Interpretive Summary

Field survey to investigate space allowance for dairy cows in Great Britain. Thompson. Housing dairy cows is a common management practice worldwide, with year round housing becoming increasingly common. Fifty randomly selected dairy farms from across Great Britain participated in a study to evaluate housing dimensions and management practices. Statistical models were used to analyze the data. Variations in building dimensions and space availability for cows were investigated and a term, “living space” was defined to compare the additional space availability for dairy cows above that deemed to be a baseline requirement. This study is the first to quantify the variation of space allowances on British dairy farms.

DAIRY COW SPACE ALLOWANCES

Field survey to evaluate space allowances for dairy cows in Great Britain

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ABSTRACT

Housing conditions can affect health by increasing exposure to biological, chemical and physical hazards, resulting in increased disease. A report in 2014 indicated that 99% of UK dairy cows are housed during winter months and that an increasing number of farms are committing to year-round indoor housing management systems. Current literature does not provide a clear understanding of the relationship between cow health, welfare and production, and the housed environment. Loafing space, in this case defined as non-feed, non-lying and non-high traffic areas of the housed environment is considered an important component of housing for dairy cows, however the scientific literature associated with this subject is sparse internationally. The aim of this research was to explore current housing of dairy cows across Great Britain, with specific focus on understanding the practices and variability associated with space allowance. A secondary aim was to explore farmer opinion and knowledge on the value of living space. A single researcher visited 53 randomly selected farms, from a representative sample group, once during the winter housing period 2017/18. Data collection consisted of three elements; collation of basic farm details, precise measurement of adult dairy cow accommodation and a questionnaire to capture farmer opinions on space allowances. Statistical analysis was undertaken to assess the variation among farms in total space, loafing space and living space per cow. A new metric termed "living space" was defined to describe the additional space availability for dairy cows above that deemed to be a baseline requirement. Large variability was identified between farms in total space available per cow, with a range from 5.4m^2 to 12.7m^2 (mean=8.3m^2, median=8.2m^2, IQR=1.9m^2). The mean living space was 2.5m^2, with a range of 0.5m^2 to 6.4m^2 (median=2.4m^2, IQR=1.6-3.2m^2). Responses from a farmer questionnaire on loafing space importance revealed that farmers felt it was essential for cow welfare, over half of farmers scoring this $\geq$8 on a 0-10 scale. Farmers were categorised into four latent classes based on their attitudes towards the importance of loafing space. In a linear model to predict the "living space" provided on each farm, geographical location and latent class of farmer attitude were covariates significantly associated with the amount of space provided. This study is the first worldwide to quantify variability in loafing and living spaces for dairy herds; further research is required to evaluate the extent to which variation in quantity and quality of space impacts upon cow health, welfare and productivity as well as farm economics and emissions.

Key words:

dairy cow, housing, health and welfare, loafing space, living space

INTRODUCTION

The human literature reports important links between the physical and mental health of people and their built environment (Gan et al., 2017); the housing in which people spend the majority of their time has been shown to be particularly important for human health (Hancock, 2002). Housing conditions can affect the health of inhabitants by increasing exposure to biological, chemical and physical hazards, resulting in increased disease (Bonnefoy, 2007; Jacobs, 2011). Populations of humans with the worst quality built environments (measured by assessing access to amenities, air quality and building design/layout) are known to be associated with greater incidence of disease (Hood, 2005), especially respiratory disease which has been highlighted as a key outcome measurement of housing quality (Krieger and Higgins, 2002). Inadequate space allowance in human housing is considered as the most important factor when assessing housing poverty (Blake et al., 2007; WHO, 2016), with overcrowding increasing the likelihood of disease transmission (WHO, 2016).

The housed environment is also of great importance to the dairy industry worldwide. A consensus panel (comprising the National Agricultural Statistics Service and the Animal and Plant Health Inspection Service) in the USA in 2013 reported that greater than 80% of dairy cattle in lactation are housed permanently indoors (USDA, 2016) and North American systems are continuing to move towards indoor housing systems rather than extensive outdoor environments (Barkema et al., 2015). A report in 2014 indicated that 99% of UK dairy cows are housed during winter months and that an increasing number of farmers are committing to year round indoor housed management systems (March et al., 2014). It is notable that this trend towards increased year-round housing of cows is occurring despite recognition that grazing is perceived to be important by consumers (Ventura et al., 2016). Farmers who continuously house cows are reported to have larger average herd sizes (March et al., 2014), suggesting a move towards intensification of the sector and increased output per farm. It is recognised that the housed environment needs to be suitable to guarantee a sustainable, welfare friendly industry (Place and Mitloehner, 2014) and the requirement for interdisciplinary research to investigate the relationship between animal welfare and the environment has been highlighted (Place and Mitloehner, 2014).

Since the 1960's, housing of lactating dairy cows in freestalls has become the most commonly used system in dairy nations worldwide (Bewley et al., 2017). Two recent reviews of the housed environment of adult dairy cows demonstrate the lack of research on loafing space allowances for cows in freestall accommodation and a lack of knowledge on its impact on cow health, welfare and productivity (Bewley et al., 2017; Smith and Cook, 2019). It has also been suggested that overcrowding could be a stressor to cows with an impact on behaviour (Templeton et al., 2014). Research on space allowances for adult cows has mainly focused on proxies such as stocking density (the number of cows per freestall) (Hill et al., 2009; Krawczel et al., 2012; Wang et al., 2016; Witaifi et al., 2018; Krawczel and Lee, 2019), feed face measurements (DeVries et al., 2004; Crossley et al., 2017a) and stall size (Bickert, 2000), but these do not necessarily reflect the space available for cows to live in such as areas for lying, standing, eating, drinking as well as space to move between these areas. Surprisingly, loafing space allowances have remained relatively unstudied.

Current recommendations for space allowance in housed cows in the UK are very varied, also suggesting a poor scientific basis. A minimum guideline of 6.5m^2 per cow (total area which cows can access including bedded areas) is reported in UK British Standard laws, BS5502 (British Standards (BS:5502), 1990) and in the UK national "Red Tractor" farm assurance standards(Red Tractor, 2014). Other industry stakeholders such as AHDB (Agriculture and Horticulture Development Board, the UK dairy farmer Levy board) and

RSPCA (Royal Society for the Prevention of Cruelty to Animals) have published recommendations that exceed these minimum guidelines at 10.5m^2 and 10m^2 respectively (AHDB Dairy, 2018; RSPCA, 2018). In the USA the most recent recommendation of space per cow was edited to 7.4m^2 in the 1980's based mainly of shed design rather than cow health and welfare (Bickert and Light, 1982). More recent recommendations are sporadic but do appear in the Federation of Animal Science Societies (FASS) in the USA and the SPCA Certified standards in Canada, both recommending 11m^2 per cow (McGlone et al., 2010; SPCA, 2018). The Canadian Code of Practice does not set a minimum figure for total space allowance in freestall accommodation, instead using a stocking density minimum of 1.2 cows per stall (NFACC, 2009).

Loafing space (in this case defined as non-feed, non-lying and non-high traffic areas of the housed environment) is considered an important component of housing for dairy cows however the scientific literature associated with this subject is sparse (Haskell et al., 2013). Although it is likely that the size and type of space in which cows live will affect their health and wellbeing, there are virtually no data available on the amount of, and variability in, space allowances in commercial dairy herds globally. The aim of this research was to explore current housing of dairy cows across a random sample of farms in Great Britain, with a specific focus to provide underpinning evidence on the quantity and variability of space provision for dairy cattle, including areas for eating, lying and passageways. A secondary aim was to explore farmer opinion and knowledge on the value of living space for dairy cows.

MATERIALS AND METHODS

Study Design

An observational, cross-sectional study was conducted to evaluate the variability in living space allowances for dairy cows in Great Britain and is reported in alignment with STROBE guidelines (von Elm et al., 2008; STROBE, 2019). Informed consent was obtained from all participants after they were provided with details about the study purpose and data capture. Ethical approval was obtained from the departmental Ethical Review Panel prior to study commencement.

Farm Selection

A large British food retailer provided a list of their supplying dairy farms (n= 739; ~12% of all GB dairy farms) which comprised the target population for this study. This pool of farms was originally selected by the retailer in 2007 and was based on milk tanker routes i.e. no selection criteria based on farm characteristics were used, so the population was considered representative of dairy farms in Great Britain. Sample farms were selected at random from this group using random number generation in Microsoft Excel (Microsoft, 2016) and the researcher (JT) was blind to farm details during selection. Farmers were invited to participate in the study by letter and email and participating farmers were telephoned to organise a date for visitation. Sample size calculations indicated a sample of 50 farms would provide an estimate of the population mean total space allowance per cow to be estimated with a 95% confidence interval of +/- 0.5m^2 and the population standard deviation also to be estimated with a 95% confidence interval of +/- 0.5m^2. Initially, 100 farms were randomly selected and ordered using random number generation; farms were contacted and invited to participate in the order defined. An initial group of 50 farms were contacted for recruitment. A further 20 farms were selected for contact 2 weeks later based on the response rate of the initial group to ensure a sample size greater than 50. Overall, of the 70 farms approached, 53 agreed to participate (75.7% response rate).

Data Collection

A single researcher (JT) visited all 53 farms once between 9th November 2017 and 19th January 2018 for approximately 3 hours in duration; the data collection window occurred during the winter housing period for all farms. Data collection consisted of three elements; collation of basic farm details, precise measurement of all adult dairy cow accommodation and a questionnaire to capture farmer opinions on space allowances for cows, as follows:

Farm Characteristics. Farmers provided detail about the management of the farm, including breed of cows, calving pattern, and number of adult dairy stock. Details on the management of cows during the housed period were obtained, including how cows were grouped and the duration and timing of groupings. Milk sold per cow per year and the most recently recorded bulk milk somatic cell count was also obtained.

Housing Area Dimensions. Measurements were taken using a Leica Disto D510 laser measuring device (Range: 200m, Tolerance ±0.10mm/10m between 10-30m) of all accommodation used for adult dairy cows in lactation. Measurements were recorded on a standardised data capture form for each building or group of animals. Dimensions recorded comprised all areas available to cows: feed passageways, stall passageways, cross-over passageways with and without-water areas, collecting yards (if accessible to cows in addition to the time waiting for parlour entry), bedded areas, loafing areas and any other living areas available to the lactating herd.

Loafing Space Opinion. An eleven question, face to face interview was conducted with the main herdsman or farm owner. Closed questions were styled to gain understanding of farmer views about loafing space and housing conditions for dairy cows. Farmers were asked to rank the overall importance of loafing space, as well as importance in terms of production, health and welfare, on a scale from 0-10. Farmers were asked to indicate their preferred option for floor surface in loafing space areas. Farmers also ranked the importance of outdoor access for housed dairy cows. Finally, farmers were asked how much total and loafing area space they believed housed dairy cows required as a minimum and optimum.

Study Definitions

Total Area:

- This incorporated all floor and bedded areas which a group of dairy cows had access to whilst housed (including cow access areas only such as stall bedding area, all passageways and indoor/outdoor loafing spaces but excluding areas in a building which did not permit cow entry such as feed alleys for tractor use only).

Passageway:

- Defined as areas used by cows to move through the accommodation; comprised of stall passageways, feed passageways and cross-over passageways.

Loafing Space:

- A non-bedded, non-passageway area where cows could roam freely which included indoor or outdoor areas. Examples include:
    a. Parlour collecting yards which are open and available to cows for a minimum of 4 hours / day, excluding the time prior to milking.

b Indoor or outdoor concrete/ sand/ straw/ woodchip pad/ pasture areas, not used for bedding and which didn't act as an access area between the stalls and feed-face.

Living Space:

- A novel bespoke definition of the space within the dairy cow accommodation that was greater than that considered a baseline requirement for movement around and feeding within the overall accommodation area, excluding lying areas. The calculation of this definition was based on bespoke parameters for this study and was estimated as follows:

Total feed-passageway area over and above a baseline allocation of $2.4m^{2*}$ per cow +

Total stall-passageway area over and above a baseline allocation of $1.32m^{2**}$ per stall +

Total Loafing space area (defined above)

** $2.4m^2$ feed-passageway: deemed in this study to be a minimal baseline space required for a cow to move into and stand at the feed-face*

***$1.32m^2$ stall-passageway: deemed in this study to be a minimal baseline passageway requirement for a cow to move in and out of a freestall (calculated using an estimated stall width of 1.10m multiplied half a minimum width deemed necessary for a stall passageway of 1.20m)*

These calculations mean that a minimum stall passageway width is taken to be 2.4m (to allow simultaneous exit from opposing stalls) and the minimum feed-passageway which includes access to stalls to be 3.6m wide (to allow for simultaneous entry/exit to a stall whilst another cow is feeding).

Maximum pen stocking density:

- A farmer stated figure for the maximum number of cows that would ever be accommodated in a defined area of the farm.

Statistical Analysis

Data analysis was carried out using the R statistical package, version R-3.5.2 (R Core Team, 2018). Data were restructured to consist of farm averages for milking cows in stalls across all cow groups housed in stalls on farm. Three farms were omitted from analysis because all milking cows were housed exclusively in straw yards. Descriptive analysis was undertaken to visualise data and linear models were used to explore the relationships between farm building features and farmer opinions with living space measurements.

Descriptive analysis. Variability between herds was evaluated using summary statistics to evaluate distributional characteristics. Histograms, scatterplots and box and whisker plots were used to visualise the data. Conventional bootstrapping (Kuhn and Johnson, 2016) of the building measurement data was carried out to estimate the 95% confidence intervals of the mean, median and IQR's.

Model 1: Estimation of Living Space from Housing Features. The aim of Model 1 was to evaluate the associations between the area defined as "living space" and other measurements made of the housed environment. The purpose was to evaluate whether total area per cow and total stall area per cow (total base area: bedded area + lunge area) would provide a good estimate of total living space.

The linear regression model took the form:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i$$

Where subscript $_i$ denoted the *i*th farm, Y_i was the living space area per cow for farm *i*. β_0 was the intercept, x_{1i} was the total building space allowance area per cow for the *i*th farm, β_1 the coefficient for x_{1i}, x_{2i} the stall area per cow (total base area: bedded area + lunge area) for the ith farm, β_2 the coefficient for c_i and ε was the residual error assumed to have a mean of zero and variance σ^2.

To explore the potential for generalisability of this model to new data, a leave-one-out-cross-validation (LOOCV) (Kuhn and Johnson, 2016) was performed. Model predictions were assessed using r^2 and mean absolute error (MAE). Fit was also assessed using conventional residual analysis and Cook's distance (Petrie and Watson, 2006).

Latent Class Analysis of Farmer Opinions on Space Allowances. A latent class analysis of farmer opinions on loafing space was conducted using the Mclust package (Scrucca et al., 2016) in R, to explore whether farmers tended to be grouped within the data in terms of their views. Data from all 53 farmers surveyed were used for analysis. The following five themes were used to evaluate farmer opinions: Importance of loafing space in general for housed dairy cows, importance of loafing space for productivity, importance of loafing space for health, importance of loafing space for welfare and importance of outdoor areas for housed dairy cows. All five questions were presented to participants on an 11-point scale (0 = completely unimportant to 10 = critically important). The unsupervised latent class analysis was conducted using model based clustering. The method comprised three elements; initialisation using model-based hierarchical agglomerative, use of an expectation-maximization algorithm for likelihood and cluster selection using Bayesian Information Criterion approximation (Fraley and Raftery, 2002). Using the technique, first the number of clusters within the data was identified and second the posterior probability of each farmer being in each latent class was estimated. Farmers were allocated to a cluster based on the maximum posterior probability; the Bayesian Information Criterion was used to identify the best model and hence optimum number of latent classes (Fraley and Raftery, 2002).

Model 2: Factors Associated with Availability of Living Space. A second generalised linear model (Marschner, 2018) was built using living space at maximum stocking density for cows in milk as the outcome variable. The aim was to explore which farm and farmer related variables were associated with availability of living space. Predictor variables tested were milk sold per cow per year, age of building, maximum number of milking cows on farm, duration of housing period, cow breed, calving pattern, farm region and latent class of farmer opinion. A forward stepwise procedure was undertaken with each variable tested and retained in model when $P \leq 0.05$. One farm was omitted from this model due to missing data for one of the covariates. The model took the form:

$$Y_i = \beta_0 + \beta_n x_n + \varepsilon_i$$

Where subscript $_i$ denoted the *i*th farm, Y_i was the living space area per cow for farm *I*, β_0 was the intercept value, x_n were model covariates for *i*th farm, β_n were the coefficients for x_n, and ε was the residual error assumed to have a mean of zero and variance σ^2.

Model predictions were assessed using r^2 and MAE. Model fit was evaluated using conventional residual analysis and Cook’s distance. LOOCV was performed to assess potential for generalisability of the model.

RESULTS

Farm Characteristics

Fifty-three farms participated in the study giving a response rate of 75.7%. Three farms were removed from the data for assessment of space allowances because they did not house cows in freestalls during lactation. Consequently the minimum target sample size, which was prospectively estimated by power analysis prior to commencing the study, was fulfilled. The 50 farms were spread across Great Britain as shown in figure 1, with the majority of farms within the South-West (18) or Midlands (19) areas. The main breed identified on each farm were Holsteins (18) or Holstein-Friesian types (27) with the remaining 5 consisting of crossbreeds or a mix of breeds without a majority. Twenty-eight farms contained between 201-400 adult dairy stock, there were 4, 10 and 8 farms with <100, 101-200 and >400 respectively (minimum = 60, maximum = 901, mean = 288, median = 265). Most farms stocked all of their cows in lactation in freestall buildings (26), with 2 farms housing <75% of their milking cows in freestalls (in these herds cows were divided between freestall and straw yard accommodation). For herds with a proportion of cows in non-freestall accommodation, calculations were based solely on measurements of, and cow numbers in, the freestall accommodation only. Calving patterns were split into 3 groups, block calving, double block calving and year round with 9, 2 & 39 farms respectively. Nineteen farms housed the milking herd year-round, with 23 farms housing cows for 6 months or less on an average year. The highest yielding herd sold 12,650 litres per cow per year, lowest 5,850L with a mean of 8,979L and median of 9,150L (the national UK mean annual milk yield in 2017 was 7893L (AHDB, 2019)). Ten of the herds produced over 10,000L per cow per year.

Housing Areas. Total area per cow showed large variability between farms, with a minimum of 5.4m^2 and maximum of 12.7m^2 , mean = 8.3m^2 (95% CI = 7.90-8.80), median =

$8.2m^2$ (95% CI = 7.8-8.8), SD = $1.64m^2$ (95% CI = 1.26-1.96) and IQR: $1.85m^2$ (95% CI = 1.25-2.70).

Specific loafing space per cow across the farms also varied, with a minimum observed of $0m^2$, and a maximum of $5.4m^2$. The mean loafing space was $1.1m^2$ (95% CI = 0.76 – 1.54), median $0.5m^2$ (95% CI = 0.0-1.3), SD = $1.44m^2$ (95% CI = 1.06-1.77) and IQR $1.9m^2$ (95% CI = 1.2-2.65). Approximately one third farms were above a specific UK recommended target of $3m^2$ for loafing space (Red Tractor, 2014).

The mean living space across the 50 farms was $2.5m^2$ per cow at maximum stocking density (95% CI = 2.15-2.92), with a minimum of $0.5m^2$ and maximum of $6.4m^2$. The median was $2.4m^2$ (95% CI = 1.95-2.75), SD = $1.40m^2$ (95% CI = 1.07-1.68) and IQR $1.6m^2$ (95% CI = 1.08-2.30). The association between total space available per cow and living space per cow at maximum stocking is illustrated in Figure 2.

The variability in living space between geographical regions is illustrated in figure 3; 7/10 farms with the most living space area per cow were in the South-West of England. All farms in the north of England and Scotland were in the bottom 50% of study farms for amount of living space area per cow.

Farmer Opinion Questionnaire; Descriptive Results. Results of the farmer opinion questionnaire are summarised in figure 4. In general, answers to the five 11-point questions were relatively high indicating farmers valued loafing space and outdoor access as relatively important for housed dairy cows. The importance of loafing space for cow welfare received the highest score, with a median of 8 and interquartile range of 8-10. The importance of outdoor access for housed dairy cows had most variation in scores (minimum = 0, maximum =10, IQR = 5-8).

When answering questions about the definitions of space there was substantial disagreement between respondents, twenty-two of 53 farmers (42%) stated that they thought all passageways (stall, feed and cross-over passages) were defined as loafing space whereas 16 farmers stated that none of these comprised loafing space.

Twenty-one farmers (40%) identified grooved concrete as the best surface for a loafing space, sixteen (30%) farmers stated this should be rubber matting and the remaining farmers selected either pasture, sand, slatted rubber matting, straw or woodchip pads.

Seventeen (50%) of the farmers responded that housed dairy cows should have greater than 2m^2 as a minimum loafing space (Min: 0.00m^2; Median: 2.00m^2; Mean: 2.65m^2; Max: 8.00m^2; IQR: 1.40-4.00m^2; NA: 20) but thought that ideally cows would be given more loafing space with a median of 5.00m^2 stated as the ideal situation (Figure 5; Min: 0.57m^2; Mean: 5.04m^2; Max: 12.00m^2; IQR: 2.95-6.13m^2; NA: 21).

Model 1: Estimation of Living Space from Housing Features.

The final model to predict living space from total area per cow and stall bedded area per cow, both at maximum stocking was:

$$\text{Living Space at Maximum Stocking} = 0.83\,T - 1.28\,\text{C} - 0.79$$

Where T was the total area per cow at maximum stocking and C was the stall bedded area per cow at maximum stocking.

This model has an MAE of 0.39m and an r^2 of 0.87. Results of the LOOCV are illustrated in figure 6. The LOOCV model produced an MAE of 0.42m and an r^2 of 0.85.

Latent Class Analysis of Farmer Opinions on Space Allowances.

The 52 farms were categorised into 4 latent classes as illustrated in figure 7. The classes contained 22, 6, 13 and 11 farms respectively. Latent class 2 contained farmers which gave the lowest scores for the importance of loafing space and outdoor access, conversely latent class 4 farmers gave the highest score for all 5 questions. Farmers in latent class 1 gave intermediate scores for loafing space importance but scored more highly than latent class 3 farmers, who scored outdoor access more highly than latent class 1 farmers.

Model 2: Factors Associated with Availability of Living Space.

Results of Model 2 are presented in table 1. Region and farmer latent class were significant variables, with farms in the South West, Wales and the South East being associated with greater amounts of living space per cow than farms in Northern England and Scotland. Farmer opinion latent class 3 (higher outdoor access importance answers but lower loafing space importance answers) had farms with more living space per cow in comparison to farmer latent class 1 (higher loafing space importance answers with lower outdoor access importance answers) ($P<0.05$). The mean absolute error for the model was 0.78m and $r^2 = 0.39$. Post fit analyses indicated that model fit was good.

DISCUSSION AND CONCLUSION

Evidence for the impact of living space allowance on health and wellbeing of housed dairy cows appears to be very limited globally. This study is the first worldwide to report the magnitude of variation in living space availability for dairy herds. The variation in space allowance spanned all current GB recommendations; 10% farms exceeded the largest GB guideline (AHDB: 10.5m^2), and one farm was below the minimum guideline set in British standards (6.5m^2). Farms with higher space allowance and living area per cow typically had outdoor loafing or feeding areas as well as wider passageways. The farms with accommodation with the least space had narrow passageways and fewer cross-over passages. Given the extent of variation observed, (the standard deviation was 20% of the mean for total space allowance per cow), the biological importance of the distribution of data is potentially of great significance although its impact is currently uncertain.

Although measuring health outcomes were not an objective of this study, previous research suggests that living conditions are likely to impact upon the health of inhabitants (Bonnefoy, 2007; Jacobs, 2011). It has been hypothesised that variation in the housed environment on farms has a relationship with health, welfare and productivity of the cows; a study looking into alternative housing systems for dairy cows has shown that the environment could influence SCC's, mastitis infection rates and reproductive performance (Barberg et al., 2007). Housing has been reported to influence lameness incidence through inappropriate design as a risk factor that could predispose cows to white line lesions, sole haemorrhage (Flower et al., 2007), or digital dermatitis (Endres, 2017). Milk production and quality has been reported to be influenced by space allowance via competition for resources, for example at the feed-face or stocking density in automatic milking systems (Deming et al., 2013; Crossley et al., 2017b), however the short term nature of such trials make these difficult to interpret. Space availability is likely to influence cow behaviour; spatial distribution analysis has shown dominant cows to have lower cow-to-cow distances and that lower ranking cows may want to space themselves further from other animals within a group (Syme et al., 1975). More recently, stocking density (defined as the number of cows to stall spaces) has been shown to decrease lying times, cause cows to spend more time in passageways and alter their social structure (Hill et al., 2009; Krawczel et al., 2012). Therefore current literature suggests that stocking density, feed-face and shed design can influence cow health, welfare and production. Surprisingly, no studies to date have evaluated the direct impact of living space allowance on cow health and welfare.

This study proposes "living space" as a novel and valuable measure of space availability to cows on farm. Many farm regulatory bodies and assurance schemes have recommendations for loafing space availability in freestall systems, however, imprecise definitions of loafing space make it difficult for assessors to measure and for farmers to modify their buildings appropriately and to some extent, the sparsity of research into loafing areas may be caused by the ambiguity around its definition. We propose that our new definition of living space, an area above that considered essential to gain access to lying and feeding areas, provides a more intuitive framework to define space availability for cows. This definition of living space encompasses all fundamental areas of a freestall building, including accounting for wider passageways and additional outdoor/indoor areas, thus providing a useful estimate of the true available space from a single measurement. Importantly, this study identified that definition of living space could be accurately estimated from two simple measurements; total housed area and total stall bedding area (Model 1) which means it can be readily estimated under commercial conditions using a standard laser measurer. Since indoor housed freestall systems are used across many large dairying nations, this definition of living space is likely to be useful for assessing the housed environment for freestall buildings on a widespread basis, including the standardisation of research studies.

Farmers whom participated in this survey considered loafing space to be relatively important to the health, welfare and productivity of their herd, as observed in the questionnaire results. However, answers to questions based around their knowledge of loafing space were very variable, for example 38% (20/53) were unable to give an answer for the minimum amount of loafing space requirements (range: 0.3m^2 to 8m^2 per cow), suggesting poor knowledge of this topic. Some of this variation could arise from different perceptions of what constitutes loafing space, especially given the different views identified in the survey on whether all passageways should be counted as part of loafing space or not. Currently, farmer attitudes towards loafing space haven't been investigated widely; it would be of interest to understand whether farmer views about the importance of loafing space is markedly different in different cultures and countries.

The observed living space measured on each farm was noticeably different to the farmer's stated minimum acceptable loafing space, with around half of farmers providing their cows less than their cited minimum value. This is an example of cognitive dissonance, where a belief does not match with behaviour (Bandura, 2000); there is evidence to show that behaviour does not always match with cognitive components of belief (LaPiere, 1934). A previous example of this occurring has been shown with footrot management in sheep (O'Kane et al., 2017) when farmer behaviour has been identified to be effected by many factors, such as habit, emotions, social norms and social capital (O'Kane et al., 2017; Shortall et al., 2018). This raises questions as to what the social norm for provision of loafing space to dairy cows is within the industry or, in terms of perceived behavioural control, how difficult farmers believe the provision of extra space to be in relation to its benefits. Our results indicate that many farmers believe loafing space is important for their cows but barriers must exist which prevent implementation, further exploration of these barriers would be beneficial but are likely to include cost and practical difficulties associated with making significant changes to existing building and farm layouts. Plausible theories preventing farmers moving between the stage of wanting to implement change to actually undertaking it may include motivation, competition with other initiatives on farm, or anticipation of potential difficulties (Green et al., 2012).

Region and latent classes of farmer beliefs were both factors associated with the amount of living space per cow actually provided on farm. Farms in the south of England provided more living space than those in the north. A possible explanation for this may be that farms with greater amounts of space tended to have additional outdoor loafing areas. From further meteorological investigation it was found that the farms in this study from the more northern areas of GB generally had higher rainfall on average than those located in the southern parts. Farms in Northern England and Scotland region grouping may be less likely to opt for outdoor loafing areas due to the higher average rainfall recorded in these areas, as this could increase the volume of slurry and therefore time and expense to manage it. Farmers in latent class 3 (intermediate loafing space importance scores, higher outdoor access score) provided more living space for cows than those in latent class 1 farmers (intermediate loafing space scores, lower outdoor access score). The main difference between these two classes was the stated importance of outdoor access for housed dairy cows with latent class 3 farmers scoring this feature higher. Therefore, it is more likely that farmers in this group would commit to providing outdoor areas for their livestock and consequently specific loafing spaces, which tend to inflate the total living space availability.

A limitation associated with the questionnaire is the potential for social desirability bias; it was known to the respondent that the researcher was from a university and loafing space was a key theme of the study. Therefore, farmers may have believed that loafing space should be important for housed dairy cows and may have inflated their scores in response to this. Although a high response rate (76.7%) was achieved from study farms, we cannot be sure that non-responders would be the same as those responding. Reasons given for non-participation included time availability (n=2), exiting the dairy business (n=2), illness (n=2), biosecurity (n=1) and non-interest (n=5). Three of the selected farmers were uncontactable despite at least 3 attempts of contact via email and telephone and the remaining farmers did not provide a reason for non-participation. It is likely that sample group was representative of the target sample because of the robust randomisation method of selection and very high response rate, however, data protection issues meant it was not possible to compare demographics of the non-responder group and study participant group meaning a degree of selection bias cannot be ruled out.

The target population in this study was all dairy producers supplying a large British retailer and it is unclear how this group relates to other British farmers. How this sample relates to other dairying nations is also unknown due to differences in management practices and legislation/guidelines.

This research has demonstrated that there is important variation in the housing conditions of dairy cows across Great Britain. It is unknown to what extent this variation impacts upon health, welfare and productivity and we believe this should be the subject of further research. It will also be important to greatly improve the understanding of the quality of space provided to cows. For example, this could include investigations of the types of spaces required for displaying natural behaviours, improving access to feed and lying areas, design of free-stall layout and the quality of floor surfaces for walkability. By combining assessment into quantity, quality and types of space provided to indoor housed dairy cows, the impact of building design should be evaluated in the context of ammonia emissions, cow health, welfare and productivity. Such research would provide a scientific basis to advise international industry standards on the quantity and quality of living space for dairy cows.

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Table 1. Results of a statistical model (Model 2) assessing factors associated with the amount of living space available for lactating cows on farm, in a study investigating space allowance in dairy cow housing in Great Britain.

	Coefficients		
	Estimate	Std. Error	Pr ($>\lvert t\rvert$)
Intercept	0.84	0.51	0.1119
Farm Region			
Northern England and Scotland	(Ref)		
Midlands	0.83	0.55	0.1356
South East	1.51	0.84	0.0796 †
South West	2.01	0.52	0.0004 ***
Wales	3.28	0.97	0.0017 **
Farmer Opinion Latent Classes			
Latent Class 1	(Ref)		
Latent Class 2	0.34	0.60	0.5743
Latent Class 3	1.03	0.44	0.0238 *
Latent Class 4	0.59	0.46	0.2098

†$P < 0.10$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Figure 1 Geographical location of 53 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain (Google Maps, 2019).

Figure 2 Scatterplot (with associated histograms) of total housing area per cow (m^2) associated with freestall accommodation against living space area per cow at maximum stocking in 50 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain. The surrounding histograms show the number of farms in each $1m^2$ block of space for both measurements used in the scatterplot.

Figure 3 Living space available per cow per farm arranged in ascending order, and how space varied by geographical region, across 50 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain.

Figure 4 Boxplots showing the spread of answers by the 53 participant GB dairy farmers to five 11-point questions asking for their opinion to the importance of loafing space and outdoor access for housed dairy cows.

Figure 5 (A) Boxplots to show the answers given by 53 GB dairy farmers when asked how much loafing space should be given to housed dairy cows. Left boxplot: in an ideal scenario (na = 20/53). Right boxplot: as a minimum (na = 21/53). (B) A scatterplot to compare the actual living space available per cow per farm from the 50 farms recruited to the investigation of space allowance studies and how this figure compared to the farmer stated minimum amount for loafing space for housed dairy cows as part of the loafing space questionnaire.

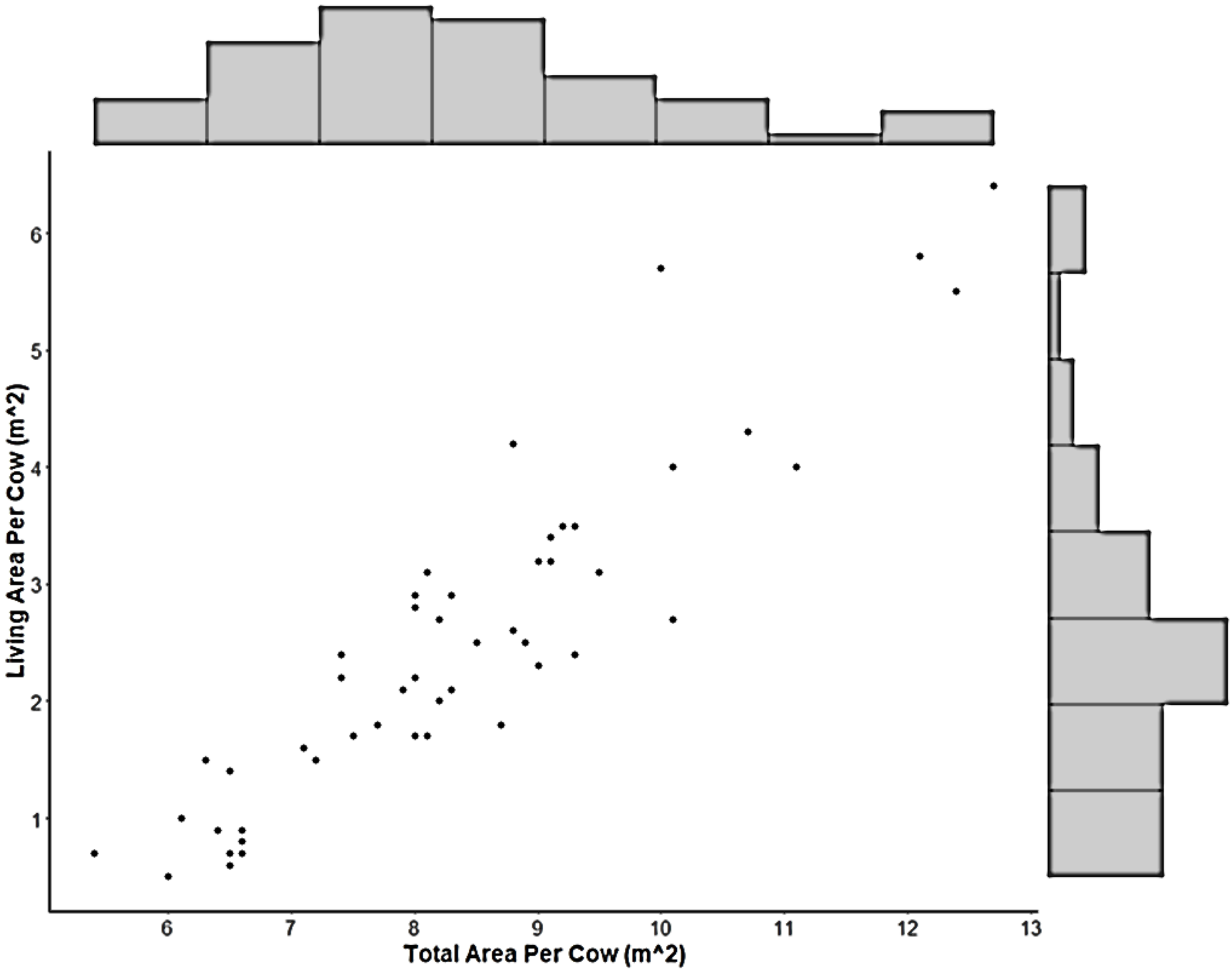
Figure 6 A scatterplot to compare the observed living space availability per cow per farm across the 50 farms recruited to a study investigating space allowance in dairy cow housing in Great Britain against the predicted living space availability per cow per farm from LOOCV predictions (Model 1); $r^2 = 0.85$.

Figure 7 Shows the mean farmer opinion score of the five 11-point questions used to form the four latent classes analysed from the loafing space farmer questionnaire completed by 53 GB dairy farmers. Latent class 1: n = 22, all farmers gave intermediate scores for the four loafing space importance questions but scored the importance of outdoor access for housed dairy cows low in comparison to latent class 3. Latent class 2: n = 6, contained farmers which ranked the 4 loafing space importance questions and importance of outdoor access lowest of all four latent classes. Latent class 3: n= 13, linked farmers who gave intermediate scores to all the questions but a higher score for importance of outdoor access for housed dairy cows in comparison to latent class 1. Latent class 4: n= 11, were a group of farmers who scored all 5 questions highly in comparison to the other latent classes.

Figure 1

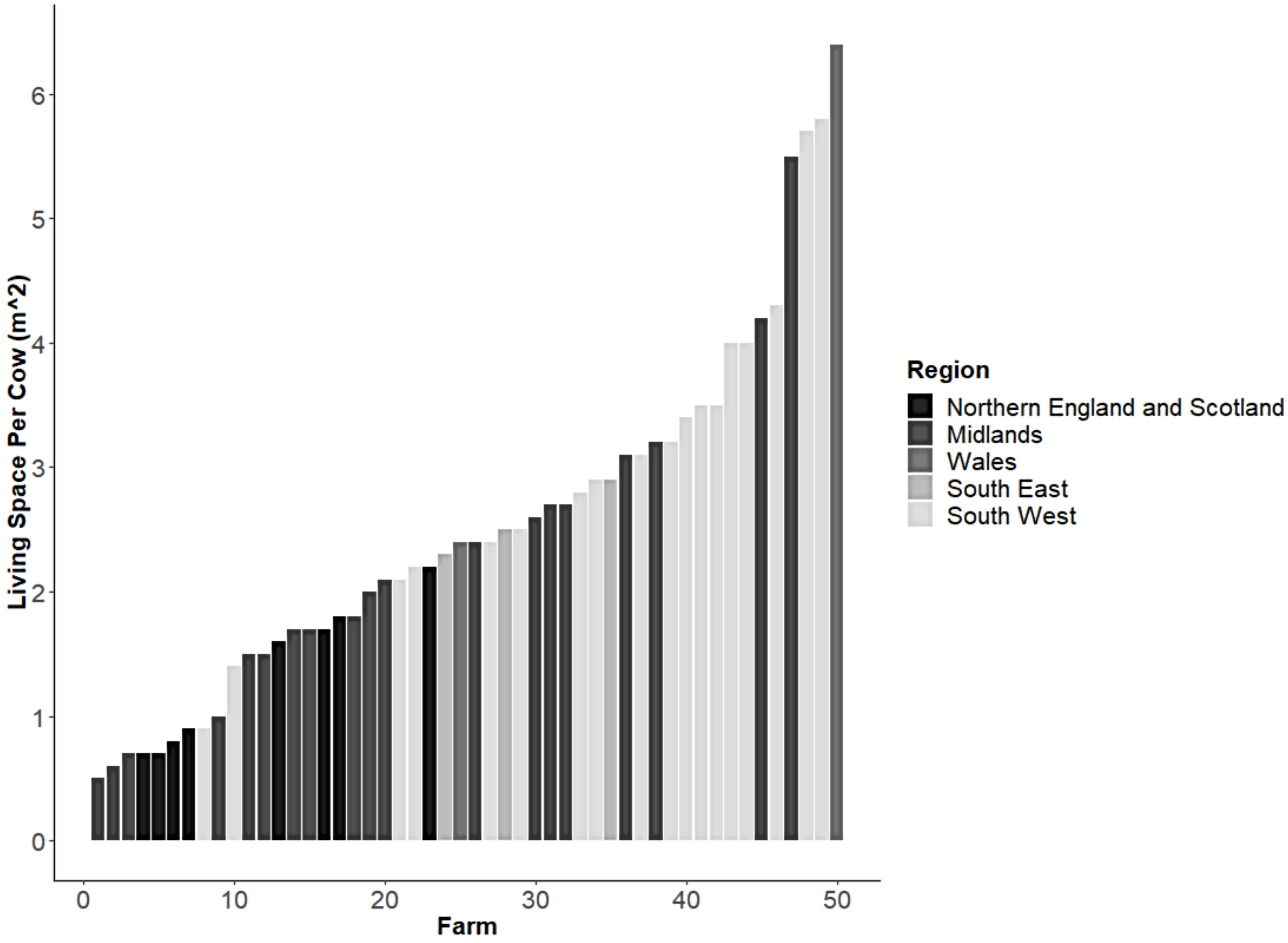
Edinburgh
Glasgow
Ayr
M74
A74(M)
Dumfries
United Kingdom
Newcastle upon Tyne
Durham
North Pennines AONB
Middlesbrough
Lake District National Park
North York Moors National Park
Scarborough
Yorkshire Dales National Park
Isle of Man
A1(M)
York
Leeds
Hull
Great Britain
M61
M1
M18
Liverpool
Manchester
M62
Chester
Peak District National Park
Nottingham
Snowdonia National Park
Leicester
Peterborough
Norwich
M54
ENGLAND
Cambridge
Ipswich
WALES
M40
Colchester
Cotswolds AONB
A1(M)
M11
Swansea
Swindon
London
Cardiff
Reading
Southend-on-Sea
M4
M25
Canterbury
Bath
M3
M20
Southampton
Brighton
Exeter
Bournemouth
Torquay
Newquay
Plymouth
Truro
St Ives
Penzance
Falmouth
Map data ©2019 GeoBasis-DE/BKG

705 Figure 2



706

707 Figure 3



708

709

Figure 4

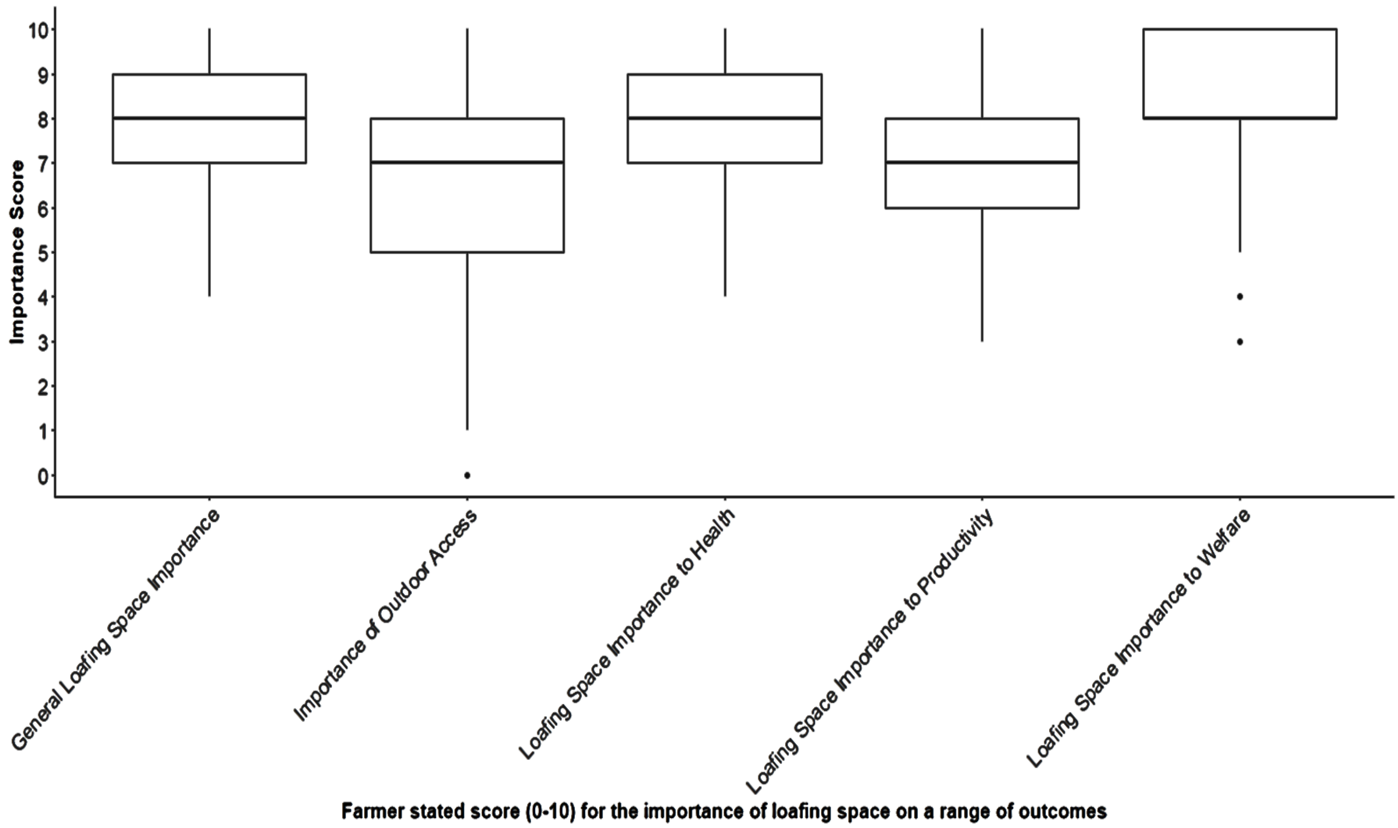
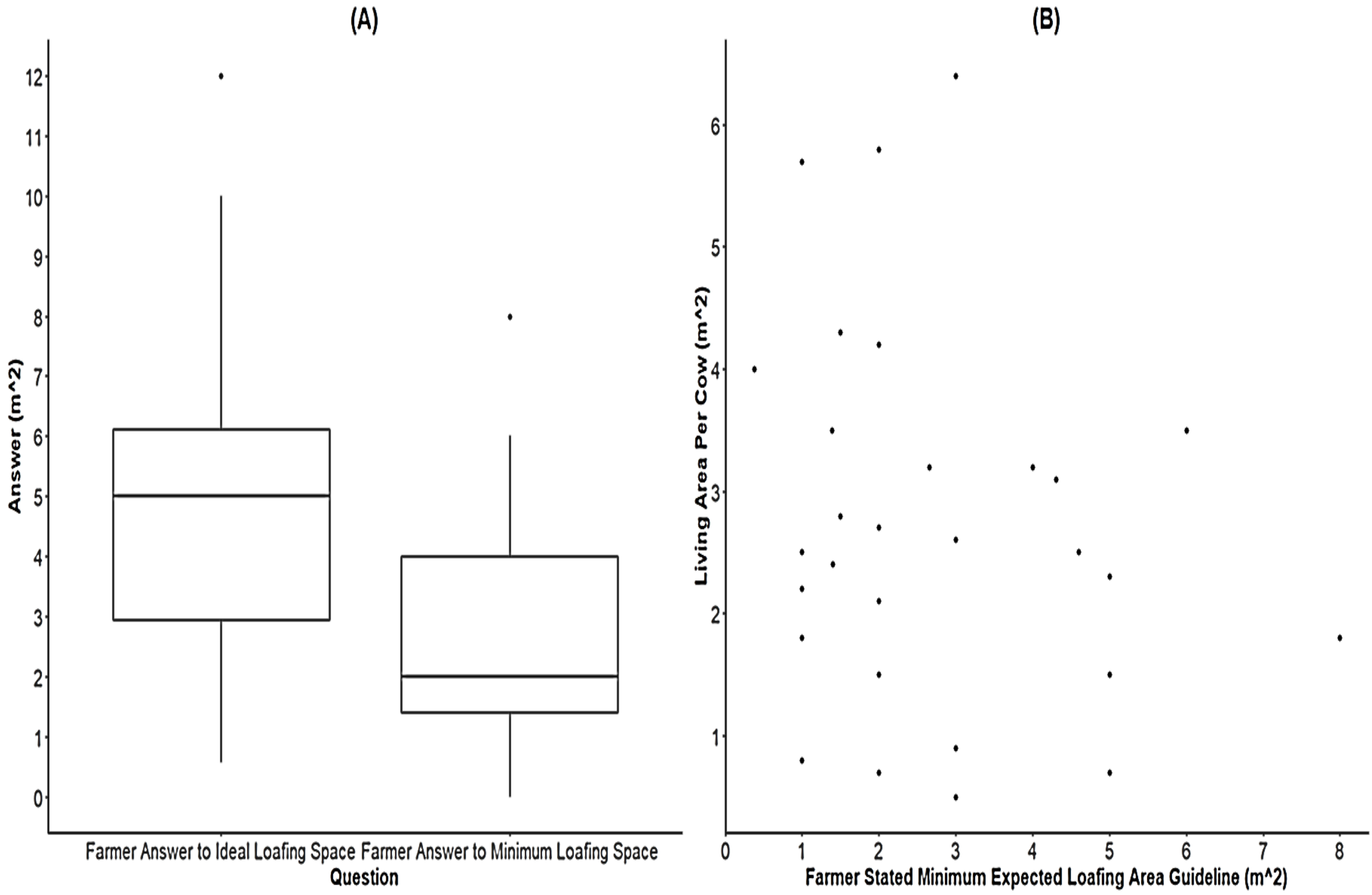
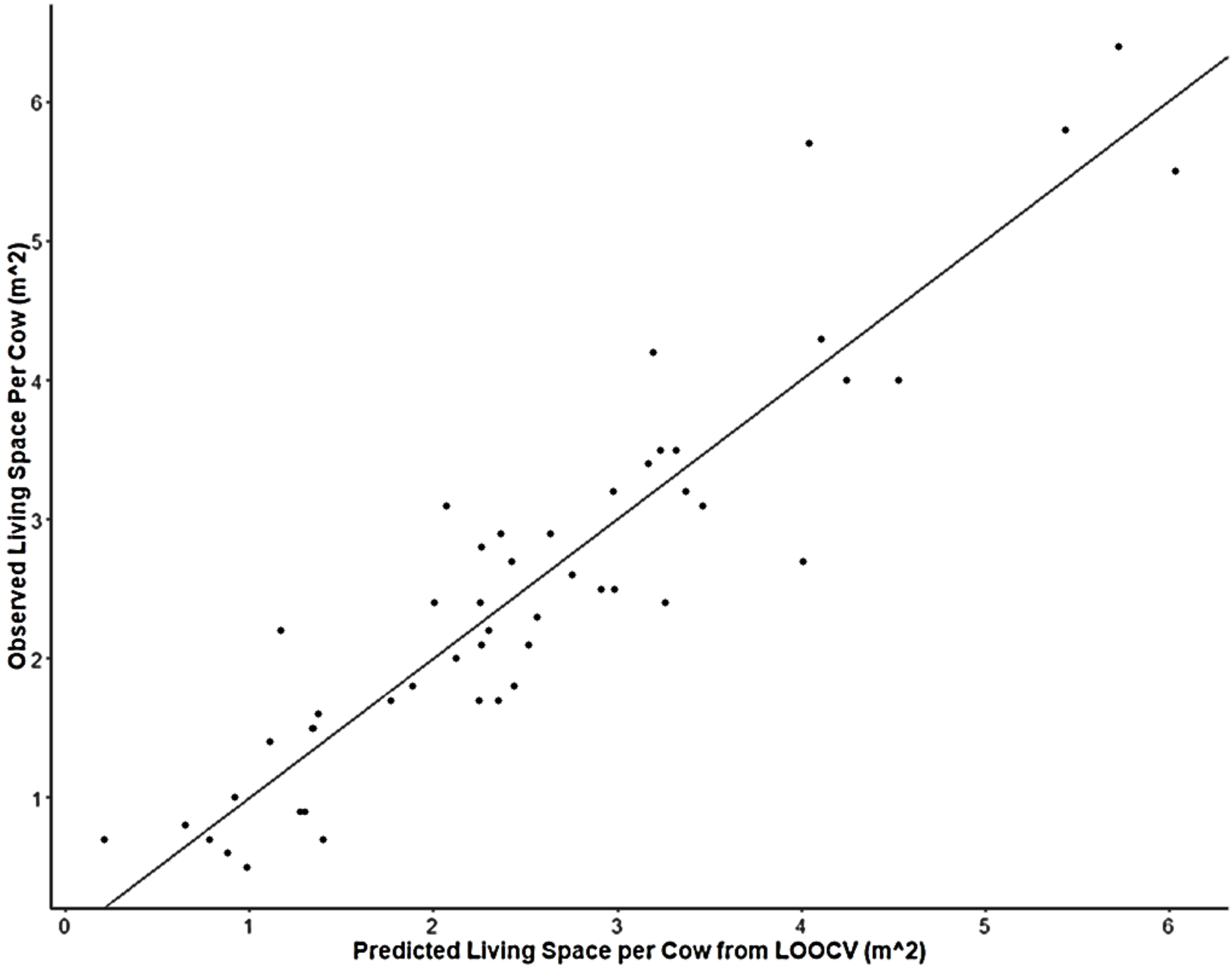

Importance Score
0
1
2
3
4
5
6
7
8
9
10
General Loafing Space Importance
Importance of Outdoor Access
Loafing Space Importance to Health
Loafing Space Importance to Productivity
Loafing Space Importance to Welfare
Farmer stated score (0-10) for the importance of loafing space on a range of outcomes

Figure 5



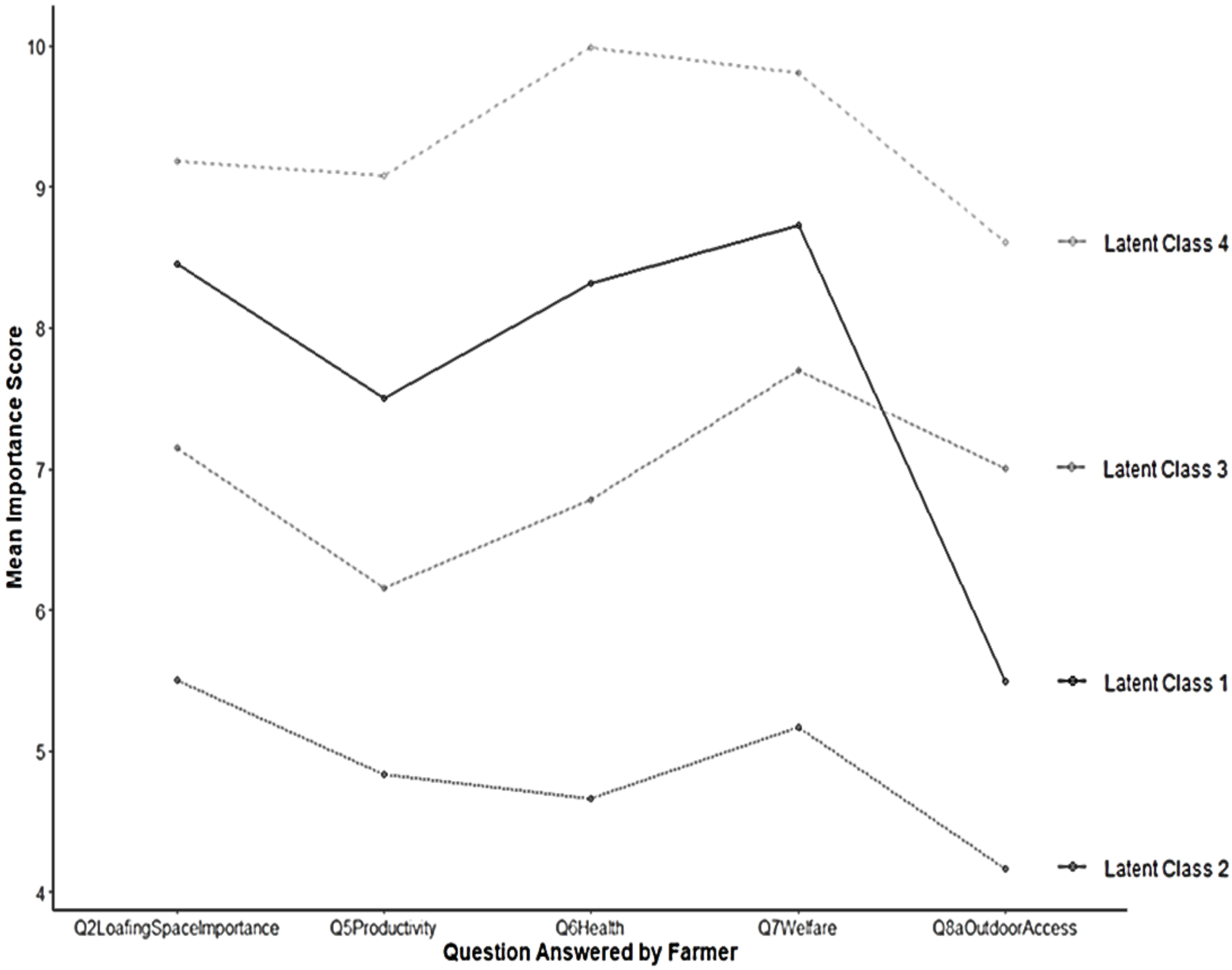
(A)
Answer (m^2)
0
1
2
3
4
5
6
7
8
9
10
11
12
Farmer Answer to Ideal Loafing Space
Farmer Answer to Minimum Loafing Space
Question
(B)
Living Area Per Cow (m^2)
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
Farmer Stated Minimum Expected Loafing Area Guideline (m^2)

Figure 6



Observed Living Space Per Cow (m^2)
1
2
3
4
5
6
0
1
2
3
4
5
6
Predicted Living Space per Cow from LOOCV (m^2)

Figure 7


Mean Importance Score
10
9
8
7
6
5
4
Latent Class 4
Latent Class 3
Latent Class 1
Latent Class 2
Q2LoafingSpaceImportance
Q5Productivity
Q6Health
Q7Welfare
Q8aOutdoorAccess
Question Answered by Farmer