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Behavioural, brain and cardiac responses to hypobaric hypoxia in broiler chickens

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Trade-offs between indicators of performance and sustainability in breeding suckler beef herds

Short title: *Profit, fertility and welfare of breeding sucker cattle*

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SUMMARY

Management of beef suckler cattle herds requires a difficult but vitally important balance between farm profits, animal health and welfare and sustainable food production. A dynamic programming (DP) model was implemented to investigate the consequences of replacement and management decisions on the interactions and possible trade-offs between animal welfare, fertility and profitability in breeding beef suckler cattle herds. The model maximized profit from the current cow and all successors by identifying the best keep/replace decision.

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The 150 states incorporated in the DP model were all combinations of: ten cow-parity, five calving periods including one barren state (five in total) as fertility indicators and three body condition scores (BCS) at weaning as an animal welfare indicator reflecting feeding and nutritional conditions of animals. Statistical models were fitted to data from a breeding suckler cattle herd, consisting of performance records of 200 cattle over 5 years, to parameterize the DP model. Estimated parameters used in the DP model were: i) probabilities of transitions between states, and ii) probability of involuntary culling. These estimates were used in the form of conditional probabilities of successful or failed (as a result of involuntary culling) transitions to the next state. In addition, statistical models were used to estimate probability of calving difficulty. There was strong evidence ($P < 0.001$) that parity affected calving difficulty and weak evidence ($P = 0.067$) that parity affected the incidence of involuntary culling. The DP model outcomes indicated that cows calving very early, i.e. those who conceived in the first 21 days after artificial insemination, showed reduced frequencies of calving difficulty as well as voluntary culling, and so gave better financial returns than late-calving cows and barren cows. As a result, fewer replacements were needed that reduced the frequency of calving difficulty, further implying a win-win scenario for both profit and welfare. In contrast, in late-calving animals, the frequency of calving difficulty increased and they were less profitable and more prone to be culled. Results of sensitivity analysis showed that the optimum voluntary culling rate was sensitive to commodity market prices. These findings suggest well-informed nutrition and reproduction management could deliver a win-win outcome for profit and animal welfare.

INTRODUCTION

Global population growth, increase in per capita consumption, changing governance of global food systems, climate change, competition for key resources and changes in consumer preferences are considered as the key drivers of change affecting the food system in the years ahead (Foresight 2011). These factors, coupled with policy changes such as Common Agricultural Policy (CAP) reforms, increase the economic and social pressure on many breeding beef suckler cattle farms (Vosough Ahmadi *et al*. 2015*a*). The challenge is particularly important in Scotland and similar high quality/low volume specialist systems in other EU member states with a good reputation for producing quality beef from extensive grass-based systems in remote and often environmentally sensitive areas. Management of breeding beef suckler herds in these systems requires a difficult but vitally important balance between often conflicting needs for farm profits, animal health and welfare and sustainable food production.

Trade-offs arise in various aspects of farming and animal husbandry including feeding, reproduction, health, welfare and marketing. For example, Drennan & Berry (2006) reported that spring-calving cows (calving early in the year) had significantly higher weight at the start of winter and greater body condition score (BCS) at the subsequent calving, but lost most live weight in the subsequent winter. Parity, lower weight gain and BCS can affect the frequency of calving difficulty (Drennan & Berry 2006). These factors could also affect animal welfare, incidence of diseases or the involuntary culling rate. Cow body weight, body condition at calving and gestation length, along with non-genetic factors such as age and parity, year and season of calving, place of calving, maintenance practises, diseases, calf sex and nutrition influence the frequency of calving difficulty (Zaborski *et al*. 2009). The frequency of calving difficulty and involuntary and voluntary culling rates that may represent the parity and age of the animals are therefore considered as indicators of animal welfare in suckler herds. High BCS reflects a good level of general health, nutrition and fertility management of the animals (Frasier & Pfeiffer 1994; Drennan & Berry 2006), but high BCS may increase the chance of calving difficulties particularly in breeds and crosses with relatively small pelvic canals such as Friesian in relation to their mature size (Lowman 1988) and could affect the probability and the timing of conceptions.

Reproduction management is an important factor affecting profitability of suckler herds. Barbudo *et al*. (2008) reported that the profitability of the herd increases as the length of calving period shortens and early conception rate, hence early calving, increases. This may require culling of late-calving animals and barren cows, and replacing them with heifers. This will change the age structure of the herd and impose extra financial costs such as variable costs of feeding and management that are required for the replacement heifers, as well as further fixed costs. This is particularly the case in winter when grazing on pasture and feed are limited. Changed culling policy and age structure of the herd may also affect animal welfare as a result of higher frequency of calving difficulty. In addition, the culling and replacement decision is also influenced by price determinants such as weight and BCS of cows as well as market prices, which affect the cost of replacing cows and rearing heifers. Understanding the potential interactions between these elements and possible trade-offs between fertility, animal welfare and profitability of breeding suckler cattle requires methodologies that could encompass at least some elements of the crucial aspects of this farming system. However, understanding depends on capturing the long term (between production cycles) as well as the short term (within production cycle) impacts of key decisions and events that govern these interactions and hence the performance of beef suckler herds.

Dynamic programming (DP) modelling has the potential to incorporate repetitive managerial decision options and related stochastic events, identifying the series of decisions that maximize the expected net present value of current and future animals in herds given bio-physical inputs and assumptions. In the past, applications of DP models in cattle farming have been confined mainly to dairy farming systems (Van Arendonk 1988; Kennedy & Stott

1993; Stott *et al*. 2002, 2005; Bar *et al*. 2008; Cha *et al*. 2010, 2011), perhaps because the detailed data required for these models are more accessible in dairy than in beef suckler herds. However, DP models have also been used in determining optimal replacement and management policies in beef cows (Frasier & Pfeiffer 1994). Replacement decisions, among many other crucial factors, affect the economics, health, fertility, welfare and environmental footprint of breeding suckler herds. For example, higher replacement rates require more breeding animals to provide replacement heifers rather than productive beef calves, therefore increasing the environmental impacts of the business, i.e. greenhouse gas emissions and soil degradation per unit of output. Applications of optimization models in suckler cattle that seek improved management strategies by evaluating the potential interactions and trade-offs between different components of these farming systems, are limited in the current literature. In the current study, this deficiency was addressed by using a DP model that was parameterized by farm performance data and with the objective of assessing the possible mentioned trade-offs. Five-year performance data obtained from a closely monitored beef suckler cattle farm was analysed and meaningful relationships between BCS and parity with other variables of interest, i.e. calving period, incidences of involuntary calving and calving difficulty scores, were evaluated. The estimates of transition probabilities between the states of cattle, probability of involuntary culling and probability of calving difficulty were subsequently incorporated to parameterize a plausible DP model. The application of an optimization DP model in assessing the trade-offs between indicators of performance (e.g. calving rate and weight gain) and indicators of sustainability (e.g. animal welfare and replacement rate) in breeding beef suckler cattle farms by using farm performance data is considered as the novelty value of the current study. Body condition score was used in the DP model as an indicator of animal welfare that reflects feeding and nutritional conditions of the animals. It should be noted that the overall animal welfare score of given farms or animals could only be captured by assessing and taking into account five freedoms (FAWC 2001) and/or by considering Welfare Quality protocols (Blokhuis *et al.* 2010).

MATERIALS AND METHODS

Data

Data were collected from Scotland's Rural College's (SRUC) Beef farm at Easter Howgate for a period of 5 years (2006–10). The herd consists of 200 suckler cows. Replacement heifers were homebred, with Limousin (LIM) and Aberdeen Angus (AA) breeds used for their suitability as sires of replacement heifers. Belgian Blue (BB), Simmental (SIM) and Charolais (CH) were also used as terminal sires (i.e. purebred sires that are used to breed crossbred dams). All the mentioned breeds were included under one categorical variable in the statistical models. Cows were bred by artificial insemination (AI) with triple synchronization of oestrus to calve during March and May. Three main AI services for the whole herd took place on 20 June, 15 July and 7 August of every year. As a result it was expected that calving would start around mid-March and extended to early May. Three calving periods corresponding to AIs were therefore considered, but as calving incidents happened until the end of May, a fourth calving period was added. The calves were weaned in October and housed. The cows were housed at weaning and fed a straw-based diet through the winter. Finished animals were sold mainly to local abattoirs at 12–14 months of age.

Data included information on individual breeding suckler cows, including breed, parity, calving period, calving difficulty score, body weights, body condition score (BCS) at weaning, number of services received and involuntary culling status. A cow was identified as barren if it did not conceive after receiving three services. The calving difficulty score (CDS) of a cow was measured on an ordinal scale (1 = no assistance; 2 = assisted by stockman; 3 = use of calving jack or calved by veterinarian performing caesarean; 4 = calf died during calving). Body condition score is determined on a scale of 1 (thin, poor) to 5 (obese, grossly fat) (Drennan & Berry 2006). In the current dataset the BCS of cows actually ranged from 2 to 4 on this 1–5 scale. For practical purposes, BCS was categorized at three levels: low (BCS < 2.50), middle ($2.50 \leq$ BCS ≤ 3.25) and high (BCS > 3.25). These are consistent with moderate/poor, good, and fat/grossly fat categories respectively, suggested by DEFRA (DEFRA 2000). Parity was categorized by ten levels with parity ten or more combined together since few cows with more than ten parities were recorded (28 out of 928 records). Finally, the categorical variable breed was considered at three levels: AAX (Aberdeen Angus and its crosses), CH & CHX (Charolais and its crosses) and other (Limousin, Simmental and other crosses).

Statistical models

Appropriate statistical models were developed for the data on the incidence of involuntary culling, CDS and frequencies of different calving periods (response variables). All models included parity as an explanatory variable (to integrate with the DP model as discussed later); breed and BCS were also candidate explanatory variables and their final inclusions in the model was based on their statistical significance ($P < 0.10$). All models initially included cow as a random effect, but due to very low estimates of between cow variability, final models excluded the cow effect. The final fitted models were subsequently used to parameterize the DP model discussed later. All statistical analyses were carried out using R software version 3.1.0 with appropriate R packages (stats, lme4, MASS, ordinal) (R Core Team 2014).

Incidence of involuntary culling

Involuntary culling was defined as an incident recorded in the dataset where a breeding cow was involuntarily culled because of the occurrence of diseases such as Johne's disease, injuries and/or poor health. The incidence of involuntary culling for the *i*-th observation (y_i) is assumed to follow a Bernoulli distribution with probabilityϕ_i, and modelled by a generalized linear model (GLM) with a logit link function. The fitted GLM is: $logit(\phi_i) = \sum_{k=1}^{10} \beta_k p_{ik}$, where p_{ik} is 1 if the parity of the *i*-th cow is *k* and 0 otherwise, and β_k represents the coefficient for the k-th parity. The fitted GLM was used to obtain the estimated probabilities of involuntary culling at each level of parity.

Calving difficulty score

The calving difficulty score (CDS) of the i-th observation (y_i) was assumed to follow a multinomial distribution with parameters $\{\varphi_{ij}\}$, where φ_{ij} denotes the probability that the *i*-th observation falls in the *j*-th category of the CDS; *j* = 1,...,4, representing four ordinal levels of CDS where increasing order of *j* suggests increasing calving difficulty. The data on y_i were modelled using a cumulative link model (CLM) where the cumulative probabilities are defined as: $\psi_{ij} = P(y_i \leq j) = \varphi_{i1} + \cdots + \varphi_{ij}$. The fitted CLM with a logit link function is: $logit(\psi_{ij}) = \theta_j - (\sum_{k=1}^{10} \beta_k p_{ik} + \sum_{m=1}^{3} \omega_m b_{im})$, where p_{ik} is 1 if the parity of the *i*-th observation is k and 0 otherwise, b_{im} is 1 if the breed of the *i*-th observation is m and 0 otherwise, θ_j is the intercept for the *j*-th category of the CDS; β_k and ω_m are coefficients for the *k*-th parity and *m*-th breed, respectively. The proportionality or equal slope assumption of the model was checked graphically. The model was parameterized in terms of ratios of lower to higher categories of calving difficulty score, i.e. normal to abnormal calving difficulty. Hence, a negative coefficient corresponds to less frequent abnormal calving, or more frequent normal calving. The fitted CLM was used to obtain the estimated probabilities of ordinal levels of CDS at each level of parity and BCS. Estimated probabilities of calving difficulties were used to calculate its annual cost per cow that is imposed on farmers (Table 1).

Calving periods

The length of the calving (mid-March to the end of May) was divided into four periods of 21 days, defined as 'calving periods'. Based on the data, four calving periods (n_i=4) and one barren state were considered. To estimate the probability that a cow calves in a given calving period conditional on other explanatory variables, the generalized linear modelling framework described earlier was extended. Let π_i be the probability that the cow was diagnosed as pregnant following artificial insemination, and $logit(\pi_i) = \sum_{k=1}^{10} \beta_k p_{ik} + \sum_{l=1}^{4} \vartheta_l s_{il} + \sum_{m=1}^{3} \omega_m b_{im}$ where p_{ik} was 1 if the parity of the *i*-th observation was *k* and 0 otherwise, s_{il} was 1 if the body condition score of the *i*-th observation was *l* and 0, otherwise, b_{im} was 1 if the breed of the *i*-th observation was *m* and 0 otherwise, and β_k, ϑ_l and ω_m were coefficients for the *k*-th parity, *l*-th body condition score and *m*-th breed, respectively. It was also assumed that coefficients β_k, ϑ_l and ω_m were constant across all calving periods, and so the probability that a cow calved at each of the four calving periods was constant. It was assumed that all cows must be either in one of the calving periods or at barren stage in a given parity. To allow some barren cows to be retained in the data, it was also assumed that cows diagnosed as non-pregnant in a breeding season had the same chance of getting pregnant in the next breeding season as a non-barren cow. Although this is a considerable assumption given that the reasons for failure to breed may persist into the next breeding season, few such cases were observed in the present dataset, and these data were penalized in the DP in other ways, i.e. through their contribution to involuntary culling, incurred variable costs and reduced stage returns as a result of their minimum reproduction performance. It is a common practice among some suckler beef farmers to keep infertile cows and mate them again during the next breeding season. Stott *et al*. (2008) reported that the proportion of barren cows put to the bull on 66 Scottish suckler herds varied from 0–0.69. Hence, the probability that a cow calved at the n_i-th calving period was: $\pi_i(1-\pi_i)^{(n_i-1)}$. For N independently recorded observations, the likelihood function therefore was $L = \prod_{i=1}^{N} \pi_i(1-\pi_i)^{(n_i-1)}$. The parameters of the model were estimated by maximizing the likelihood function using a simplex algorithm proposed by Nelder & Mead (1965). The fitted model was used to obtain the probability of transition from the one calving period state (conditional on the parity and body condition score) to all possible future calving period states.

Optimization model

A dynamic programming (DP) model was developed and used; DP uses the repetitiveness of the decision to save computation time. It uses Bellman's Principle of Optimality (Bellman 1957): "an optimal policy has the property that, whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision". This makes it possible to obtain the optimal policy by backward recursion from the optimal strategy in the final stage through to all possible states in the current stage, thus greatly reducing the computation required compared to a total enumeration of the problem. For further explanation and a simplified worked example see Stott *et al.* (2005). The present DP model is an extension of the models described by Stott (1994), Stott *et al*. (2002) and Stott *et al*. (2005) that was adapted and parameterized to model the suckler cow replacement decision problem. A mathematical representation of the model is given in the appendix. The objective of the DP was to maximize the expected gross margins (i.e. expected net present value (ENPV) of returns expressed as an annuity) from a current suckler cow and future cows over an infinite time horizon by making appropriate replacement decisions.

This DP model drew on a closely monitored farm where recorded data, particularly on fertility in relation to parity, calving period and artificial insemination as well as on incidences of calving difficulty, were available to parameterize the model. Commercial practice (Barbudo *et al*. 2008) suggests that theoretical fertility performances suggested in the literature (e.g. Sinclair *et al*. 2002) are not entirely matched with actual farming practices, and therefore, an empirical approach was taken in the current work by using recorded data, rather than a theoretical one.

The possible decision options were either to 'keep' the current cow, or 'replace' her with an in-calf heifer at the start of each stage (annual production cycle). In either case involuntary replacement was still possible as a result of failure during the calving interval due to death, serious disease, injury etc. The probability of involuntary replacement was estimated from the GLM of the data described earlier and was used in the DP model as probability of failure for parity one to ten. The financial stage return thus included the expected (probability weighted) cost of involuntary replacement following failure. Cows were represented by 150 states in the DP including: ten states of cow parity, four states representing all possible 21-day calving periods in any parity plus one barren-cow status and three states for BCS. States of cow parity represented the maximum productive lifespan of individual cows, while five states of calving period, including barren status, influenced the probabilities of moving from current states into future calving states, henceforth called 'transition probabilities', were proxy for fertility (see Stott *et al.* 1999). Three BCS states, consisting of low, middle and high, represented approximately the overall body condition of the cow during any stage. State-specific herd management input parameters including feeding regime, and hence cow-calf performance (Table 2) and feed costs, were included in the financial stage returns for each cattle state in the DP (see next section). The transition probabilities for BCS that were used in the DP model (Table 3), represented the tendency for high, medium or low BCS to remain in that state or move to another state.

Stage return

To establish the stage returns, least-cost diet formulations were obtained using the 'FeedByte' software (Schofield *et al*. 1998) from the Scottish Rural College (SRUC) to obtain the gross margin of calf sales over feed supplementation and other variable costs for all possible 150 states. Barren cows incurred only maintenance costs, resulting in negative gross margins reflecting their non-productive status. Calf sale outcomes were calculated using an average of male and female calves' weight (data not presented) based on their market prices in 2010. This was done with a spreadsheet budget model in gross margin format using parameter estimates obtained either from the literature (Table 1) or from a survey of reproductive management in 66 spring calving commercial Scottish suckler herds reported by Barbudo *et al*. (2008). The expected cost of involuntary replacement, i.e. net involuntary replacement cost weighted by the probability of involuntary replacement (p) was included in all stage returns. In addition, the net cost of voluntary replacement weighted by 1-p was included in stage returns when the decision was to replace. Net replacement cost was calculated for both voluntary and involuntary culling (represented by S and S'in Appendix 1) and replacement as the product of the live weight of the animals in different states (Table 2) and the cull cow price (£ per kg). If the replacement was involuntary, a loss of 3% in live weight was considered. This is due to premature cull value loss reported for Johne's disease (Bennett 2003) based on an assumption that the majority of these culls were due to diseases such as Johne's. The decision to keep or replace a cow is taken by the DP based on the probability adjusted stage return that is determined by both probabilities of survival or failure, as a result of diseases for example, and the marginal returns of the animals in various states, based on their weights and incurred variable costs. Keeping a cow for parity imposes extra costs, particularly for barren cows, and therefore the DP model optimized the culling and replacement decision.

The DP model was run using general purpose DP software (GPDP; Kennedy 1986). An optimal culling strategy, expected net present values and infinite state probabilities were thereby generated. By changing key parameters in the DP and re-optimizing, the impact of alternative assumptions and management strategies, including over-wintered body condition, was explored. The DP runs included a baseline model run, three animal welfare scenarios and sensitivity analysis scenarios. Three animal welfare scenarios (Table 3) were examined with respect to transition probabilities from current body condition scores to the next. These included baseline welfare, negligible transition and declining welfare. Sensitivity of a model's outcome to the input variables including calf sale price, feed price, heifer purchase price, cull cow price and Scottish beef calf scheme was tested by implementing a series of model runs using alternative input parameter values. The scenarios tested were 50% and 100% decrease and increase in the actual default values used for the baseline scenario.

Validation of the DP model was done by reviewing assumptions and input parameters, both from the dataset and statistical models, as well as by comparing results or data from other sources and references to the outputs of the DP model. To do this, optimized (long run state probabilities, which are fixed in this stationary DP model, see Stott *et al.* 2005) proportions of animals in each of the four calving periods 1–4 and barren states, generated by the DP model, were compared with a benchmarking tool, the actual data used in the current paper, and observed commercial data. These were: (i) SRUC's target for herd fertility (Riddell *et al.* 2013), (ii) SRUC's Easter Howgate actual data that were analysed and used in the DP model, and (iii) a survey of Scottish commercial breeding suckler herds (Barbudo *et* *al*. 2008). The aim was to provide a basis for comparisons that helped to validate the DP model.

RESULTS

Estimated effects and standard errors of explanatory variables including parity, BCS, breed and others using the generalized linear model and cumulative link model for the three response variables including the incidence of involuntary culling, calving difficulty score and calving period are presented in Table 4. For the model on involuntary culling, the intercept value indicates the mean proportion of involuntary culling (on the logit scale) of cows at the reference level of Parity 1. Weak evidence (P = 0.067) was observed of an effect of parity on the mean proportion of involuntary culling of cows. Compared to parity 1, the mean proportions of involuntary culling cases did not differ significantly in parities 2 to 6, 8 and 9 ($P \geq 0.170$), but it increased significantly in parity 7 (P = 0.042) and parity 10 or more (P = 0.002). There was no evidence that BCS (P = 0.143) or breed (P = 0.660) influenced the mean proportion of involuntary culling in the studied suckler cow herd and therefore they were removed from the final analysis.

The cumulative link model showed that breed ($P < 0.001$) and parity ($P < 0.001$) had a statistically significant effect on the mean proportion of CDS. However, there was no evidence that BCS had an effect on CDS (P = 0.408). Table 4 presents the estimated effects (standard errors) of different explanatory variables on the CDS and associated P-values. The intercept value is the coefficient for the CDS score between 1 and 2 (1|2), which indicates the cumulative mean proportion (on the logit scale) of cows with CDS less than a given score at reference levels of other factors (Parity 1, Breed AAX). Compared with AAX (Aberdeen Angus and its crosses) and other (Limousin, Simmental and other crosses) crossbreds, there was strong evidence ($P < 0.001$) that cows of CH & CHX (Charolais and its crosses) were more prone to higher categories of calving difficulty score, i.e. abnormal calving difficulty. Results also showed that cows on parities 2 onwards (P < 0.010) were more likely to have lower CDS compared with cows on parity 1. This suggests that the probability of lower CDS increased with subsequent parities of cows.

Table 4 presents the estimated effects (standard errors) of different explanatory variables on the calving period and associated P-values. The intercept value indicates the mean proportion of successful conception (on the logit scale) of cows at reference levels of other factors (Parity 1, BCS Low, Breed AAX). Results showed that BCS had a statistically significant effect (P = 0.009) on the mean proportion of successful conception following artificial insemination. Cows with low BCS had a significantly lower conception rate than cows with middle (P = 0.036) and high (P = 0.004) BCS. Weak evidence (P = 0.063) was found for a breed effect on the mean proportion of successful conception. The mean conception rate of cows of CHX breed was lower than cows of AAX breed (P = 0.004). The data did not suggest (P = 0.970) that the mean conception rate changed across parities.

The results of the DP model runs showed that the ENPV, expressed as an annuity in the baseline welfare scenario (Table 3), was estimated to be £174 (± 2.4 S.E.) per cow per year (Table 5). Cows calving in calving periods 1 and 2 were more profitable than the average profitability per cow at herd level. Late calving in periods 3 and 4 generated return below the average and barren cows had the lowest gross margin. Early calving favoured a 'keep' decision (cows calving in calving period 1 had a voluntary culling rate of 0.08 when the herd average was 0.11. Thus, very early calving cows were allowed to remain and live longer than the average age in the herd (4.7 and 4.3 parity, respectively). A possible reason is that early calving gives higher stage return (i.e. profit) due to heavier calves and a higher chance for early calving in later stages. Barren cows had the lowest voluntary culling rate (0.07), as optimized by the DP model, due to their low maintenance cost and their assumed potential to calve early in the next stage. Conversely, the model gave calving states 2, 3 and 4 (i.e. later calving periods) more ‘replace’ decisions, resulting in higher than the average herd-level voluntary culling rate (0.15, 0.15 and 0.12, respectively) in these states with less chance of early calving in subsequent stages. An explanation for slightly lower voluntary culling rate of cows in calving period 4 (0.12) than cows in calving periods 2 and 3 (0.15) is that the average weight of their calves over the 10 parity in BCS1 and BCS 2 states were higher (Table 2) and therefore had the potential of generating higher profit. Optimized results of the DP model also suggested that animals with a higher body condition score were more prone to be voluntarily culled than animals with low and middle BCS. This is mainly due to the potential of high BCS animals to generate more profit because of their higher live weight than animals in middle and low BCS categories.

A comparison of the optimized proportions of animals in each of the four calving periods 1–4 and barren states with three alternative sources is presented in Fig. 1. The main emphasis on the Fertbench tool as a benchmark target is to have the majority of the animals (0.65) calving in the first period, 0.25 in the second, 0.07 in the third and 0.03 in the fourth period without keeping cows in a barren state. The comparison showed that the Easter Howgate actual data and the Fertbench target values followed a very similar pattern in terms of proportions of animals in each calving period. The DP’s long-term optimized results, however, have more similarity to the calving patterns of commercial beef sucker farms. One reason for the differences between the background data and optimized results could be that the advantages of early calving (suggested by the Easter Howgate actual data and achieved by using AI) are not sufficient to justify the costs of expected heavier culling rates. The long-run results of the DP had equal proportions of animals (0.21) in calving periods 1–4 and 0.16 in the barren state. The DP’s long-run state probabilities are the outcome of the optimal culling regime given the fixed assumptions used in the DP model and the management of the SRUC herd. This may make it uneconomic to improve because the advantages of early calving are not sufficient to justify the costs of heavier culling rates. The commercial herd survey had 0.15 of the herd in calving periods 1–3, but a large proportion (0.45) in the calving period 4, and 0.1 in the barren state.

Three animal welfare scenarios (Table 3) were examined with respect to transition probabilities from current body condition scores to the next. Results (Fig. 2) suggested that the scenario of negligible or minimum transition between BCS states generated the highest financial return (£177/cow/year) compared with the baseline and declining welfare scenarios (£174 and £172 respectively). The minimum transition welfare scenario incurred the highest total culling rate at 0.16 compared with 0.15 and 0.13 for the baseline and the declining welfare scenarios respectively. The optimized results under the baseline welfare scenario showed that approximately 0.56 of the animals were in parity 1–4 (Fig. 3) while > 0.92 animals had middle or higher BCS in each parity (Fig. 4).

The results of the sensitivity analysis showed that the financial returns were highly sensitive to a decrease of heifer purchase/rearing price, increase in cull cow price and calf sale price (Fig. 5). Results were also sensitive to decrease in feed costs and increase in subsidy.

DISCUSSION

The current paper analysed a 5-year production database of a closely monitored breeding beef suckler cattle herd, estimated probabilities of involuntary culling and calving difficulty and transition probabilities between different state variables, and subsequently parameterized a DP model to analyse potential interactions and trade-offs between fertility, animal welfare and profitability of suckler cattle.

The analysis showed the probability of successful conception in each of the four 21-day periods after post-partum anoestrus (followed by successful calving) was not influenced by parity. This is contrary to the common expectation that the probability of conception declines as a cow ages at subsequent parities. In agreement with the current results, Drennan & Berry (2006) also found that cow parity did not affect the fertility rates of breeding suckler cows. Cows on parities 2 onwards were more likely to have lower CDS compared with cows on parity 1. The likelihood of increased calving difficulty at the first parity has practical and welfare implications, as higher incidence of calving difficulties in the first parity will result in increased culling and replacement rate. On the other hand, later parities increased the frequency of involuntary culling marginally, particularly for the cows of parities 7 and 10 or more, thus incurring extra losses. Additionally, a biased effect of parity on involuntary culling probabilities could also result from the statistical modelling of the data which were already constrained by culling due to infertility or other health problems.

It was observed that cows having low BCS had lower conception rates compared with cows having middle and high BCS. In contrast, no evidence was found that BCS had an effect on the probability of involuntary culling or calving difficulty score. This suggests that associating BCS with welfare related problems of cows such as lameness and other natural threats were not mirrored in the herd used for the current work. This may be a reflection of reduced variability in BCS in this closely monitored herd compared to commercial practice.

Optimized results of the DP model indicate that very early calving animals (conception within 21 days after the post-partum anoestrus period) contribute to maximizing the financial profitability of beef suckler herd as well as reducing the voluntary culling rate. Results also showed that reducing the voluntary culling rate is attributed to fewer animals in their first parity and thus the lower calving difficulty in subsequent parities. This is a win-win scenario for profit and welfare. In order to obtain the best result, an increased calving rate in the first calving period could be achieved by aiming to have a larger proportion of cows in parity 2–4 and middle BCS at weaning.

The expected trade-off between animal welfare, fertility and profitability was not apparent in the current results. Animals with low BCS suffered from lower nutrient intake (lower welfare), but were also less profitable than animals with higher BCS. Achieving such improvements in BCS depends on a high energy feed regime in the winter time, which adds some extra costs, but these were outweighed by improved technical performances such as having a higher calf weight at birth as well as higher calf growth rate, and eventually, a higher generated revenue at sale. Obviously, the current results are dependent upon the assumptions made and the herd-specific relationships incorporated in the model. There may well be circumstances in practice whereby improving welfare reduces the profit and therefore a trade-off occurs. However, such trade-offs (i.e. opposite effects of welfare and profit; see McInerney (2004)) are not inevitable, and there are probably many opportunities such as this to obtain a win-win for profit and for welfare in current farming practice. Lawrence & Stott (2009) provided the data and analytical tools to understand the key relationships involved and use them to adjust management towards more sustainable, productive and efficient outcomes.

It was assumed that a high BCS state implied better animal welfare status. The presented optimized results of the DP model, however, suggest that animals in such herds are more prone to be culled (voluntarily here, but could be culled on an involuntary basis too) and replaced by heifers, and thus their longevity is shorter than the low BCS states. In so far as longevity is a mark of good welfare, there is a potential conflict here, i.e. overall welfare may not be adequately captured by one index alone. This issue has been dealt with elsewhere, e.g. by Vosough Ahmadi *et al* (2011) and Stott *et al*. (2012). However, as with any model, the current one was a simplification of the true situation, for example, interactions among all the modelled variables that could exist in practice were not modelled.

As well as difficulties with welfare assessment, the current results can be used in highlighting possible conflicts and also synergies between policy on animal welfare and policy on other important issues such as the environment and sustainable intensification. The sustainable intensification concept incorporates the ambition to increase or maintain the current level of agricultural yields while reducing negative ecological and environmental impacts (Vosough Ahmadi *et al.* 2015*b*). Presented statistical models linked to a DP model showed that better financial and economic performances could be achieved with less feeding and lower BCS animals without compromising animal welfare as defined in the current paper. This was a result of having access to data from a well-managed farm and the described analyses and interpretations. In future, recording, collecting and analysing detailed bio-physical data will be essential part of farm management of commercial breeding suckler cattle farms that will be a key to sustainable intensification. Similarly the AI practice that was used in the studied farm, which is not currently commonly used in commercial farms, is made more feasible for suckler herds with new technologies. By integrating AI in reproduction management of breeding suckler cattle farms, it will be possible to get higher genetic gain, which will add to the merits of sustainable intensification.

Results presented in the current paper suggest that providing high energy diet that leads to heavier cows with high BCS required more in-calf heifer replacements as a result of heavier culling rate. This will lead to a higher number of animals on the farm, compared to providing a low nutritional level, as farms under this management regime need to raise higher numbers of replacement heifers or buy them from the market. Because cattle have been identified as a threat to the climate, forests and wildlife (Gill *et al.* 2010; Foresight 2011), increasing the population of suckler cows as a result of a different feeding regime as well as culling/replacement strategies is detrimental to the environment. Herds with high BCS cows require more ‘bought-in’ roughage and concentrates during the winter time, and higher quantities of fertilizers and perhaps pesticides to grow grazing pastures in summer time. These all adversely affect the environment (e.g. air and water pollution), and therefore, the trade-offs between these environmental concerns and financial performance of the out-wintering suckler cows and their welfare concerns need to be studied further using an integrated framework.

CONCLUSIONS

The expected trade-off between animal welfare, fertility and profitability was not apparent in the current results. Animals with low BCS suffered from lower nutrient intake (lower welfare), but were also less profitable than animals with higher BCS. Achieving such improvements in BCS depends on a high energy feed regime in the winter time, which adds some extra costs, but these were outweighed by improved performance such as having a higher calf weight at birth as well as higher calf growth rate, and eventually, a higher generated revenue at sale. There may well be circumstances in practice where a trade-off occurs. However, such trade-offs are not inevitable, and there are probably many opportunities such as this to obtain a win-win for profit and for welfare in current farming practice provided the data and analytical tools are available, as provided in the current work, to understand the key relationships involved and use them to adjust management towards more sustainable, productive and efficient outcomes. The main practical conclusion regarding herd management is that increasing the number of very early calving cows (those who conceived in the first 21 days after artificial insemination) by optimizing reproduction management improves both financial and animal welfare scores of suckler cattle farms. It can be concluded that good reproduction management could deliver a win-win situation with regards to profit, animal welfare and environment.

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REFERENCES

BAR, D., TAUER, L. W., BENNETT, G., GONZÁLEZ, R. N., HERTL, J. A., SCHULTE, H. F., SCHUKKEN, WELCOME, F. L. & GRÖHN, Y. T. (2008). Use of a dynamic programming model to estimate the value of clinical mastitis treatment and prevention options utilized by dairy producers. *Agricultural Systems* **99**, 6-12.

BARBUDO, A.V. (2005). *An economic evaluation of the main causes of infertility in the Scottish beef suckler herd*. PhD Thesis, University of Aberdeen, UK.

BARBUDO, A.V., GUNN, G. J. & STOTT, A.W. (2008). Combining models to examine the financial impact of infertility caused by bovine viral diarrhoea in Scottish beef suckler herds. *The Journal of Agricultural Science, Cambridge* **146**, 621-632.

BELLMAN, R. (1957). *Dynamic Programming.* Princeton, NJ, USA: Princeton University Press.

BENNETT, R. (2003). The 'direct costs' of livestock disease: the development of a system of models for the analysis of 30 endemic livestock diseases in Great Britain. *Journal of Agricultural Economics* **54**, 55-71.

BLOKHUIS, H. J., VEISSIER, I., MIELE, M. & JONES, B. (2010). The Welfare Quality® project and beyond: Safeguarding farm animal well-being. *Acta Agriculturae Scandinavica Section A: Animal Science* **60**, 129-140.

CHA, E., HERTL, J. A., BAR, D. & GRÖHN, Y. T. (2010). The cost of different types of lameness in dairy cows calculated by dynamic programming. *Preventive Veterinary Medicine* **97**, 1-8.

CHA, E., BAR, D., HERTL, J. A., TAUER, L. W., BENNETT, G., GONZÁLEZ, R. N., SCHUKKEN, Y. H., WELCOME, F. L. & GRÖHN, Y. T. (2011). The cost and management of different types of clinical mastitis in dairy cows estimated by dynamic programming. *Journal of Dairy Science* **94**, 4476-4487.

DEFRA (2000). *Condition Scoring of Beef Suckler Cows and Heifers*. London: HMSO. Available online from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69370/pb6491-cattle-scoring-020130.pdf (accessed 11 April 2016).

DRENNAN, M.J. & BERRY, D.P. (2006). Factors affecting body condition score, live weight and reproductive performance in spring-calving suckler cows. *Irish Journal of Agricultural and Food Research* **45**, 25-38.

FAWC (2001). *Interim Report on the Animal Welfare Implications of Farm Assurance Schemes*. Publication number 5797. Surbiton, UK: Farm Animal Welfare Council.

FORESIGHT (2011). *The Future of Food and Farming. Final Project Report.* London, UK: The Government Office for Science.

FRASIER, W. M. & PFEIFFER, G. H. (1994). Optimal replacement and management policies for beef cows. *American Journal of Agricultural Economics* **76**, 847-858.

GILL, M., SMITH, P. & WILKINSON, J.M. (2010). Mitigating climate change: the role of domestic livestock. *Animal* **4**, 323-333.

KENNEDY, J.O.S. (1986). *Dynamic Programming: Applications to Agriculture and Natural Resources.* London: Elsevier Applied Science.

KENNEDY, J.O.S. & STOTT, A.W. (1993). An adaptive decision-making aid for dairy cow replacement. *Agricultural Systems* **42**, 25-39.

LAWRENCE, A.B. & STOTT, A.W. (2009). Profiting from animal welfare: an animal-based perspective. *Journal of the Royal Agricultural Society of England* **170**, 40-47.

LOWMAN, B. (1988). Suckler cow management. *In Practice* **10**, 91-100.

MCINERNEY, J. (2004). *Animal Welfare, Economics and Policy*. *Report on a Study Undertaken for the Farm & Animal Health Economics Division of Defra*. London: Defra. Available online from: http://webarchive.nationalarchives.gov.uk/20130402151656/http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/documents/animalwelfare.pdf (accessed 11 April 2016).

NELDER, J. A. & MEAD, R. (1965). A simplex algorithm for function minimization. *The Computer Journal* **7**, 308–313.

R CORE TEAM (2014). *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing.

RIDDELL, I., CALDOW, G., LOWMAN, B., PRITCHARD, I. & MORGAN, C. (2013). *A Guide to Improving Suckler Herd Fertility*. Ingliston, Midlothian, UK: Quality Meat Scotland.

SAC, 2010. Farm Management Handbook 2010/2011. Scottish Agricultural College (2010).

SAC, 2011. Agribusiness News, Scottish Agricultural College (August, 2011).

SINCLAIR, K.D., MOLLE, G., REVILLA, R., ROCHE, J.F., QUINTANS, G., MARONGIU, L., SANZ, A., MACKEY, D.R. & DISKIN, M.G. (2002). Ovulation of the first dominant follicle arising after day 21 post partum in suckling beef cows. *Animal Science* **75**, 115-126.

SCHOFIELD J.L., CALDER J.M., FRASER I.R., LEWIS M., OLDHAM J.D., OFFER N.W. and ROOKE J.A. (1998). FeedByte – Ration Formulation and Evaluation. In: Proceedings 7th International Conference on Computers in Agriculture, Orlando, Florida, USA, 26-30 October.

STOTT, A.W. (1994). The economic advantage of longevity in the dairy cow. *Journal of Agricultural Economics* **45**, 113-122.

STOTT, A. W., VEERKAMP, R.F. & WASSELL, T. R. (1999). The economics of fertility in the dairy herd. *Animal Science* **68**, 49–57.

STOTT, A.W., JONES, G.M., GUNN, G.J., CHASE-TOPPING, M., HUMPHRY, R.W., RICHARDSON, H. & LOGUE, D.N. (2002). Optimum replacement policies for the control of subclinical mastitis due to S.aureus in dairy cows. *Journal of Agricultural Economics* **53**, 627-644.

STOTT, A.W., JONES, G.M., HUMPHRY, R.W. & GUNN, G.J. (2005). The financial incentive to control paratuberculosis (Johne's disease) on UK dairy farms. *Veterinary Record* **156**, 825-831.

STOTT, A. W., GUNN, G. J. & BARBUDO, A.V. (2008). *Management of reproduction in Scottish suckler herds*. Paper presented at the 82nd annual conference of the Agricultural Economics Society. Royal Agricultural College, Cirencester. 31 March–2 April.

STOTT, A. W., VOSOUGH AHMADI, B., DWYER, C. M., KUPIEC, B., MORGAN-DAVIES, C., MILNE, C. E., RINGROSE, S., GODDARD, P. PHILLIPS, K. & WATERHOUSE, A. (2012). Interactions between profit and welfare on extensive sheep farms. *Animal Welfare* **21,** Supp 1, 57-64.

VAN ARENDONK, J.A.M. (1988). Optimum replacement policies and their consequences determined by dynamic programming. In *Modelling of Livestock Production Systems* (Eds S. Korver & J.A.M. van Arendonk), pp. 105-111. Series: Current Topics in Veterinary Medicine and Animal Science volume 46. Dordrecht, the Netherlands: Kluwer Academic Publishers.

VOSOUGH AHMADI, B., SHRESTHA, S., THOMSON, S.G., BARNES, A.P. & STOTT, A.W. (2015*a*). Impacts of greening measures and flat rate regional payments of the Common Agricultural Policy on Scottish beef and sheep farms. *Journal of Agricultural Science, Cambridge* **153**, 676-688.

VOSOUGH AHMADI B., MORAN, D., BARNES, A.P. & BARET, P.V. (2015*b*). Comparing decision-support systems in adopting sustainable intensification criteria. *Frontiers in Genetics* **6,** 23. doi: 10.3389/fgene.2015.00023

VOSOUGH AHMADI, B., STOTT, A.W., BAXTER, E.M., LAWRENCE, A.B. & EDWARDS, S.A. (2011). Animal welfare and economic optimization of farrowing systems. *Animal Welfare* **20**, 57-67.

ZABORSKI, D., GRZESIAK, W., SZATKOWSKA, I., DYBUS, A., MUSZYNSKA, M. & JEDRZEJCZAK, M. (2009). Factors affecting dystocia in cattle. *Reproduction in Domestic Animals* **44**, 540–551.

Table 1. *Financial and technical assumptions used in the DP model*

Parameters	Value	Unit	References
Discount rate	5	%	Authors' assumption
Calf (steers) sale price (liveweight)	1.75	£/kg	SAC (2010)
Calf (heifers) sale price (liveweight)	1.70	£/kg	SAC (2010)
Cull cow sale price (liveweight)	1.30	£/kg	SAC (2011)
In-calf heifer purchase price	1100	£/head	SAC (2010)
Veterinary and medicines cost	24	£/cow/year	SAC (2010)
Straw bedding cost*	30	£/cow/year	SAC (2010)
Commission, haulage and tags	32	£/cow/year	SAC (2010)
Feed/forage (high energy diet)†	0.88–0.91	£/cow/day	SCHOFIELD (1998)
Feed/forage (middle energy diet)‡	0.88–0.88	£/cow/day	SCHOFIELD (1998)
Feed/forage (low energy diet)§	0.72	£/cow/day	SCHOFIELD (1998)
Cost of calving difficulty	0.034–0.17	£/cow	Own calculations#
Scottish Beef Calf Scheme	50	£/cow/year	SAC (2010)

* Straw bedding cost for in-house system

† Assumed for BCS3 cows

‡ Assumed for BCS2 cows

§ Assumed for BCS1 cows

#Available from the corresponding author on request.

Table 2. *Arithmetic averages of suckler cow live weight (kg) based on parity, calving period* and body condition score derived/estimated from the data and used in the DP†*

	Calving period 1			Calving period 2		
Parity	BCS1	BCS2	BCS3	BCS1	BCS2	BCS3
1	572	583	629	556	580	617
2	613	643	656	692	668	681
3	603	690	722	729	712	667
4	792	740	810	658	750	785
5	657	713	745	824	745	903
6	703	749	764	618	764	687
7	672	701	752	802	711	751
8	724	693	755	717	702	731
9	663	706	769	756	683	718
10	645	680	736	709	733	684

	Calving period 3			Calving period 4		
Parity	BCS1	BCS2	BCS3	BCS1	BCS2	BCS3
1	521	583	552	557	598	578
2	728	623	560	599	612	605
3	706	686	860	747	635	859
4	602	658	630	817	774	859
5	664	686	754	773	690	732
6	757	784	730	572	753	654
7	610	708	684	678	701	654
8	755	739	770	714	773	654
9	777	708	846	714	773	654
10	634	745	698	677	698	718

* It was assumed barren cows have the same weight as cows calved in calving period 4.
† All these figures are based on historic data subject to the non-optimal culling policy operated on the herd. If DP was applied then these parameters would change i.e. our results based on future culling are biased by historic parameter estimates (This was discussed in Kennedy & Stott 1993).

Table 3. *Transition probability matrix*[*] *of body condition scores used in the model*

	Probability of body condition scores in next parity		
Current parity	BCS1	BCS2	BCS3
Baseline welfare†			
BCS1	0.10	0.70	0.20
BCS2	0.10	0.45	0.45
BCS3	0.05	0.35	0.60
Negligible transition†			
BCS1	0.98	0.01	0.01
BCS2	0.01	0.98	0.01
BCS3	0.01	0.01	0.98
Declining welfare†			
BCS1	0.20	0.70	0.10
BCS2	0.45	0.45	0.10
BCS3	0.60	0.35	0.05

* The dataset did not supply these data. Above assumptions were used to represent three scenarios with respect to animal welfare and the impact was examined in sensitivity analysis.

† Three animal welfare scenarios were examined with respect to transition probabilities from current body condition scores to the next.

Table 4. *Estimated effects (standard errors) and associated p-values of explanatory variables from the fitted statistical models for three response variables*

	Involuntary culling*		Calving difficulty score†		Calving period‡	
Terms§	Effects (S.E.)	*P*-value	Effects (S.E.)	*P*-value	Effects (S.E.)	*P*-value
(Intercept)	–3.7 (0.45)	<0.001	1.5 (0.23)	<0.001	0.2 (0.19)	0.241
Parity 2	0.34 (0.64)	0.599	–1.5 (0.36)	<0.001	–0.0 (0.18)	0.863
Parity 3	0.8 (0.62)	0.177	–2.1 (0.48)	<0.001	0.0 (0.20)	0.999
Parity 4	0.21(0.74)	0.773	–2.6 (0.57)	<0.001	–0.1 (0.21)	0.776
Parity 5	–0.12 (0.85)	0.831	–1.8 (0.45)	<0.001	0.0 (0.21)	0.969
Parity 6	0.7 (0.68)	0.304	–2.5 (0.63)	<0.001	0.0 (0.22)	0.863
Parity 7	1.3 (0.65)	0.042	–2.4 (0.75)	0.002	–0.1 (0.24)	0.565
Parity 8	0 (1.1)	0.919	–1.9 (0.75)	0.011	–0.2 (0.27)	0.537
Parity 9	0 (1.1)	0.953	–3 (1.0)	0.013	–0.1 (0.28)	0.704
Parity 10+	1.9 (0.59)	0.002	–2.0 (0.74)	0.008	–0.2 (0.26)	0.452
BCS medium	–	–	–	–	0.4 (0.17)	0.036
BCS high	–	–	–	–	0.7 (0.22)	0.004
CH & CHX	–	–	1.6 (0.36)	<0.001	–0.5 (0.16)	0.004
Other	–	–	0.4 (0.27)	0.108	–0.2 (0.12)	0.226

* The intercept value indicates the mean proportion of involuntary culling (on the logit scale) of cows at the reference level of Parity 1. The final model does not include BCS and Breed.
† The intercept value is the coefficient for the CDS score between 1 and 2 (1|2), which indicates the cumulative mean proportion (on the logit scale) of cows with CDS less than a given score at reference levels of other factors (Parity 1, Breed AAX). Estimates and SEs of other intercepts are: 2|3 (2.02; 0.25) and 3|4 (3.28; 0.32). The final model does not include BCS.
‡ The intercept value indicates the mean proportion of successful conception (on the logit scale) of cows at reference levels of other factors (Parity 1, BCS Low, Breed AAX). The final model includes all factors i.e. Parity, BCS and Breed.
§ Parity: 10 levels (1,...,10); Body condition score (BCS): 3 levels (low, medium, high); Breed: 3 levels (AAX, Aberdeen Angus and its crosses; CH & CHX, Charolais and its crosses; Other, Limousin, Simmental and other crosses.

Table 5. *Expected financial performances (annuity of NPV in an infinite time horizon), voluntary culling rates and parity of cows in five states of calving period and three states of body condition score under the baseline welfare scenario*

States	ENPV (£/cow/year)	Voluntary culling rate (proportion cow/year)	Average parity
Herd baseline			
All	174	0.11	4.3
*Calving period**			
CP1	185	0.08	4.7
CP2	178	0.15	4.4
CP3	171	0.15	4.3
CP4	166	0.12	4.4
Barren	162	0.07	4.1
Body condition score†			
Low	173	0.08	4.4
Middle	172	0.08	4.4
High	173	0.15	4.4

* Four 21-day intervals and one barren state
† Using 1–5 scale: low: <2.5; middle: 2.5–3.25; high: >3.25.

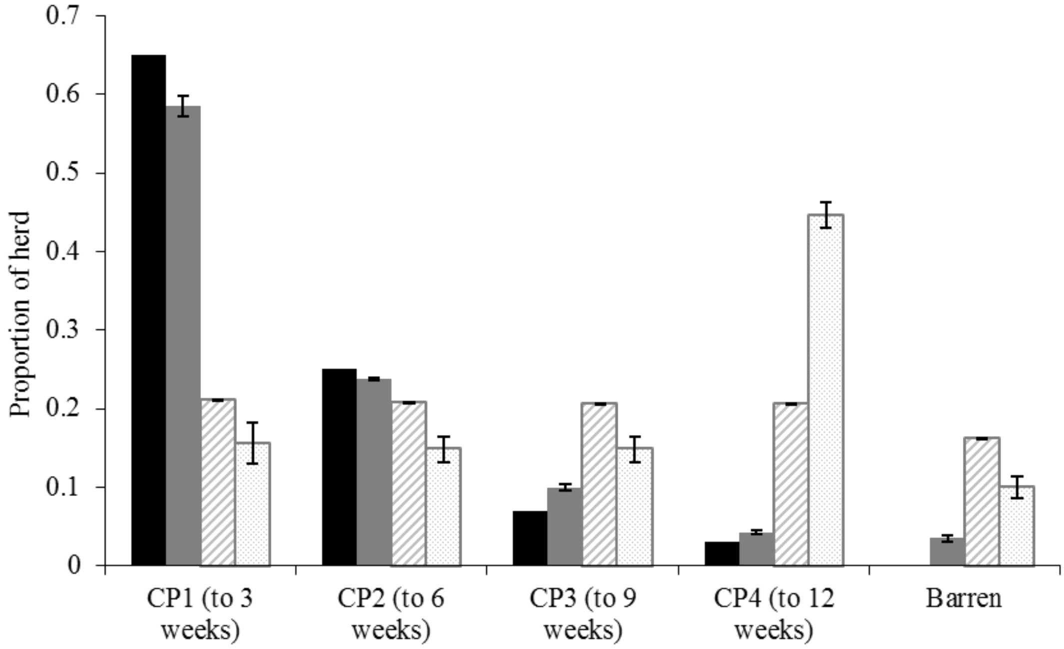
Fig. 1. Calving pattern of SRUC's Fertbench targets (black solid bars), compared with the current analysed dataset of Easter Howgate herd (solid grey bars), the optimized results of the DP model baseline welfare scenario (dashed bars) and the results of a survey of commercial Scottish breeding suckler herds performed in 2005 (Barbudo 2005) (dotted bars). Error bars represent standard error of means.

Fig. 2. Expected net present value £/cow/year ± S.E. (bars) and estimated total culling rates ± S.E. (■) under three scenarios using different transition probabilities for body condition scores presented in Table 3. Error bars represent standard error of means.

Fig. 3. Optimum proportion of herd based on five calving period categories and parity and ENPV per parity predicted by the DP model under baseline welfare scenario as given in Table 3.

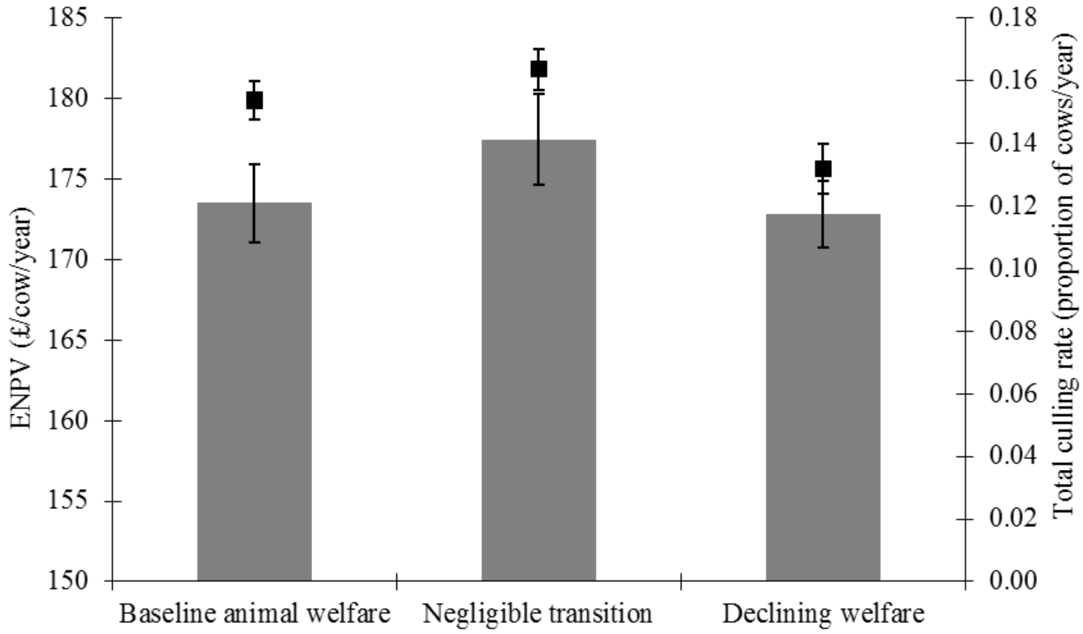
Fig. 4. Optimum proportion of herd (i.e. final distribution in long-term after all culling and replacement decisions have been taken) based on body condition score category and parity predicted by the DP model under baseline welfare scenario as given in Table 3.

Fig. 5. Sensitivity of the expected net present value (ENPV) to input parameters. The scenarios tested were 50% and 100% decrease and increase in the actual default values used for the baseline scenario.



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion of herd
CP1 (to 3 weeks)
CP2 (to 6 weeks)
CP3 (to 9 weeks)
CP4 (to 12 weeks)
Barren

Fig. 1.



185
180
175
170
165
160
155
150
ENPV (£/cow/year)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Total culling rate (proportion of cows/year)
Baseline animal welfare
Negligible transition
Declining welfare

Fig. 2.

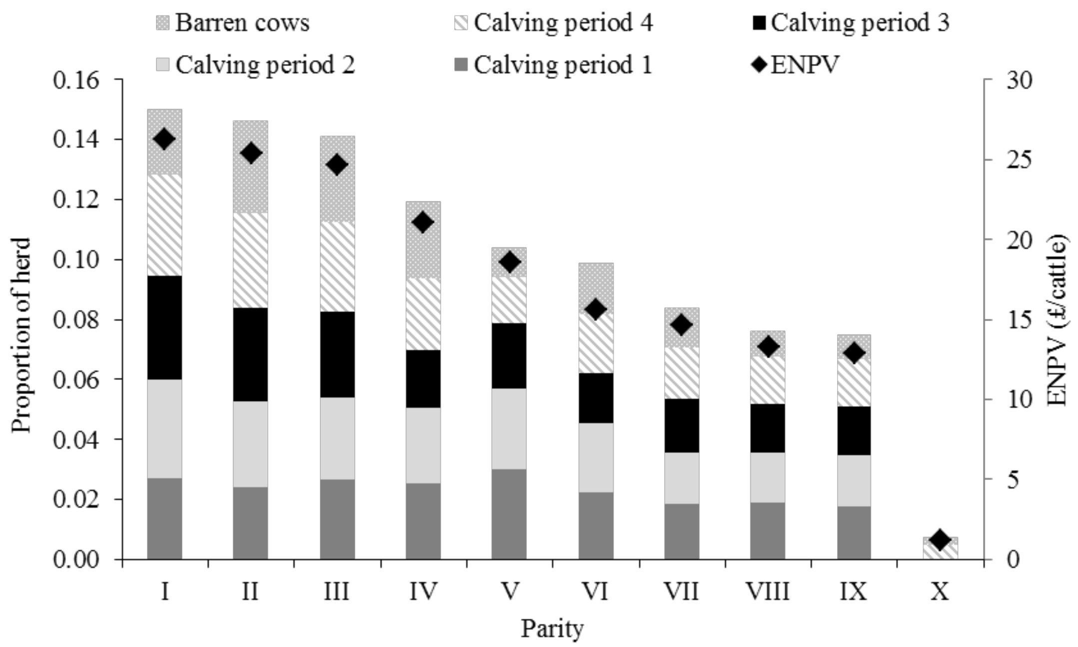

Barren cows
Calving period 4
Calving period 3
Calving period 2
Calving period 1
ENPV
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Proportion of herd
30
25
20
15
10
5
0
ENPV (£/cattle)
I
II
III
IV
V
VI
VII
VIII
IX
X
Parity

Fig. 3.

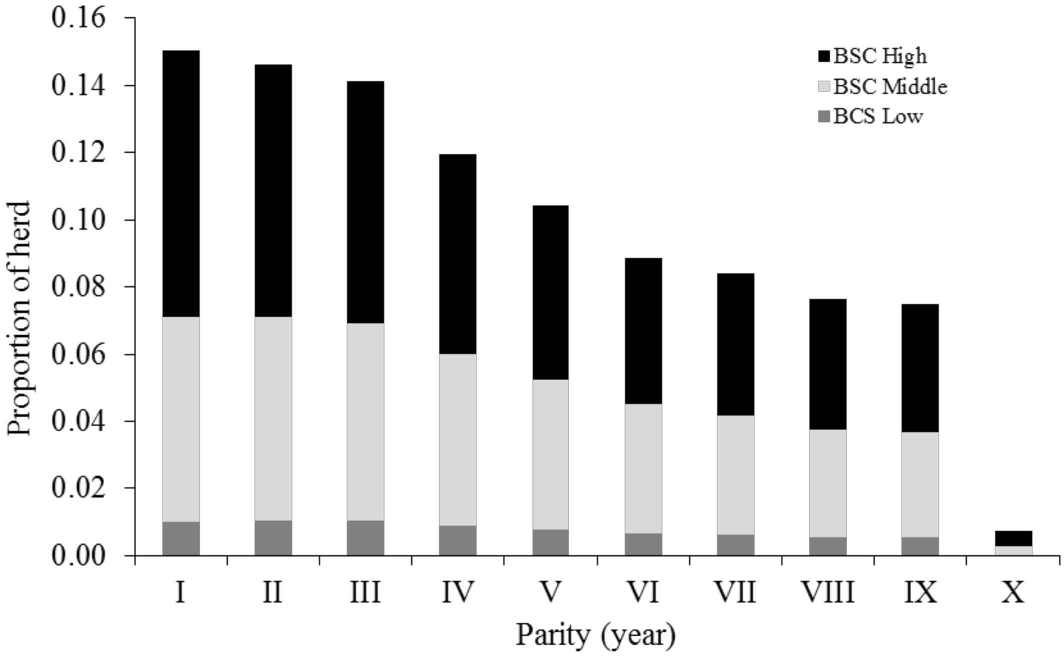

0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Proportion of herd
BSC High
BSC Middle
BCS Low
I
II
III
IV
V
VI
VII
VIII
IX
X
Parity (year)

Fig. 4.

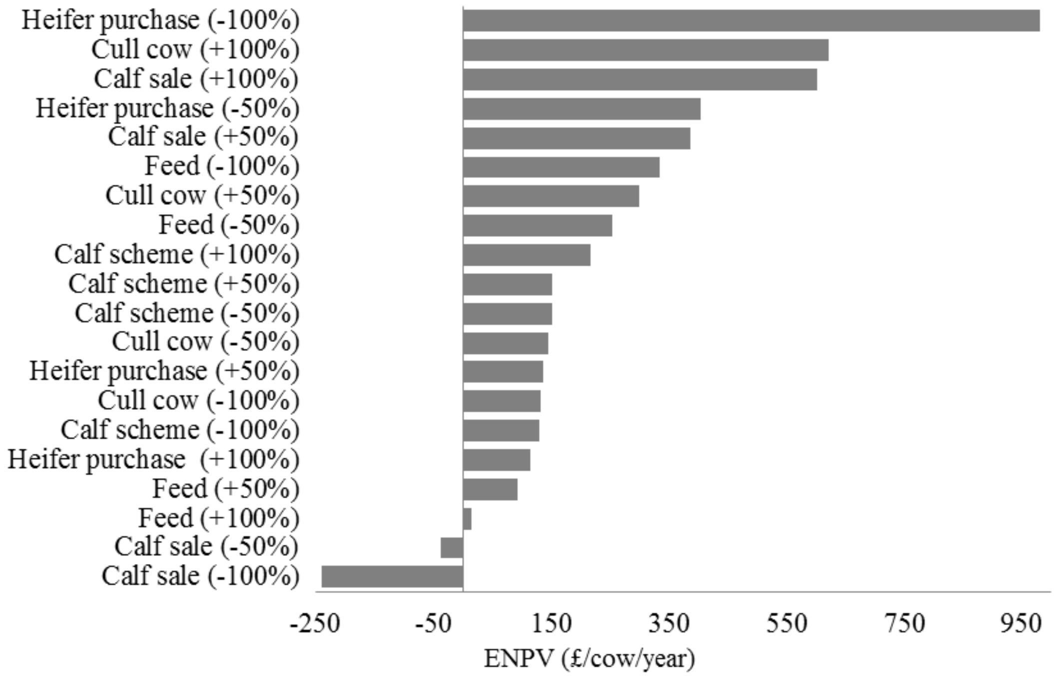

Heifer purchase (-100%)
Cull cow (+100%)
Calf sale (+100%)
Heifer purchase (-50%)
Calf sale (+50%)
Feed (-100%)
Cull cow (+50%)
Feed (-50%)
Calf scheme (+100%)
Calf scheme (+50%)
Calf scheme (-50%)
Cull cow (-50%)
Heifer purchase (+50%)
Cull cow (-100%)
Calf scheme (-100%)
Heifer purchase (+100%)
Feed (+50%)
Feed (+100%)
Calf sale (-50%)
Calf sale (-100%)
-250
-50
150
350
550
750
950
ENPV (£/cow/year)

Fig. 5.