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The Effects of Weather on Beef Carcass and Growth Traits

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1 **The Effects of Weather on Beef Carcass and Growth Traits**

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5 **Abstract**

6 To predict the impact of climate change on our beef animals and systems, we need a
7 better understanding of how beef cattle traits are affected by varying weather and
8 frequency of extreme events. We analysed the effect of minimum and maximum
9 temperature and average daily precipitation on a range of important carcass traits,
10 including age at slaughter, cold carcass weight, carcass growth rate and
11 conformation and fat score (N= >1.6 million), as well as calf 200-day live weight and
12 growth rate (N= >270 000), using data from abattoirs across Britain (carcass traits)
13 and calves in Scottish suckler beef herds (live weights and growth). Animals which
14 experienced higher daily maximum and minimum temperatures had slower carcass
15 and calf growth rates. Increased precipitation also led to poorer cold carcass
16 weights, conformation scores, calf 200-day weights and calf growth. We also
17 analysed the effect of frequency of extreme weather events, including heatwaves,
18 cold waves, and dry and wet days. The frequency of heatwaves, dry and wet days
19 were shown to have significant negative effects on almost all traits considered, for
20 example, predicting that an increase in frequency of heatwaves by 1 day per 100
21 days of life would reduce cold carcass weights by about 200g and increase age at
22 slaughter by about 3 days. Results show that that varying weather and frequency of
23 extreme weather, across the lifetime of a beef animal, influences traits which affect

24 the potential profit for a beef farmer. These effects may be due to several factors,
25 including direct effects on the animal, as well as feed availability and management
26 decisions made by the farmer. However, there is potential to mitigate negative
27 effects through a range of animal management strategies.

28 **Keywords:** Climate, Cattle, Heat stress, Extreme weather, Resilience

29 **Implications**

30 Our results show that varying weather and frequency of extreme weather events
31 experienced by a beef animal, influences important beef traits. We predict a 1°C
32 increase in average daily maximum temperatures would reduce carcass growth rates
33 by about 6g per day and calf growth rates by about 50g per day. We also predict an
34 increase in frequency of heatwaves by 1 heatwave day per 100 days of life would
35 reduce cold carcass weights by about 200g and increase age at slaughter by about 3
36 days. Without mitigation, these effects could reduce profit for farmers as well as
37 increasing environmental impact.

38 **Introduction**

39 Climate change predictions show UK weather is likely to change significantly over
40 the coming decades, both in terms of average weather conditions but also the
41 frequency of extreme weather events (European Environment Agency, 2017). There
42 is a need for British livestock farming to adapt to these challenges, both to maintain
43 profits for farmers, but also to reduce further climate and environmental impacts
44 (Wreford and Topp, 2020). However, to plan potential mitigation strategies, we need
45 to understand how varying climate impacts UK livestock farming.

46 There is good evidence that cattle are affected by climate. In the tropics, cattle
47 experiencing high temperatures (especially combined with high humidity) experience
48 heat stress which has negative impacts on milk production (Mbutia et al., 2021),
49 health and fertility (Polsky and von Keyserlingk, 2017; Bagath et al., 2019; Herbut et
50 al., 2019) and growth (Brown-Brandl, 2018). Studies suggest air temperatures below
51 -0.5 and over 20-26 °C cause negative impacts on dairy cattle (Berman et al., 1985;
52 West, 2003). Despite cattle in the UK not experiencing these same high
53 temperatures, studies show that even Scottish dairy cattle experience a drop in milk
54 yield due to both extreme highs and lows in temperature (Hill and Wall, 2014). Cold
55 weather also affects other cattle traits. Studies have shown animals that are more
56 exposed to cold weather during winter have lower growth rates (Holmes et al., 1978)
57 and the use of calf jackets, particularly for dairy calves is thought to mitigate this
58 (Robertson, 2020). We also expect precipitation to have an effect on cattle traits, as
59 it affects plant growth (Dellar et al., 2018) and will likely affect grazing feed quality
60 and availability.

61 Many of these studies consider the effects on dairy cattle and we lack large scale
62 studies on the effects of weather in temperate environments on beef cattle. Beef
63 cattle have higher upper critical temperatures than dairy cattle (Wreford and Topp,
64 2020), so may be less affected by heat stress. However, typically UK beef cattle are
65 not housed as much as dairy (Smith et al., 2001) which may mean they are more
66 greatly affected by weather. Our aim is to investigate the effect of weather and
67 frequency of extreme weather events on a range of cattle traits important to beef
68 production.

69 **Material and methods**

70 To investigate the effects of weather on beef production, we analysed two datasets:
71 (i) slaughter records from UK abattoir companies across England, Wales and
72 Scotland (Pritchard et al., 2021) (summarised in Table 1); and (ii) calf records in
73 Scotland recorded through the Scottish Government's Beef Efficiency Scheme 2016-
74 2021 (summarised in Table 2). These were both combined with data supplied from
75 British Cattle Movement Service (**BCMS**) and weather data from the MetOffice
76 HadUK-Grid database (Perry and Hollis, 2004; Hollis and Perry, 2005). Final
77 datasets, after removing animals with missing information, contained 1 771 367
78 abattoir records from animals alive between 2000 to 2019 and over 274 376 calf
79 records from calves alive between 2016-2019.

80 ***Animal phenotypes***

81 Carcass traits included cold carcass weight (**CCW**), conformation class and fat class.
82 Typically, conformation is assessed using the EUROP classification and fat class
83 using a 1-5 scale. However, most abattoirs further sub-divide these classes.
84 Therefore, these data were transformed to two 15-point scales, where 15 represents
85 the best conformation and the fattest carcasses. Age at slaughter (**AAS**) was
86 calculated using date of birth from BCMS data and kill date from abattoir data. A
87 measure of carcass growth rate was calculated by dividing CCW by AAS. We call
88 this average daily carcass gain (**ADCG**), but it is important to note that we have
89 omitted birth weight in this calculation for simplicity as birth weight data was
90 unavailable. Edits were made to remove extreme records, including those more than
91 3 standard deviations from the mean of CCW, animals which were less than 365 or
92 more than 1095 days old at slaughter and those with an ADCG more than 3 standard
93 deviations from the mean. As well carcass data from abattoirs, we also had live
94 weights for over 270 000 calves in Scotland, measured at approximately 200 days.

95 The actual age at weighing varied from 100-300 days. We used these values to also
96 calculate a calf growth rate trait, dividing the live weight by age at weighing.

97 A range of other factors and covariates were included. Sex was defined using data
98 from the abattoir as castrated male (n=934 341 or 56%), female (n=527 741 or 31%)
99 or entire male (n=219 722 or 13%). This was checked using data from BCMS where
100 animals were recorded as male or female. For calves, we did not have information
101 about castration status so all calves were recorded as male or female. Breed,
102 including crossbred type, was defined using the breed code recorded in BCMS. In
103 the carcass data, only animals from breeds or crossbred types with more than 1 000
104 animals were included, resulting in the inclusion of 47 breeds and crosses. The most
105 common three were Aberdeen Angus cross (n=287 687), Limousin cross (273 081)
106 and Holstein (212 256). In the calf data, only animals from breeds or crossbred types
107 with more than 100 animals were included, resulting in the inclusion of 27 breeds
108 and crosses, the most common of which were Aberdeen Angus cross (55 230),
109 Charolais cross (53 132) and Limousin cross (47 244).

110 Data about the dam of each animal was also extracted from BCMS. This included
111 the age of the dam at the birth of the animal. Only individuals with dams older than
112 365 days were included. This resulted in a dam age range of 371 - 3 649 days with a
113 mean of 1 787 days and a standard deviation of 752 days. We also included the
114 proportion of dairy breed in the dam's pedigree as this has been shown to have an
115 important effect on carcass traits, particularly conformation score (Pritchard et al.,
116 2021). This varied from 0.03-100%, with a mean of 80.22% and a standard deviation
117 of 28.31%.

118 We needed to account for varying management practices which might be regionally
119 distributed and therefore correlated with weather. We achieved this by including two
120 contemporary groups in our model. First, we grouped animals according to their birth
121 location, year and season (**BirthHYS**), where season was defined as three classes
122 (Feb - May; Jun - Sep; Oct – Jan). We only included animals in BirthHYS groups that
123 contained at least 5 animals. For the abattoir data, this resulted in 111,895 BirthHYS
124 groups, ranging in size from 5 to 527, with a mean size of 15.0 animals. Secondly for
125 the abattoir data only, we grouped animals according to their finishing location, year
126 and season (**FinishHYS**). We defined finished location as the location where an
127 animals stayed for at least 60 days before slaughter (excluding up to 7 days before
128 death to account for holding animals were moved through before slaughter). This
129 resulted in 53 994 FinishHYS groups, ranging in size from 5 to 975 animals with a
130 mean size of 31.2 animals. Finally, for the abattoir data, the location of death was
131 also included. There were 32 death locations with between 785 and 181 494 animal
132 slaughter records.

133 ***Weather parameters***

134 We used weather data from the Met Office HadGrid-UK database, a data set of
135 gridded climate variables derived from the network of UK land surface observations.
136 Variables include daily maximum and daily minimum temperatures and daily total
137 precipitation for each 1km square across the UK. Animal locations and dates of stay
138 were extracted from the BCMS database and the nearest centre of a corresponding
139 km square from the HadGrid data found. This allowed us to calculate the average
140 daily maximum temperature (**Tmax**), average daily minimum temperature (**Tmin**)
141 and average daily precipitation (**Rain**) for the lifetime of each animal. Figure 1 shows
142 the mean of each of these for animals with varying years of birth within the carcass

143 data. The daily weather was also used to define the occurrence of extreme weather
144 events, including heatwaves, coldwaves, dry days and wet days. The Met Office
145 definition of a heatwave is a period of at least 3 days where the daily maximum
146 temperature exceeds a threshold. The threshold is specific to the location, with four
147 threshold regions defined by the met office in the UK: London, the South East of
148 England, an area around the South East of England and the rest of the UK, with
149 thresholds of 28°C, 27°C, 26°C and 25°C respectively. For cold waves, a similar
150 definition was used, where a period consisted of at least 3 days where the daily
151 maximum temperature did not exceed 0°C. Wet and dry days were defined as days
152 where rainfall was greater than 7.65mm and less than 0.12mm respectively. These
153 values correspond to 90th and 10th percentile of the daily precipitation across the UK
154 for the period 2000-2019. For wet and dry days no minimum number of consecutive
155 days was required. The total number of each type of extreme day experienced by
156 each animal was calculated and divided by its AAS or age at weighing for calves, to
157 calculate the frequencies of extreme weather days. Figure 2 shows the mean of
158 each of these for animals with varying years of birth within the carcass data.

159 ***Statistical analysis of results***

160 Analyses were carried out using general linear models using AS-REML (Butler et al.,
161 2017) and R. Two models were produced for each trait, the first to assess the effect
162 of average weather and the second to assess the effect frequency of extreme
163 weather events. For each carcass trait, all other carcass traits, except ADCG, were
164 included as covariates. For ADCG, AAS and CCW were also not included. For the
165 two calf traits (calf weight and calf growth), no other traits and no FinishHYS or death
166 location were included. We expected interactions between weather to be important
167 so tested a range of interactions effects and found interactions between Tmax and

168 Tmin and between Tmin and Rain were significant for a number of traits so were
169 included in the average weather models. For more detail, see supplementary tables
170 S1 and S2. The generalised model was as follows:

171 *Trait ~ weather parameters + other traits + sex + breed + BirthHYS + FinishHYS +*
172 *death location + dam age + dam %dairy*

173 **Results**

174 ***Average weather***

175 Almost all average weather parameters had a significant ($p < 0.05$) effect on every
176 trait assessed (Table 3), although the proportion of the variation they explain is
177 small, as R^2 values for models with weather were only slightly higher than those
178 without (0.56-0.62 compared to 0.51-0.53, respectively). An increase in AAS, which
179 is undesirable as increases farmer costs, was seen in animals which experienced
180 higher Tmax ($\beta = 10.17 \text{ days } ^\circ\text{C}^{-1}$, SE = 0.21), lower Tmin ($\beta = -1.34 \text{ days } ^\circ\text{C}^{-1}$, SE =
181 0.54) and lower Rain ($\beta = -19.73 \text{ days mm}^{-1}$, SE = 0.65). The effect of the
182 interactions between Tmin-Tmax ($\beta = -0.86 \text{ days } ^\circ\text{C}^{-2}$, SE = 0.031) and Tmin-Rain (β
183 = $2.78 \text{ days } ^\circ\text{C}^{-1} \text{ mm}^{-1}$, SE = 0.10) were also significant for AAS.

184 CCW was not significantly affected by Tmax ($p > 0.05$), but higher weights were
185 associated with higher Tmin ($\beta = 2.12 \text{ kg } ^\circ\text{C}^{-1}$, SE = 0.37) and lower Rain ($\beta = -1.39$
186 kg mm^{-1} , SE = 0.44). Again, the effect of the interactions between Tmin-Tmax ($\beta = -$
187 $0.19 \text{ kg } ^\circ\text{C}^{-2}$, SE = 0.021) and Tmin-Rain ($\beta = -0.23 \text{ kg } ^\circ\text{C}^{-1} \text{ mm}^{-1}$, SE = 0.070) were
188 also significant. Higher conformation scores were seen for animals which
189 experienced high Tmax ($\beta = 0.017 ^\circ\text{C}^{-1}$, SE = 0.006) and Tmin ($\beta = 0.062 ^\circ\text{C}^{-1}$, SE =
190 0.015) and lower Rain ($\beta = -0.043 \text{ mm}^{-1}$, SE = 0.018). Interactions between Tmin-

191 Tmax ($\beta = -0.005 \text{ }^\circ\text{C}^{-2}$, SE = 0.001) and Tmin-Rain ($\beta = 0.010 \text{ }^\circ\text{C}^{-1}\text{mm}^{-1}$, SE = 0.003)
192 were also shown to have a significant effect on conformation score.

193 An increase in fat score was seen in animals which experienced higher Tmax ($\beta =$
194 $0.072 \text{ }^\circ\text{C}^{-1}$, SE = 0.008) and Tmin ($\beta = 0.199 \text{ }^\circ\text{C}^{-1}$, SE = 0.020) and lower Rain ($\beta = -$
195 0.033 mm^{-1} , SE = 0.024). For fat score, only the interaction between Tmin and Rain
196 ($\beta = -0.014 \text{ }^\circ\text{C}^{-1}\text{mm}^{-1}$, SE = 0.001) was significant ($p < 0.05$).

197 For ADCG, higher growth rates were associated with animals that experience lower
198 Tmax ($\beta = -0.0060 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-1}$, SE = 0.00025) and Tmin ($\beta = -0.0022 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-1}$,
199 SE = 0.00063) and higher Rain ($\beta = 0.0073 \text{ kg day}^{-1} \text{ }^\circ\text{mm}^{-1}$, SE = 0.00077). Again,
200 interactions between Tmin-Tmax ($\beta = 0.00060 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-2}$, SE = 0.00004) and
201 Tmin-Rain ($\beta = -0.0014 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-1} \text{ mm}^{-1}$, SE = 0.00012) were also shown to have
202 a significant effect on ADCG.

203 For the calf traits, greater 200-day live weights were associated with animals that
204 had experienced lower Tmax ($\beta = -7.19 \text{ kg }^\circ\text{C}^{-1}$, SE = 1.90), higher Tmin ($\beta = 18.11$
205 $\text{kg }^\circ\text{C}^{-1}$, SE = 3.98) and lower Rain ($\beta = -20.82 \text{ kg mm}^{-1}$, SE = 7.14). Interactions
206 between weather effects were not significant ($p > 0.05$). An increase in calf growth
207 rate was seen for animals that had experienced lower Tmax ($\beta = -0.053 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-1}$,
208 SE = 0.0031), Tmin ($\beta = -0.033 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-1}$, SE = 0.0058) and Rain ($\beta = -0.049$
209 $\text{kg day}^{-1} \text{ mm}^{-1}$, SE = 0.0096). Interactions between Tmin-Tmax ($\beta = 0.0060 \text{ kg day}^{-1}$
210 $^\circ\text{C}^{-2}$, SE = 0.0003) and Tmin-Rain ($\beta = -0.0083 \text{ kg day}^{-1} \text{ }^\circ\text{C}^{-1} \text{ mm}^{-1}$, SE = 0.0021)
211 were also shown to have a significant effect on calf growth rate.

212 ***Extreme weather***

213 In the models including extreme weather frequencies, where effects were significant
214 ($p < 0.05$) an increased frequency of extreme weather days had a negative effect on
215 almost all traits (Table 4, assuming that a reduced AAS and increased fat classes
216 are desirable. Only for conformation score was an increase in frequency of dry days
217 ($\beta = 0.31$ (dry days per day of life) $^{-1}$, SE = 0.051) and wet days ($\beta = 0.26$ (wet days
218 per day of life) $^{-1}$, SE = 0.030) associated with improved conformation score. The
219 effect of frequency of cold waves was only significant for conformation score
220 ($p < 0.05$), where an increase in frequency of cold waves experienced was associated
221 with a lower conformation score ($\beta = -4.25$ (coldwave days per day of life) $^{-1}$, SE =
222 0.78). For the calf traits, fewer types of extreme days had effects. Calf 200-day
223 weight was only affected by the frequency of heatwaves ($\beta = -1.29$ kg (heatwave
224 days per day of life) $^{-1}$, SE = 0.57) and calf growth was only affected by the frequency
225 of heatwaves ($\beta = -0.010$ kg day $^{-1}$ (heatwave days per day of life) $^{-1}$, SE = 0.0026)
226 and dry days ($\beta = -0.0065$ kg day $^{-1}$ (dry days per day of life) $^{-1}$, SE = 0.0011).

227 **Discussion**

228 It is clear from these results that varying weather across the lifetime of a beef animal
229 influences traits which affect the potential profit for a beef farmer. These effects may
230 be due to several factors, including the effects of weather on feed quality and
231 availability, management decisions made by the farmer and the physiology and
232 behaviour of the animal (Wreford and Topp, 2020).

233 An increase in average daily maximum temperature led to poorer AAS, calf weight
234 and calf and carcass growth rates, but improved conformation and higher fat class.
235 Animals which have experienced high average temperatures (especially alongside
236 high humidity which we were unable to account for in these analyses) are more likely

237 to have experienced heat stress, which has been shown to have a detrimental
238 impact on growth rate in beef cattle, due to both reduced feed intake but also direct
239 effects on metabolism (Brown-Brandl, 2018). Typically, these effects are considered
240 in countries with warmer climates, but effects have been seen in UK dairy cattle
241 where extremes of THI led to reduced milk yields (Hill and Wall, 2014). The threshold
242 where UK animals will be affected will be much lower than those acclimated to
243 warmer climates (Collier et al., 2019) which is why we expect to see effects even at
244 the lower temperatures seen in the UK. Supporting this, our results show that
245 animals which experience an increased number of heatwaves days per day of life
246 tend to have poorer AAS, conformation and fat score and carcass and calf weights
247 and growth rates. On these extreme hot days, cattle feed less, both to avoid leaving
248 shaded areas but also to reduce heat production in the rumen, as well as expending
249 additional energy to attempt to dissipate heat (Van laer et al., 2014).

250 An increase in the average daily minimum temperature experienced by an animal
251 has similar effects to those seen for maximum temperature for a subset of the traits
252 studied. However, whereas calf weights were reduced and CCW was not
253 significantly affected with increasing maximum temperatures, both carcass and calf
254 weights increased with increasing minimum temperatures. Cold temperatures will
255 reduce forage yields as growth is limited (Hurtado-Uria et al., 2013), which may lead
256 to reduced feed intake levels affecting liveweights if feed availability is limited.

257 However, this may be mitigated by supplementary feeding. Cold temperatures will
258 also have a direct impact on the physiology of the animal. Outside the boundaries of
259 the thermo-neutral zone, animals must expend energy, in this case to remain warm
260 (Van laer et al., 2014). This lower limit is higher for calves than adult animals (Van
261 laer et al., 2014) so we expect their weights to be more negatively affected, which is

262 in line with our results. One unexpected result is the increase in fat class seen under
263 increasing daily minimum temperatures. We might expect animals experiencing less
264 cold weather to have reduced levels of subcutaneous fat, decreasing the fat score
265 (Van laer et al., 2014). Our result may be due to the reduced energy requirements
266 for maintenance under warmer daily minimum temperatures, allowing more energy
267 to be stored as fat. Despite the important effects of average daily minimum
268 temperature, we did not see significant effects for frequency of cold waves, except
269 for a decrease in conformation score (which is in line with the effect of average daily
270 minimum temperature). This is possibly due to the relatively small number of cold
271 waves seen within the dataset compared to heatwaves.

272 Our results show that increased rainfall leads to a poorer CCW, conformation score,
273 fat score, calf weight and calf growth rate. Increased rainfall is associated with
274 increased risk of fluke infection (Skuce et al., 2014). Presence of a fluke infection
275 has been shown to be associated with reduced CCW and lower conformation and fat
276 scores (Bellet et al., 2016) which corresponds with our results. However increased
277 rainfall also led to improved growth rates for abattoir animals and lower AAS. This
278 beneficial effect seems unlikely to be due to a direct effect on either the physiology
279 or behaviour of the cattle, therefore this is more likely to be due to either a change in
280 feed availability or some other change in management. Indeed, we expect increased
281 rainfall to lead to improved pasture yields (Dellar et al., 2018) which could account
282 for this increase in growth rate and reduced age to slaughter. However, when we
283 consider the number of extreme wet days experienced by an animal, we predict a
284 reduction in carcass growth rates and poorer AAS, showing that although generally
285 more rain may have some beneficial effects, days of extreme wet weather are
286 detrimental to growth. This could be due to several factors, including a change in

287 animal behaviour during these extreme periods which leads to reduced feeding
288 either to avoid rain or even flooding. Alternatively, these could reflect damage to
289 pastures leading to reduced feed availability or changes in management surrounding
290 these days, for example limited access to provide supplementary feed. Extreme dry
291 days also led to poorer AAS, CCW and both carcass and calf growth rates. This is
292 unlikely to be a direct effect on the physiology of animal, as animals will have water
293 provisions even during dry periods. The effect is more likely due to a reduced
294 pasture yield and quality as grass growth is severely limited during dry periods
295 (Dellar et al., 2018). This reduces feed quality and availability for grazing animals.

296 Another key result is the importance of interactions between average lifetime
297 weather parameters, particularly between maximum and minimum temperatures and
298 between minimum temperature and precipitation. For example, although both
299 average daily maximum and minimum temperatures were negatively associated with
300 carcass and calf growth rates, the interaction effect between minimum and maximum
301 temperature was positively associated with the traits. This means that although
302 generally animals experiencing higher daily maximum temperatures tend to have
303 lower growth rates, if they also experience higher daily minimum temperatures, this
304 negative effect is less extreme. This suggests that more stable temperatures may be
305 beneficial, which aligns with the negative effects of extreme weather days seen in
306 our other analyses. In other cases, a significant interaction effects exacerbates
307 negative effects. For example, colder average daily minimum and increased
308 precipitation are both negatively associated with carcass weight. There is also a
309 significant negative interaction effect, suggesting that the negative effect of cold or
310 wet weather is further exacerbated by the effect of both. This is what we'd expect at
311 a physiological level, as if animals are wet, they will lose heat more quickly than if

312 they are dry, increasing the effect of being cold. However, our results may also be
313 due to effects on growth on pasture or feed.

314 The analysis of two different datasets using the same methods allows us to compare
315 results for similar traits, giving an idea of the reliability of results. Generally, the
316 comparable traits (carcass & calf weight and carcass & calf growth) are similarly
317 affected by each weather variable tested in terms of the direction of effect, which
318 suggests results are robust. One difference seen is that whilst calf weight is negative
319 associated with increasing maximum temperatures, carcass weight is not
320 significantly affected, although significant interaction effects between lifetime
321 average weather parameters were found for carcass weight but not for calf weight.
322 Also, whilst increased precipitation over the lifetime of an animal was positive
323 associated with carcass growth rate, calves which experienced more rainfall tended
324 to have lower growth rates. This may suggest that whilst the negative physiological
325 effect of being wet is important for calves, who are more prone to heat loss (Roland
326 et al., 2016) , the benefit to the pasture and feed growth of increased precipitation
327 (Dellar et al., 2018) and therefore increased feed availability was more important for
328 older animals who are more able to control their body temperatures. Another key
329 difference is that the size of each significant weather parameter tends to be greater
330 compared to the mean value for the calf traits than the carcass traits, potentially
331 indicating that calves are more susceptible to weather effects than older animals.

332 Within datasets, we might also expect weights and growth rates to be similarly
333 affected by weather parameters. This is the case for the extreme weather analysis,
334 but for weather averaged across the lifetime of the animal, there were some
335 differences in the direction of the effects. For carcass traits, increased rain was
336 associated with reduced carcass weights, but a greater carcass growth rate. This is

337 likely due to the negative association between rain and age at slaughter, where
338 animals which experienced more rain tended to be younger at slaughter, which
339 would reduce growth rates, likely due to increased pasture and feed growth with
340 increased rainfall (Dellar et al., 2018), leading to increased feed quality and
341 availability, as described previously. The average daily minimum temperature also
342 had some opposing effects. Less cold minimum temperatures were associated with
343 heavier carcass and calf weights and younger age at slaughter, but lower growth
344 rates for both carcasses and calves. In these cases, it's important to consider the
345 interaction effects, particularly the interaction between minimum and maximum
346 temperatures. Despite both high minimum and high maximum temperatures being
347 individually associated with reduced growth rates, the significant positive interaction
348 effect between the two in practice means that an increase in minimum temperatures
349 alongside increasing maximum temperatures is associated with increased growth
350 rates, for both carcasses and calves. A significant interaction effect is not present for
351 calf weight and the effect is negative for carcass weight.

352 Current climate change projections suggest that in the UK summer and winter
353 temperatures will increase, whilst summer rainfall will decrease and winter rainfall
354 will increase (Wreford and Topp, 2020). Without changes to management or
355 acclimatisation of cattle, these changes may lead to some negative impacts to beef
356 production. We predict a 1°C increase in average daily maximum temperatures
357 would reduce carcass growth rates by about 6g per day and calf growth rates by
358 about 50g per day. These effects may not appear substantial, especially when
359 compared to the effect of heat stress in the tropics, but across the lifetime of an
360 animal and across whole herds and the whole UK beef sector, could lead to

361 reductions in the potential profit for farmers as well as increasing environmental
362 impact by increasing GHG emissions.

363 Unlike the more gradual change in climate, animals are unlikely to acclimatise to
364 extreme weather events (Collier et al., 2019) and these may also be more difficult to
365 mitigate through management changes. Frequency of these extreme events are
366 likely to increase (European Environment Agency, 2017) and our results predict a
367 negative impact of this on almost all traits. For example, our results predict that an
368 increase in frequency of heatwaves by one heatwave day per 100 days of life would
369 reduce CCW by about 200g and increase AAS by about three days, again reducing
370 the potential profit for farmers as well as increasing environmental impact.

371 There is potential to reduce these effects through a number of varying strategies.
372 Planting more hedges and trees around pastures to provide cover could negate the
373 negative effects of heat, cold and rain on the animal (Van laer et al., 2014) and this
374 strategy would be relatively inexpensive and potentially provide environmental
375 benefits (Forman and Baudry, 1984). More substantial shelter could also be provided
376 in the form of housing, particularly for some outwintered cattle. For housed cattle
377 experiencing heat stress, better ventilation could be used to mitigate the negative
378 effects (Van laer et al., 2014). Where weather affects pasture growth, more
379 supplementary feeding may be required, although this may be costly, both for farmer
380 profit but also environmental impact (Sasu-Boakye et al., 2014). In addition to these
381 strategies, farmers may want to consider selecting breeds or genotypes which are
382 more resilient and therefore less affected by varying weather (Sánchez-Molano et
383 al., 2020; Poppe et al., 2021).

384 **Conclusion**

385 In conclusion, our results show that that varying weather and frequency of extreme
386 weather, across the lifetime of a beef animal, influences traits which affect the
387 potential profit for a beef farmer. These effects may be due to several factors,
388 including direct effects on the animal, as well as feed availability and management
389 decisions made by the farmer. However, there is potential to mitigate negative
390 effects through a range of strategies.

391 **Ethics approval**

392 Not applicable

393 **Data and model availability statement**

394 The HadUK-Grid Gridded Climate Observations on a 1km grid over the UK data set
395 v1.1.0.0 is available at [https://data.ceda.ac.uk/badc/ukmo-](https://data.ceda.ac.uk/badc/ukmo-hadobs/data/insitu/MOHC/HadOBS/HadUK-Grid/v1.1.0.0/1km)
396 [hadobs/data/insitu/MOHC/HadOBS/HadUK-Grid/v1.1.0.0/1km](https://data.ceda.ac.uk/badc/ukmo-hadobs/data/insitu/MOHC/HadOBS/HadUK-Grid/v1.1.0.0/1km). Animal data were not
397 deposited in an official repository and are confidential.

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401 **Author contributions**

402 **H Bunning:** Methodology, Formal analysis, Data curation, Writing **E Wall:**
403 Conceptualization, Writing and reviewing, Supervision, Project administration,
404 Funding acquisition

405 **Declaration of interest**

406 None

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409 on the GenTORE website (Bunning and Wall, 2021).

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493

495 **Table 1**

496 Summary of data used for cattle carcass trait analysis, including the units, range,
 497 mean and SD of each carcass traits, along with the same for each weather variable,
 498 including lifetime average daily maximum (Tmax) and minimum temperatures (Tmin),
 499 lifetime average daily precipitation (Rain), heatwave (HW), coldwave (CW), dry day
 500 and wet day frequency, for cattle included in the carcass analysis.

Variable	Units	Range	Mean	SD
Cold Carcass Weight	kg	80.8 - 766.9	336.0	49.3
Age at Slaughter	days	366 – 1 094	714.3	160.1
Conformation	scale	1 - 15	6.9	2.1
Fat Class	scale	1 - 15	9.0	1.9
Carcass Growth	kg/day	0.10 - 1.47	0.49	0.13
Tmax	°C	8.2 - 19.0	14.0	1.4
Tmin	°C	4.8 - 10.2	6.3	1.1
Rain	mm	1.2 - 7.8	2.7	0.7
HW frequency	days/day of life	0 - 0.084	0.007	0.009
CW frequency	days/day of life	0 - 0.071	0.001	0.003
Dry day frequency	days/day of life	0 - 0.523	0.271	0.051
Wet day frequency	days/day of life	0 - 0.708	0.502	0.065

501

502 **Table 2**

503 Summary of data used for cattle calf trait analysis, including the units, range, mean
 504 and SD of calf traits, along with the same for each weather variable, including
 505 lifetime average daily maximum (Tmax) and minimum temperatures (Tmin), lifetime
 506 average daily precipitation (Rain), heatwave (HW), coldwave (CW), dry day and wet
 507 day frequency, for animals included in the calf analysis.

Variable	Units	Range	Mean	SD
Calf weight	kg	11.0 – 720.0	296.2	64.0
Age at Weighing	day	80.0 – 300.0	225.1	40.7
Calf Growth rate	kg/day	0.04 - 2.98	1.33	0.26
Tmax	°C	5.4 - 20.2	15.0	2.5
Tmin	°C	1.1 -12.4	7.0	1.9
Rain	mm	0.7 - 10.2	2.7	0.9
HW frequency	days/day of life	0 - 0.058	0.002	0.006
CW frequency	days/day of life	0 - 0.048	0.0002	0.002
Dry day frequency	days/day of life	0 - 0.21	0.01	0.01
Wet day frequency	days/day of life	0 -1.00	0.05	0.06

508

509

510 **Table 3**

511 Table of linear model solutions and SE (in brackets) for weather variables, including
 512 average daily maximum (Tmax) and minimum (Tmin) temperatures, average daily
 513 precipitation (Rain) and their interactions from models for each cattle carcass trait,
 514 including age at slaughter, cold carcass weight, conformation, fat class and carcass
 515 growth rate, and each calf trait, including calf 200 day weight, and calf growth rate.
 516 All effects are significant where given ($p < 0.05$). Non-significant effects are denoted
 517 by ns.

	Tmax (°C)	Tmin (°C)	Rain (mm)	Tmin x Tmax (°C ²)	Tmin x Rain (°Cmm)
Age at Slaughter (days)	10.17 (0.21)	-1.34 (0.54)	-19.73 (0.65)	-0.86 (0.031)	2.78 (0.10)
Carcass Weight (kg)	ns	2.12 (0.37)	-1.39 (0.44)	-0.19 (0.021)	-0.23 (0.070)
Conformation (15 points)	0.017 (0.006)	0.062 (0.015)	-0.043 (0.018)	-0.005 (0.001)	0.010 (0.003)
Fat Class (15 points)	0.072 (0.008)	0.199 (0.020)	-0.033 (0.024)	ns	-0.014 (0.001)
Carcass growth rate (kg/day)	-0.00603 (0.00025)	-0.00216 (0.00063)	0.00730 (0.00077)	0.00060 (0.00004)	-0.00142 (0.00012)
Calf 200-day weight (kg)	-7.19 (1.90)	18.11 (3.98)	-20.82 (7.14)	ns	ns
Calf 200-day growth (kg/day)	-0.0528 (0.0031)	-0.0332 (0.0058)	-0.0490 (0.0096)	0.0060 (0.0003)	-0.0083 (0.0021)

518

519 **Table 4**

520 Table of linear model solutions and SE (in brackets) for number of extreme weather
 521 days per day of life, from models for each cattle carcass trait, including age at
 522 slaughter, cold carcass weight, conformation, fat class and carcass growth rate, and
 523 each calf trait, including calf 200 day weight, and calf growth rate. All effects are
 524 significant where given ($p < 0.05$). Non-significant effects are denoted by ns.

	Heatwaves (days/day of life)	Cold Waves (days/day of life)	Dry Days (days/day of life)	Wet Days (days/day of life)
Age at Slaughter (days)	312.5 (10.7)	ns	167.3 (1.78)	83.18 (1.04)
Carcass Weight (kg)	-20.44 (7.34)	ns	-13.51 (1.23)	-16.84 (0.72)
Conformation (15 points)	-0.80 (0.30)	-4.25 (0.78)	0.31 (0.051)	0.26 (0.030)
Fat Class (15 points)	-2.61 (0.40)	ns	-0.61 (0.067)	-0.53 (0.039)
Carcass growth rate (kg/day)	-0.18 (0.013)	ns	-0.082 (0.0022)	-0.050 (0.0013)
Calf 200-day weight (kg)	-1.29 (0.57)	ns	ns	ns
Calf 200-day growth (kg/day)	-0.010 (0.0026)	ns	-0.0065 (0.0011)	ns

525

526 **Figure 1**

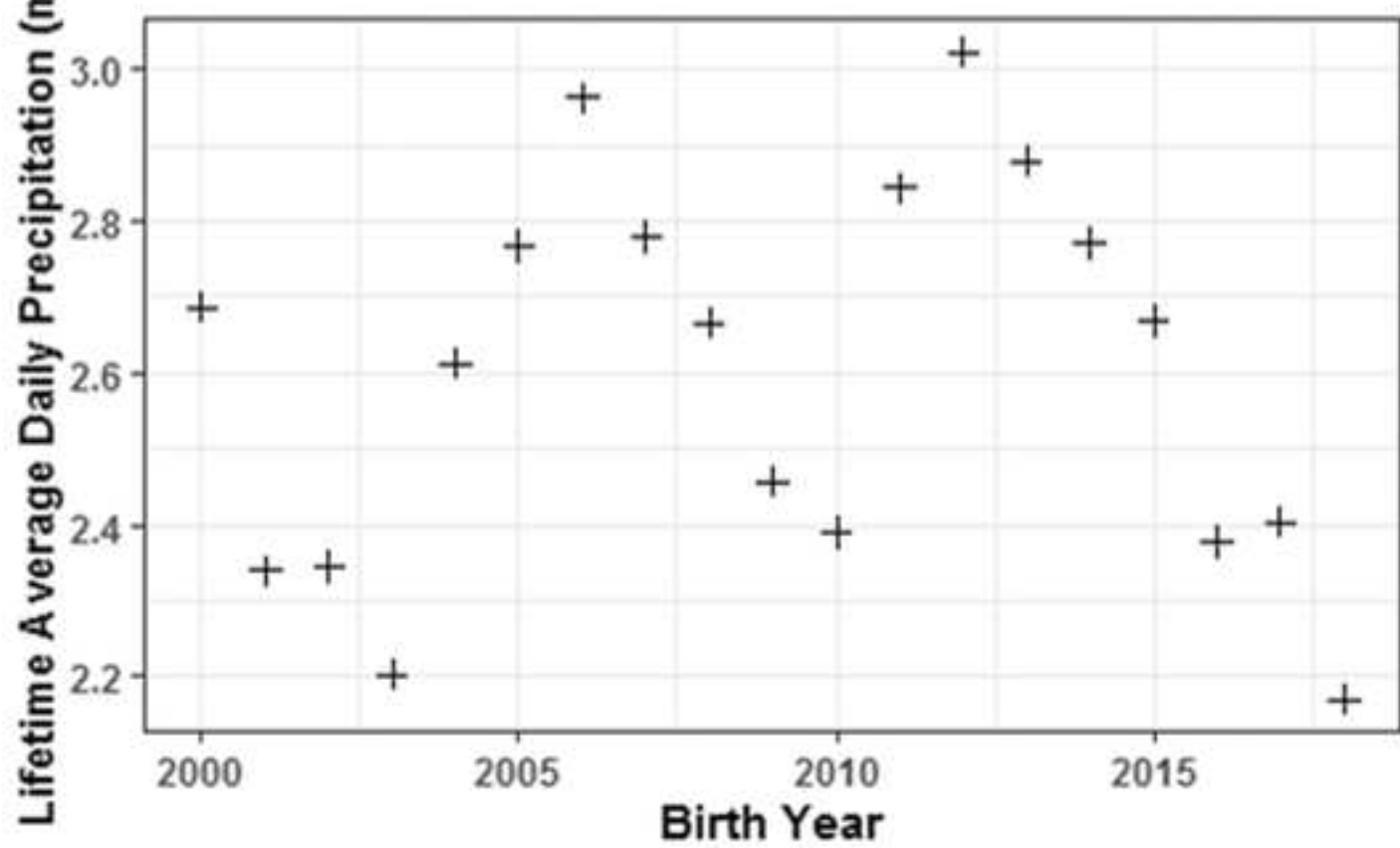
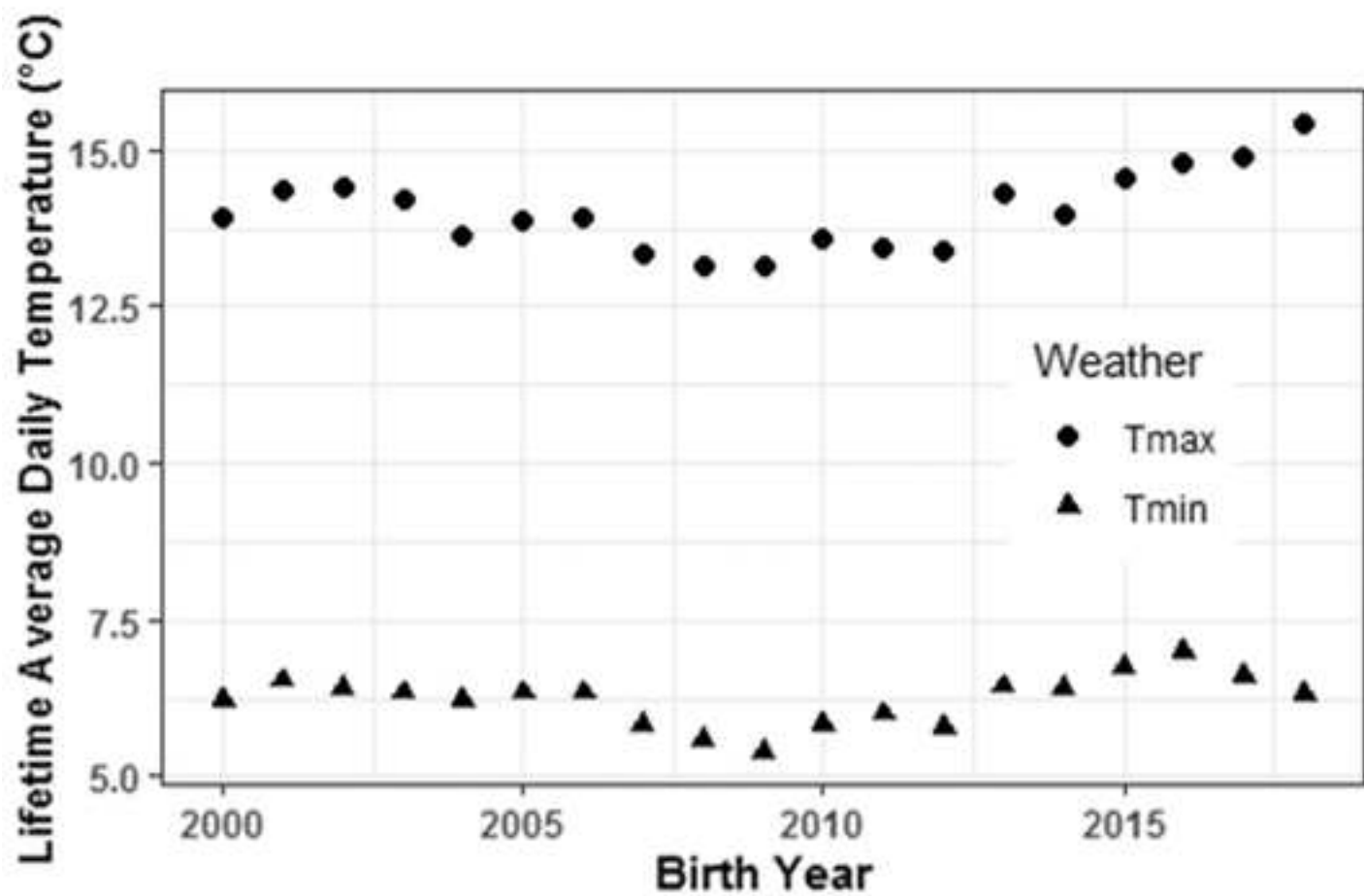
527 Mean average daily maximum temperature (**Tmax**), minimum temperature (**Tmin**)
528 and precipitation for cattle grouped by year of birth within the carcass data.

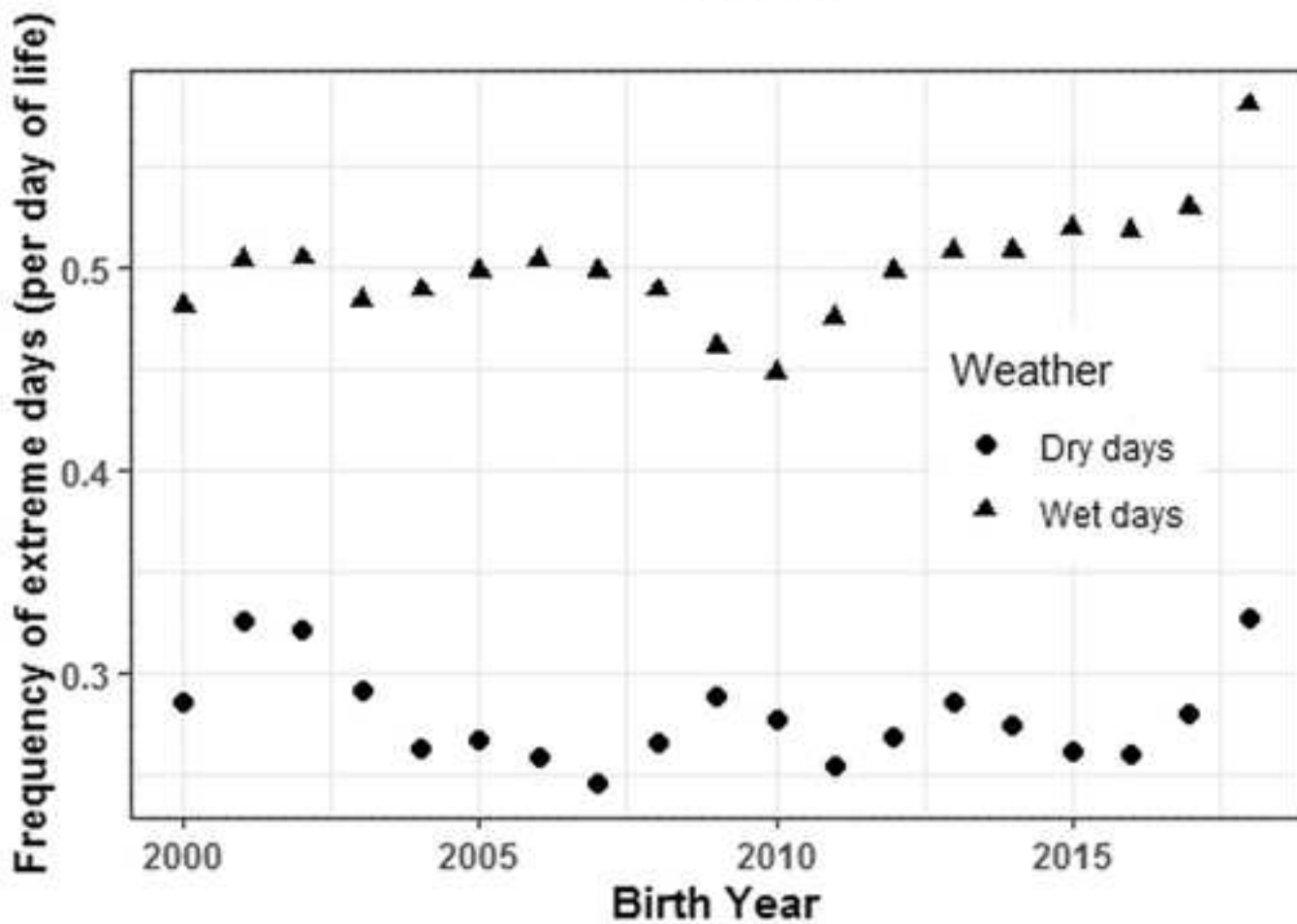
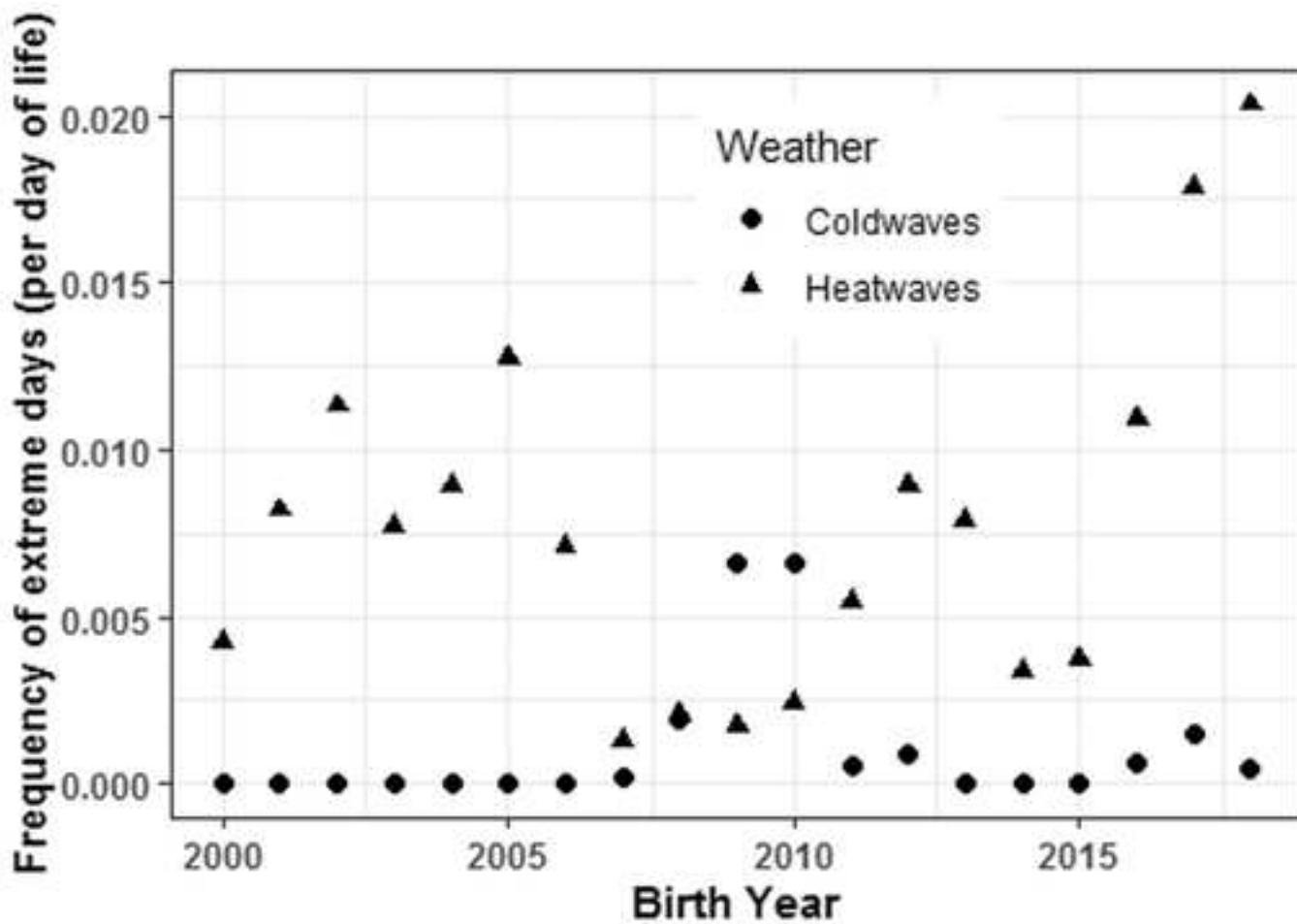
529

530 **Figure 2**

531 Mean frequencies of heatwave, cold wave, dry and wet days (per day of life) for
532 cattle grouped by year of birth within the carcass data.

533





The Effects of Weather on Beef Carcass and Growth Traits

H Bunning & E Wall, animal

Supplementary tables

Table S1. Model terms included for average daily weather analysis. Each column represents a single GLM with rows corresponding to factors and covariates that were included, represented by a x. Traits include age at slaughter (AAS), cold carcass weight (CW), carcass conformation, carcass fat, carcass growth, calf 200 day weight (200dW) and calf growth rate. Weather variables include average daily maximum (Tmax) and minimum (Tmin) temperatures, average daily rainfall (Rain) and their interactions. Other factors and covariates include sex, breed, birth-herd-year-season (BHYS), finishing-herd-year-season (FHYS), death location, dam age and the percentage of dairy breeds with a dam's pedigree (Dam Dairy %).

	AAS	CW	Conformation	Fat	Carcass Growth	200dW	Calf Growth
Tmax	x	x	x	x	x	x	x
Tmin	x	x	x	x	x	x	x
Rain	x	x	x	x	x	x	x
TminxTmin	x	x	x	x	x	x	x
TminxRain	x	x	x	x	x	x	x
AAS	n/a	x	x	x	x		
CW	x	n/a	x	x			
Conformation	x	x	n/a	x	x		
Fat	x	x	x	n/a	x		
Sex	x	x	x	x	x	x	x
Breed	x	x	x	x	x	x	x
BHYS	x	x	x	x	x	x	x
FHYS	x	x	x	x	x		
Death location	x	x	x	x	x		
Dam Age	x	x	x	x	x	x	x
Dam Dairy %	x	x	x	x	x	x	x

Table S2. Model terms included for extreme weather frequency analysis. Each column represents a single GLM with rows corresponding to factors and covariates that were included, represented by a x. Traits include age at slaughter (AAS), cold carcass weight (CW), carcass conformation, carcass fat, carcass growth, calf 200 day weight (200dW) and calf growth rate. Weather variables include frequency (f) of heatwaves, coldwaves, wet days and dry days. Other factors and covariates include sex, breed, birth-herd-year-season (BHYS), finishing-herd-year-season (FHYS), death location, dam age and the percentage of dairy breeds with a dam's pedigree (Dam Dairy %).

	AAS	CW	Conformation	Fat	Carcass Growth	200dW	Calf Growth
Heatwave f	x	x	x	x	x	x	x
Coldwave f	x	x	x	x	x	x	x
Dry day f	x	x	x	x	x	x	x
Wet day f	x	x	x	x	x	x	x
AAS	n/a	x	x	x	x		
CW	x	n/a	x	x			
Conformation	x	x	n/a	x	x		
Fat	x	x	x	n/a	x		
Sex	x	x	x	x	x	x	x
Breed	x	x	x	x	x	x	x
BHYS	x	x	x	x	x	x	x
FHYS	x	x	x	x	x		
Death location	x	x	x	x	x		
Dam Age	x	x	x	x	x	x	x
Dam Dairy %	x	x	x	x	x	x	x

Highlights

- Does climate affect beef traits of cattle in the UK?
- Temperature and precipitation have varying effects on carcass and growth traits.
- Extreme weather has a negative impact on cattle carcass and growth traits.
- 1 additional heatwave day per 100 days increases age at slaughter by about 3 days
- Climate change could reduce farmer profit and increase environmental impact.