The Effects of Weather on Beef Carcass and Growth Traits

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The effects of weather on beef carcass and growth traits

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ABSTRACT

To predict the impact of climate change on our beef animals and systems, we need a better understanding of how beef cattle traits are affected by varying weather and frequency of extreme events. We analysed the effect of minimum and maximum temperatures and average daily precipitation on a range of important carcass traits, including age at slaughter, cold carcass weight, carcass growth rate and conformation and fat score (*N* = >1.6 million), as well as calf 200-day live weight and growth rate (*N* = >270 000), using data from abattoirs across Britain (carcass traits) and calves in Scottish suckler beef herds (live weights and growth). Animals which experienced higher daily maximum and minimum temperatures had slower carcass and calf growth rates. Increased precipitation also led to poorer cold carcass weights, conformation scores, calf 200-day weights and calf growth. We also analysed the effect of frequency of extreme weather events, including heatwaves, cold waves, and dry and wet days. The frequency of heatwaves, dry and wet days were shown to have significant negative effects on almost all traits considered, for example, predicting that an increase in the frequency of heatwaves by 1 day per 100 days of life would reduce cold carcass weights by about 200 g and increase age at slaughter by about 3 days. Results show that varying weather and frequency of extreme weather, across the lifetime of a beef animal, influences traits which affect the potential profit for a beef farmer. These effects may be due to several factors, including direct effects on the animal, as well as feed availability and management decisions made by the farmer. However, there is potential to mitigate negative effects through a range of animal management strategies.

Implications

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

Introduction

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

There is good evidence that cattle are affected by climate. In the tropics, cattle experiencing high temperatures (especially combined with high humidity) experience heat stress which has negative impacts on milk production (Mbuthia et al., 2021), health and fertility (Polsky and von Keyserlingk, 2017; Bagath et al., 2019; Herbut et al., 2019) and growth (Brown-Brandl, 2018). Studies suggest air temperatures below −0.5 and over 20–26 °C cause negative impacts on dairy cattle (Berman et al., 1985; West, 2003). Despite cattle in the UK not experiencing these same high temperatures, studies show that even Scottish dairy cattle experience a drop in milk yield due to both extreme highs and lows in temperature (Hill and Wall, 2015). Cold weather also affects other cattle traits. Studies have shown animals that are more exposed to cold weather during winter have lower growth rates (Holmes et al., 1978) and the use of calf jackets, particularly for dairy calves, is thought to mitigate this (Robertson, 2020). We also expect precip-

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itation to have an effect on cattle traits, as it affects plant growth (Dellar et al., 2018) and will likely affect grazing feed quality and availability.

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

Material and methods

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

Table 1
Summary of data used for cattle carcass trait analysis, including the units, range, mean and SD of each carcass trait, along with the same for each weather variable, including lifetime average daily maximum (Tmax) and minimum temperatures (Tmin), lifetime average daily precipitation (Rain), heatwave (HW), coldwave (CW), dry day 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

Table 2
Summary of data used for cattle calf trait analysis, including the units, range, mean and SD of calf traits, along with the same for each weather variable, including lifetime average daily maximum (Tmax) and minimum temperatures (Tmin), lifetime average daily precipitation (Rain), heatwave (HW), coldwave (CW), dry day and wet 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

Animal phenotypes

Carcass traits included cold carcass weight (**CCW**), conformation class and fat class. Typically, conformation is assessed using the EUROP classification and fat class using a 1–5 scale. However, most abattoirs further sub-divide these classes. Therefore, these data were transformed into two 15-point scales, where 15 represents the best conformation and the fattest carcasses. Age at slaughter (**AAS**) was calculated using the date of birth from BCMS data and kill date from abattoir data. A measure of carcass growth rate was calculated by dividing CCW by AAS. We call this average daily carcass gain (**ADCG**), but it is important to note that we have omitted birth weight in this calculation for simplicity as birth weight data were unavailable. Edits were made to remove extreme records, including those more than 3 SD from the mean of CCW, animals which were less than 365 or more than 1 095 days old at slaughter and those with an ADCG more than 3 SD from the mean. As well carcass data from abattoirs, we also had live weights for over 270 000 calves in Scotland, measured at approximately 200 days. The actual age at weighing varied from 100 to 300 days. We used these values to also calculate a calf growth rate trait, dividing the live weight by age at weighing.

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

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

We needed to account for varying management practices which might be regionally distributed and therefore correlated with weather. We achieved this by including two contemporary groups in our model. First, we grouped animals according to their birth location, year and season (**BirthHYS**), where season was defined as three classes (February–May; June–September; October–January). We only included animals in BirthHYS groups that contained at least five animals. For the abattoir data, this resulted in 111 895 BirthHYS groups, ranging in size from 5 to 527, with a mean size of 15.0 animals. Secondly for the abattoir data only, we grouped animals according to their finishing location, year and season (**FinishHYS**). We defined finished location as the location where animals stayed for at least 60 days before slaughter (excluding up to 7 days before death to account for holding animals were moved through before slaughter). This resulted in 53 994 FinishHYS groups, ranging in size from 5 to 975 animals with a mean size of 31.2 animals. Finally, for the abattoir data, the location of death was also included. There were 32 death locations with between 785 and 181 494 animal slaughter records.

Weather parameters

We used weather data from the Met Office HadGrid-UK database, a dataset of gridded climate variables derived from the network of UK land surface observations. Variables include daily maximum and daily minimum temperatures and daily total precipitation for each 1 km square across the UK. Animal locations and dates of stay were extracted from the BCMS database and the nearest centre of a corresponding km square from the HadGrid data found. This allowed us to calculate the average daily maximum temperature (**Tmax**), average daily minimum temperature (**Tmin**) and average daily precipitation (**Rain**) for the lifetime of each animal. Fig. 1 shows the mean of each of these for animals with varying years of birth within the carcass data. The daily weather was also used to define the occurrence of extreme weather events, including heatwaves, coldwaves, dry days and wet days. The Met Office definition of a heatwave is a period of at least 3 days where the daily maximum temperature exceeds a threshold. The threshold is specific to the location, with four threshold regions defined by the met office in the UK: London, the South East of England, an area around the South East of England and the rest of the UK, with thresholds of 28 °C, 27 °C, 26 °C and 25 °C respectively. For cold waves, a similar definition was used, where a period consisted of at least 3 days where the daily maximum temperature did not exceed 0 °C. Wet and dry days were defined as days where rainfall was greater than 7.65 mm and less than 0.12 mm, respectively. These values correspond to 90th and 10th percentile of the daily precipitation across the UK for the period 2000–2019. For wet and dry days, no minimum number of consecutive days was required. The total number of each type of extreme day experienced by each animal was calculated and divided by its AAS or age at weighing for calves, to calculate the frequencies of extreme weather days. Fig. 2 shows the mean of each of these for animals with varying years of birth within the carcass data.

Statistical analysis of results

Analyses were carried out using GLMs using AS-REML (Butler et al., 2017) and R. Two models were produced for each trait, the first to assess the effect of average weather and the second to assess the effect frequency of extreme weather events. For each carcass trait, all other carcass traits, except ADCG, were included as covariates. For ADCG, AAS and CCW were also not included. For the two calf traits (calf weight and calf growth), no other traits and no FinishHYS or death location were included. We expected interactions between weather to be important so tested a range of interaction effects and found interactions between Tmax and Tmin and between Tmin and Rain were significant for a number of traits so were included in the average weather models. For more detail, see Supplementary Tables S1 and S2. The generalised model was as follows:

$$\text{Trait weather parameters} + \text{other traits} + \text{sex} + \text{breed} + \text{BirthHYS} + \text{FinishHYS} + \text{death location} + \text{dam age} + \text{dam \%dairy}.$$

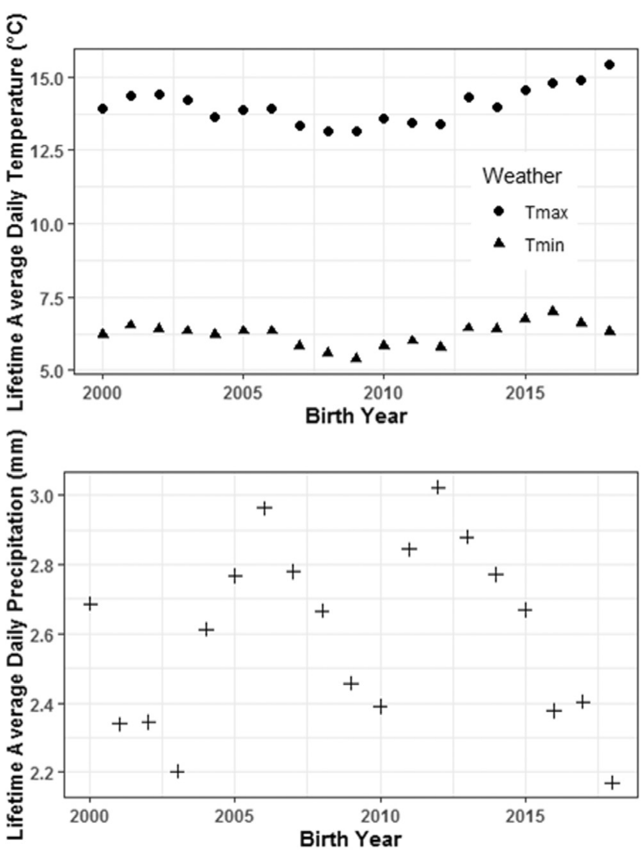

Fig. 1. Mean average daily maximum temperature (**Tmax**), minimum temperature (**Tmin**) and precipitation for cattle grouped by year of birth within the carcass data.

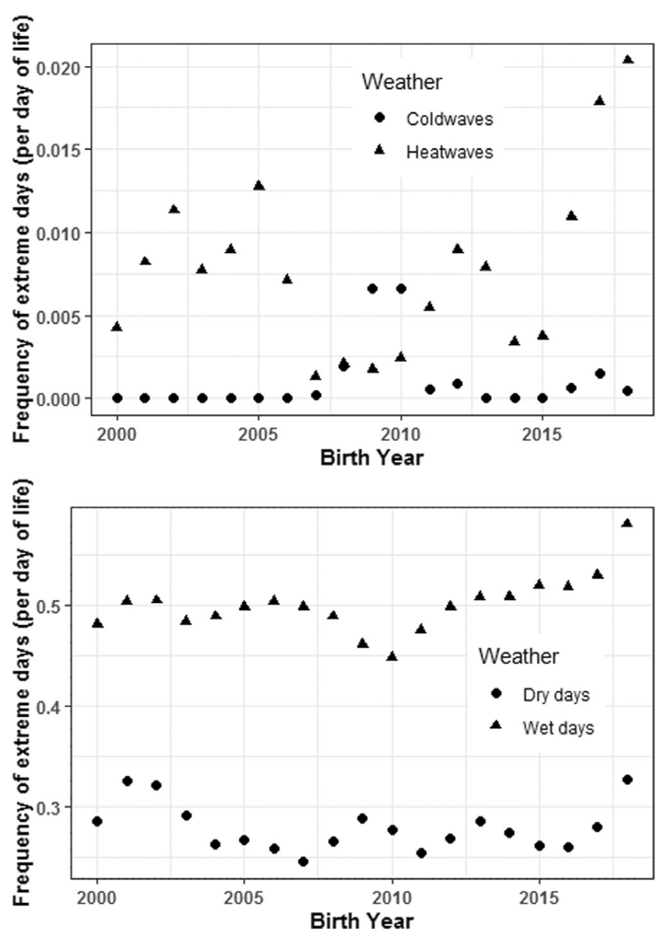

Fig. 2. Mean frequencies of heatwave, cold wave, dry and wet days (per day of life) for cattle grouped by year of birth within the carcass data.

Results

Average weather

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

CCW was not significantly affected by Tmax ($P > 0.05$), but higher weights were associated with higher Tmin (β = 2.12 kg/°C, SE = 0.37) and lower Rain (β = −1.39 kg/mm, SE = 0.44). Again, the effect of the interactions between Tmin-Tmax (β = −0.19 kg/°C^2, SE = 0.021) and Tmin-Rain (β = −0.23 kg/°C per mm, SE = 0.070) were also significant. Higher conformation scores were seen for animals which experienced high Tmax (β = 0.017/°C, SE = 0.006) and Tmin (β = 0.062/°C, SE = 0.015) and lower Rain (β = −0.043/mm, SE = 0.018). Interactions between Tmin-Tmax (β = −0.005/°C^2, SE = 0.001) and Tmin-Rain (β = 0.010/°C per mm, SE = 0.003) were also shown to have a significant effect on conformation score.

An increase in fat score was seen in animals which experienced higher Tmax (β = 0.072/°C, SE = 0.008) and Tmin (β = 0.199/°C, SE = 0.020) and lower Rain (β = −0.033/mm, SE = 0.024). For fat score, only the interaction between Tmin and Rain (β = −0.014/°C per mm, SE = 0.001) was significant ($P < 0.05$).

For ADCG, higher growth rates were associated with animals that experience lower Tmax (β = −0.0060 kg/day per °C, SE = 0.00025) and Tmin (β = −0.0022 kg/day per °C, SE = 0.00063) and higher Rain (β = 0.0073 kg/day per mm, SE = 0.00077). Again, interactions between Tmin-Tmax (β = 0.00060 kg/day per °C^2, SE = 0.00004) and Tmin-Rain (β = −0.0014 kg/day per °C per mm, SE = 0.00012) were also shown to have a significant effect on ADCG.

For the calf traits, greater 200-day live weights were associated with animals that had experienced lower Tmax (β = −7.19 kg/°C, SE = 1.90), higher Tmin (β = 18.11 kg/°C, SE = 3.98) and lower Rain (β = −20.82 kg/mm, SE = 7.14). Interactions between weather effects were not significant ($P > 0.05$). An increase in calf growth rate was seen for animals that had experienced lower Tmax (β = −0.053 kg/day per °C, SE = 0.0031), Tmin (β = −0.033 kg/day per °C, SE = 0.0058) and Rain (β = −0.049 kg/day per mm, SE = 0.0096). Interactions between Tmin-Tmax (β = 0.0060 kg/day per °C^2, SE = 0.0003) and Tmin-Rain (β = −0.0083 kg/day per °C per mm, SE = 0.0021) were also shown to have a significant effect on calf growth rate.

Extreme weather

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

Discussion

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

An increase in average daily maximum temperature led to poorer AAS, calf weight and calf and carcass growth rates, but improved conformation and higher fat class. Animals which have experienced high average temperatures (especially alongside high humidity which we were unable to account for in these analyses) are more likely to have experienced heat stress, which has been shown to have a detrimental impact on growth rate in beef cattle, due to both reduced feed intake and direct effects on metabolism (Brown-Brandl, 2018). Typically, these effects are considered in

Table 3
Table of linear model solutions and SE (in brackets) for weather variables, including average daily maximum (Tmax) and minimum (Tmin) temperatures, average daily precipitation (Rain) and their interactions from models for each cattle carcass trait, including age at slaughter, cold carcass weight, conformation, fat class and carcass growth rate, and each calf trait, including calf 200-day weight, and calf growth rate. All effects are significant where given ($P < 0.05$). Non-significant effects are denoted by ns.

	Tmax (°C)	Tmin (°C)	Rain (mm)	Tmin × Tmax (°C^2)	Tmin × 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)

Table 4
Table of linear model solutions and SE (in brackets) for number of extreme weather days per day of life, from models for each cattle carcass trait, including age at slaughter, cold carcass weight, conformation, fat class and carcass growth rate, and each calf trait, including calf 200-day weight, and calf growth rate. All effects are 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

countries with warmer climates, but effects have been seen in UK dairy cattle where extremes of THI led to reduced milk yields (Hill and Wall, 2015). The threshold where UK animals will be affected will be much lower than those acclimated to warmer climates (Collier et al., 2019) which is why we expect to see effects even at the lower temperatures seen in the UK. Supporting this, our results show that animals which experience an increased number of heatwaves days per day of life tend to have poorer AAS, conformation and fat score and carcass and calf weights and growth rates. On these extreme hot days, cattle feed less, both to avoid leaving shaded areas and to reduce heat production in the rumen, as well as expending additional energy to attempt to dissipate heat (Van laer et al., 2014).

An increase in the average daily minimum temperature experienced by an animal has similar effects to those seen for maximum temperature for a subset of the traits studied. However, whereas calf weights were reduced and CCW was not significantly affected with increasing maximum temperatures, both carcass and calf weights increased with increasing minimum temperatures. Cold temperatures will reduce forage yields as growth is limited (Hurtado-Uria et al., 2013), which may lead to reduced feed intake levels affecting live weights if feed availability is limited. However, this may be mitigated by supplementary feeding. Cold temperatures will also have a direct impact on the physiology of the animal. Outside the boundaries of the thermo-neutral zone, animals must expend energy, in this case to remain warm (Van laer et al., 2014). This lower limit is higher for calves than adult animals (Van laer et al., 2014) so we expect their weights to be more negatively affected, which is in line with our results. One unexpected result is the increase in fat class seen under increasing daily minimum temperatures. We might expect animals experiencing less cold weather to have reduced levels of subcutaneous fat, decreasing the fat score (Van laer et al., 2014). Our result may be due to the reduced energy requirements for maintenance under warmer daily minimum temperatures, allowing more energy to be stored as fat. Despite the important effects of average daily minimum temperature, we did not see significant effects for frequency of cold waves, except for a decrease in conformation score (which is in line with the effect of average daily minimum temperature). This is possibly due to the relatively small number of cold waves seen within the dataset compared to heatwaves.

Our results show that increased rainfall leads to a poorer CCW, conformation score, fat score, calf weight and calf growth rate. Increased rainfall is associated with increased risk of fluke infection (Skuce et al., 2014). Presence of a fluke infection has been shown to be associated with reduced CCW and lower conformation and fat scores (Bellet et al., 2016) which corresponds with our results. However, increased rainfall also led to improved growth rates for abattoir animals and lower AAS. This beneficial effect seems unlikely to be due to a direct effect on either the physiology or behaviour of the cattle; therefore, this is more likely to be due to either a change in feed availability or some other change in management. Indeed, we expect increased rainfall to lead to improved pasture yields (Dellar et al., 2018) which could account for this increase in growth rate and reduced age to slaughter. However, when we consider the number of extreme wet days experienced by an animal, we predict a reduction in carcass growth rates and poorer AAS, showing that although generally more rain may have some beneficial effects, days of extreme wet weather are detrimental to growth. This could be due to several factors, including a change in animal behaviour during these extreme periods which leads to reduced feeding either to avoid rain or even flooding. Alternatively, these could reflect damage to pastures leading to reduced feed availability or changes in management surrounding these days, for example limited access to provide supplementary feed. Extreme dry days also led to poorer AAS, CCW and both carcass and calf growth rates. This is unlikely to be a direct effect on the physiology of animal, as animals will have water provisions even during dry periods. The effect is more likely due to a reduced pasture yield and quality as grass growth is severely limited during dry periods (Dellar et al., 2018). This reduces feed quality and availability for grazing animals.

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

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

Within datasets, we might also expect weights and growth rates to be similarly affected by weather parameters. This is the case for the extreme weather analysis, but for weather averaged across the lifetime of the animal, there were some differences in the direction of the effects. For carcass traits, increased rain was associated with reduced carcass weights, but a greater carcass growth rate. This is likely due to the negative association between rain and age at slaughter, where animals which experienced more rain tended to be younger at slaughter, which would reduce growth rates, likely due to increased pasture and feed growth with increased rainfall (Dellar et al., 2018), leading to increased feed quality and availability, as described previously. The average daily minimum temperature also had some opposing effects. Less cold minimum temperatures were associated with heavier carcass and calf weights and younger age at slaughter, but lower growth rates for both carcasses and calves. In these cases, it is important to consider the interaction effects, particularly the interaction between minimum and maximum temperatures. Despite both high minimum and high maximum temperatures being individually associated with reduced growth rates, the significant positive interaction effect between the two in practice means that an increase in minimum temperatures alongside increasing maximum temperatures is associated with increased growth rates, for both carcasses and calves. A significant interaction effect is not present for calf weight, and the effect is negative for carcass weight.

Current climate change projections suggest that in the UK, summer and winter temperatures will increase, whilst summer rainfall will decrease and winter rainfall will increase (Wreford and Topp, 2020). Without changes to management or acclimatisation of cattle, these changes may lead to some negative impacts on beef production. We predict a 1 °C increase in average daily maximum temperatures would reduce carcass growth rates by about 6 g per day and calf growth rates by about 50 g per day. These effects may not appear substantial, especially when compared to the effect of heat stress in the tropics, but across the lifetime of an animal and across whole herds and the whole UK beef sector, could lead to reductions in the potential profit for farmers as well as increasing environmental impact by increasing GHG emissions.

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

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

Conclusion

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

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2022.100657.

Ethics approval

Not applicable.

Data and model availability statement

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

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Declaration of interest

None.

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