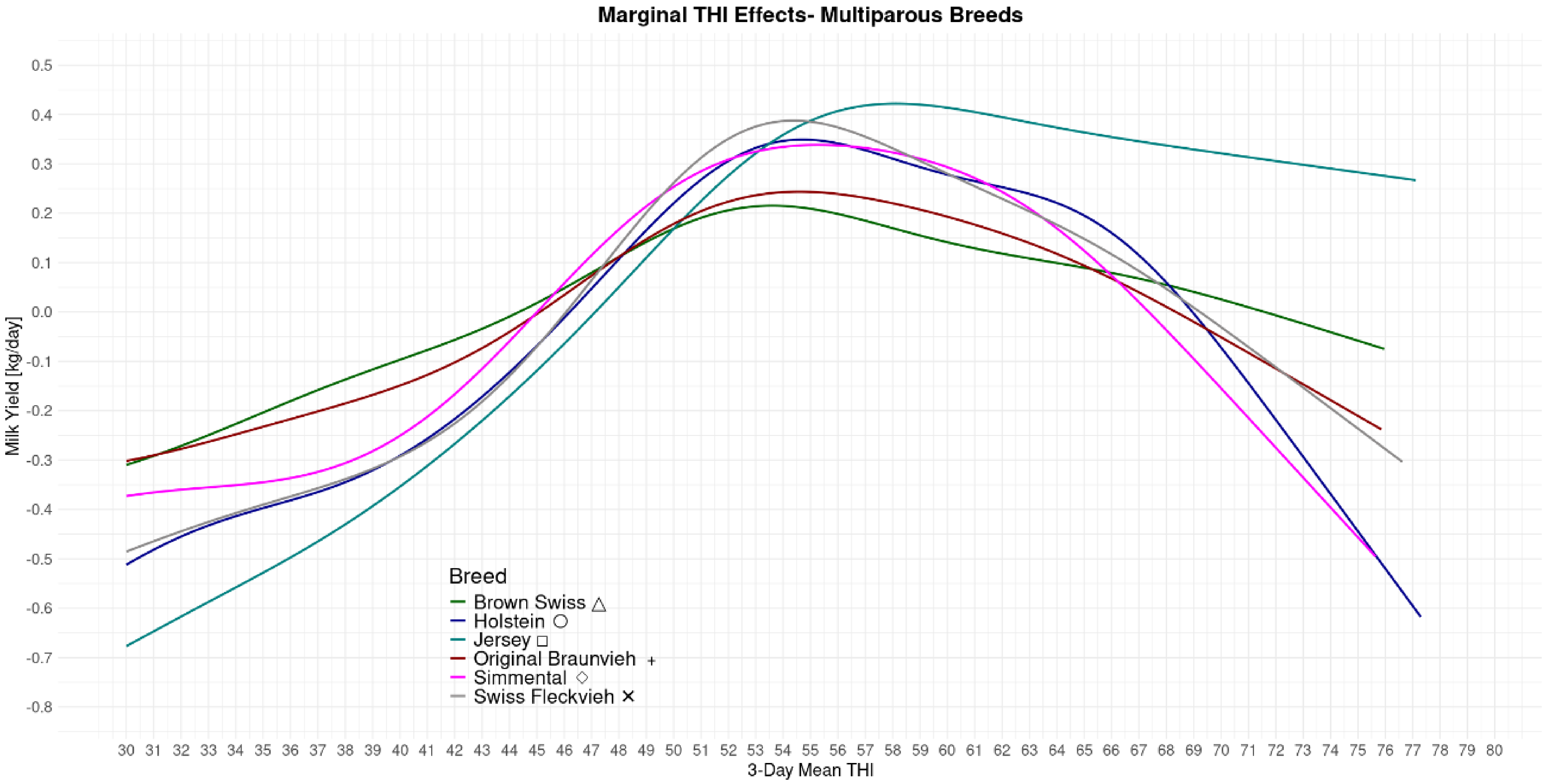


Results: ECM Yield – Marginal Effects for Primiparous Cows after 2010

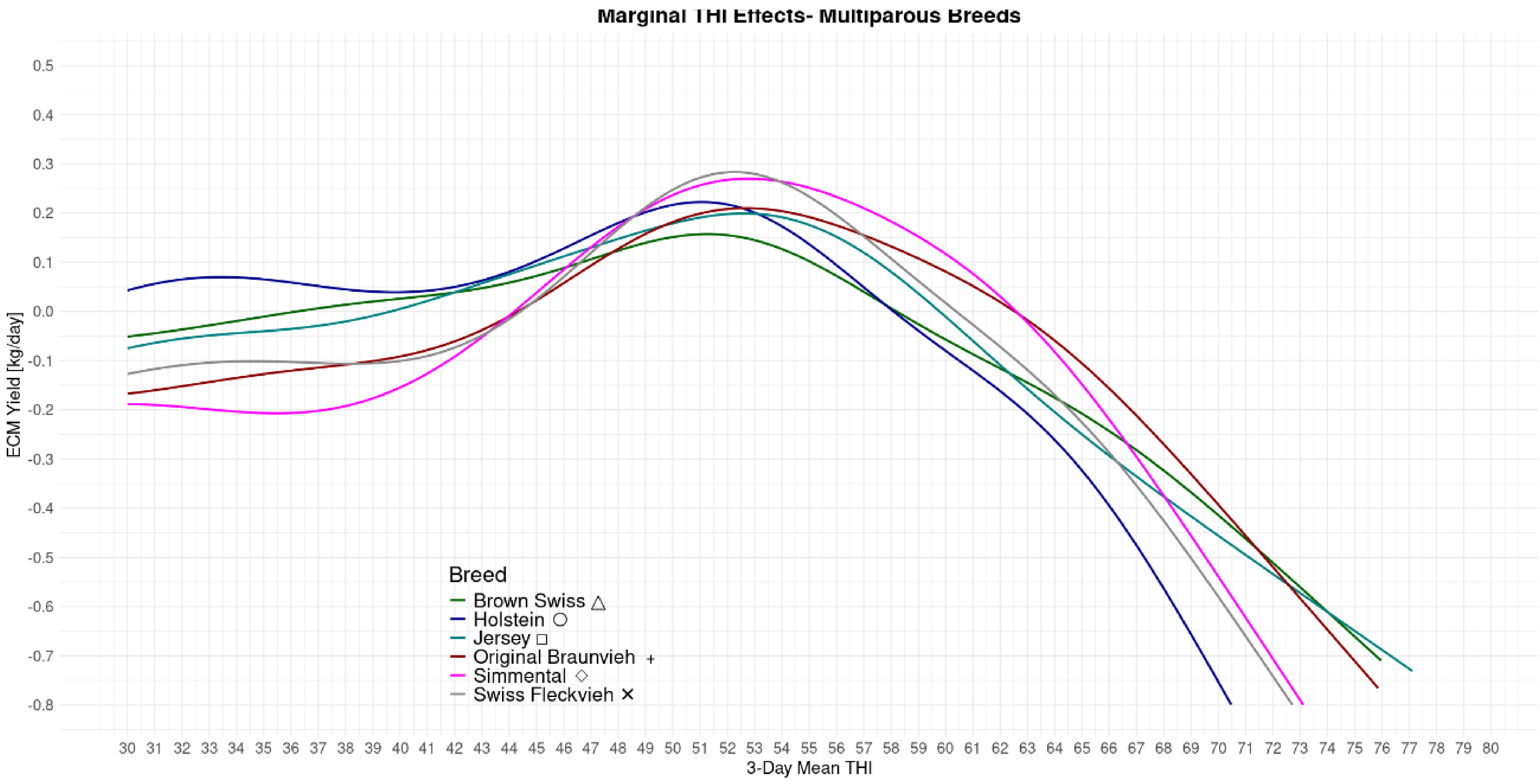


Marginal Effects – Full Period

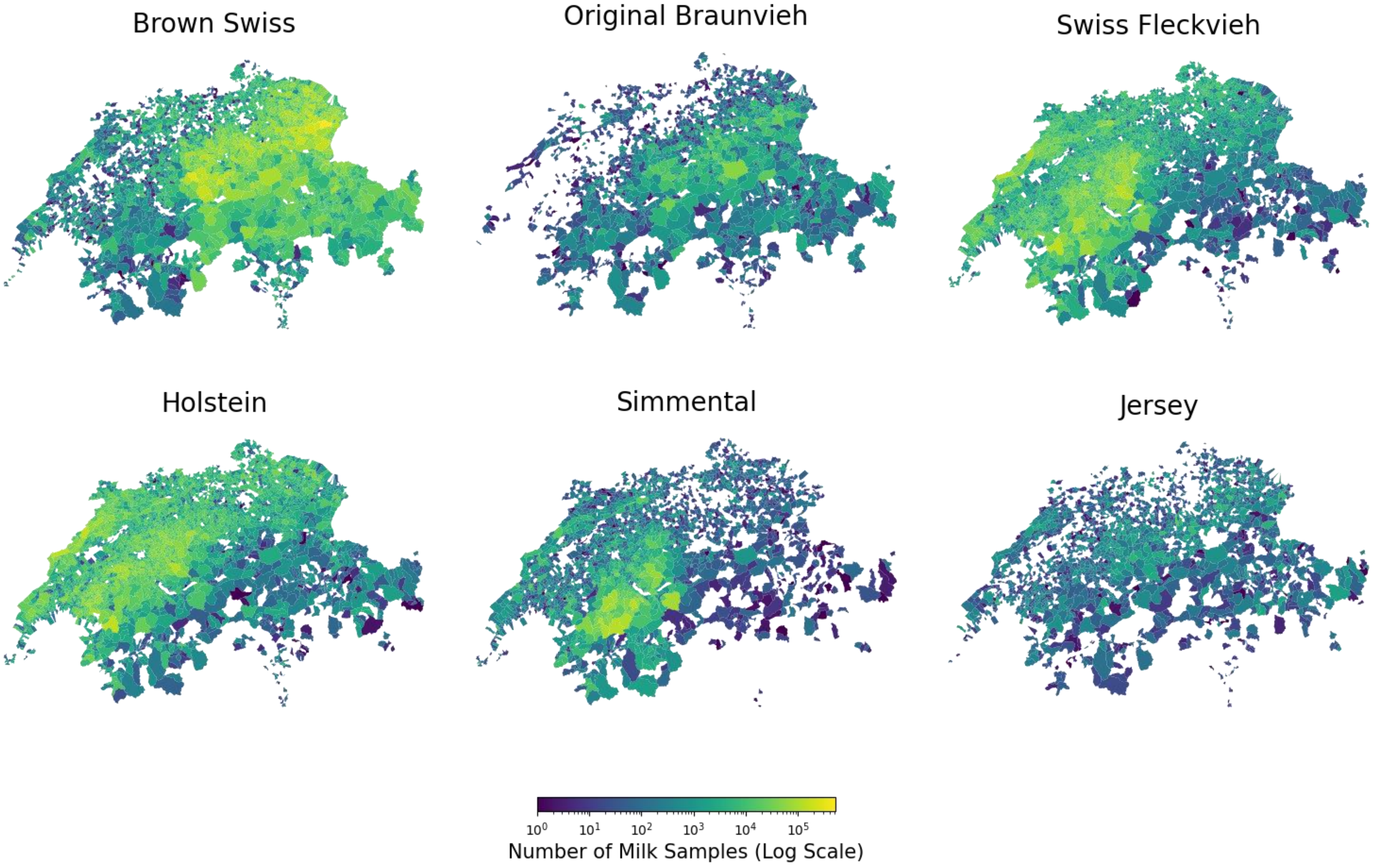
Marginal Effects



Marginal Effects



Sample Distribution by Breed (> 1000 samples)



Multi-Stage Data Cleaning

IQA Filtering – Drop unrealistic values	E.g. 90 kg milk, 90% Protein
Only take samples where all target variables of interest are simultaneously available	Milk, Protein, Fat
Drop Research Farms, Farm Schools, Breeding Associations, Research Organizations	ETH, Agroscope, Qualitas
Only Farms in Switzerland – Drop foreign farms	Keep cows with international ID

Conservative data cleaning approach.

Agricultural Policies in Switzerland

Agricultural Policies	Enactment
RAUS	1993
BTS	1996
Milk price supplement	1999
Milk quota abolition	2009
Grassland-based feeding	2014
Commercial milk	2019
Pasture payment	2023