Improvement of mammary gland health of dairy cows in eighty-one “sentinel herds” in England and Scotland between 2012 and 2021 – a cohort study.

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ETHICS STATEMENT

No specific Ethical and Welfare Committee approval was necessary because data were collected from existing farm records, requiring no interventions on animals. Written informed consent to use data for research purposes was obtained from all farmers at recruitment.

AUTHOR CONTRIBUTIONS

Conception, design and acquisition of funding - Andrew Bradley and Martin Green

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ABSTRACT

BACKGROUND Achieving a reduction in mastitis in dairy cows is a common industry goal but there is no recent peer reviewed record of progress in the UK.

METHODS A convenience sample of 125 herds in England and Scotland was recruited based on quality of records in 2016, willingness to participate, and representative geographical distribution. Individual cow somatic cell counts and clinical mastitis data from 2012 to 2021 were summarised annually and temporal changes analysed. Eighty-one herds had sufficient data for comparison between 2012 and 2021, for one or more parameters.

RESULTS Over this period, median incidence rate of clinical mastitis reduced from 40.0 to 21.0 cases per hundred cows per year ($P<0.001$), with improvement in both lactation and dry period indicators. Lactation new infection rate calculated from individual cow somatic cell counts fell from 8.75% to 5.95% ($P<0.001$), dry period new infection rate from 16.8% to 14.1% ($P<0.05$) and proportion of cows over 200,000 cells/ml from 20.0% to 14.3% ($P<0.001$).

LIMITATIONS Data were necessarily from herds with good records and do not provide absolute values for the industry.

CONCLUSION The findings reflect good progress over a ten-year period in a cohort of well-recorded herds and align with other national datasets.

BACKGROUND

Reducing the incidence of mastitis in the UK dairy herd is an important goal from the point of view of animal welfare, production efficiency, milk quality and environmental concerns. Mastitis is painful, reducing the nociceptive threshold [1], and reduces milk production [2] and processing quality [3,4]. Antibiotics are used in treatment of mastitis, and historically were widely used in its prevention. The emergence of antimicrobial resistance has been a driver for reduction of antimicrobial use [5]. As part of the UK antimicrobial stewardship campaign, there are specific targets for reduction of antimicrobial use in farm animals [6]. Prevention of disease is an effective contributor to avoiding antibiotic use, promoted by many national and international bodies, e.g. British Veterinary Association, Responsible Use of Medicines in Agriculture, National Mastitis Council. With relevance to climate change, compromised yields exacerbate levels of greenhouse gas generation per litre of milk produced [7], while reductions in clinical and subclinical mastitis would reduce CO_2-equivalent emissions per cow and per kg milk solids produced [8,9]. Therefore, reducing mastitis incidence in the national herd would benefit all stakeholders in the dairy industry, and the public good.

However, national figures on trends in mastitis over time are lacking because there is no central collation of national data in the UK. Some annual figures are published by the UK Agriculture and Horticulture Development Board (AHDB) and National Milk Records (NMR) and a number of consultancy firms provide annual summaries, but none of these sources follow an entirely consistent group of herds. AHDB publishes bulk milk somatic cell counts (SCC), submitted by milk purchasers, providing an overview of national trends - although bulk milk SSCs can be greatly influenced by producers with-holding high SCC milk from sale. Annual reports on production and health Key Performance

Indicators (KPI's) in 500 UK Holstein-Friesian herds recording with NMR have been published since 2010 [10]. Approximately 10% of the herds in the sample population change from year to year. Clinical mastitis indicators have been included since 2016. Performance figures are also available from a number of consultancy firms, summarising the performance achieved by registered clients. For example, Kingshay have been publishing a Dairy Costings Report since 2011, and this includes figures for Bulk Milk Somatic Cell Count (BMSCC) and clinical mastitis incidence [11,12]. Whilst these sources all reveal a general downward trend in the incidence of mastitis, there is no peer reviewed publication that reports the change in mammary gland health of a consistent group of herds over a prolonged period, using key performance indicators for clinical and subclinical mastitis.

A UK national mastitis control scheme, the DairyCo Mastitis Control Plan, later renamed the AHDB Dairy Mastitis Control Plan (DMCP), [13,14] was developed as a farm specific structured approach to mastitis control and tested in an intervention study between 2004 and 2006 [15]. It was subsequently rolled out in 2009, by training 150 veterinary surgeons and agricultural consultants as "Plan Deliverers". The number of Plan Deliverers trained had increased to 280 by the end of 2012. The actions and monitoring involved in the DMCP focus on reducing new infections. The advice is targeted by an understanding of the origin of new infections – whether these are predominantly contagious or environmental, and whether the majority originate during lactation or in the dry period [16,17]. A number of specific indicators calculated from SCC dynamics and information on new cases of clinical mastitis are used to inform this classification of mastitis "patterns". Particular importance is given to the relative influence of infection during lactation and the dry period, as revealed by both clinical and subclinical infection parameters, since this is especially helpful in understanding the origins of infection, and therefore relevant control measures [18].

In 2017, as part of DMCP activities, Quality Milk Management Services Ltd (QMMS) (Wells, UK) and the University of Nottingham (UoN) sought to recruit a sample of farms to monitor over time in order to track the direction of progress in the British herd, following the rollout of the DMCP. Funding was available to cover four prospective years and it was considered reasonable that data could be relied upon for five retrospective years. The aim of this paper is to assess the performance of a closed cohort of "sentinel herds", comparing mammary gland health indicators between 2012 and 2021, to demonstrate the trend over this period of time. The objective was to monitor performance of a consistent group of herds, over the period of time since the DMCP had become established, not to evaluate the effect of the DMCP *per se*. A number of different udder health indicators were calculated, to allow an understanding of any change in the epidemiological patterns of disease, in addition to merely reporting prevalence.

MATERIALS AND METHODS

Herd Selection

A convenience sample of herds was used to create a closed cohort. Since this was a surveillance exercise rather than a controlled experiment, the selection of the cohort was designed to provide broad geographical coverage and herd variation. The aim was to retain a total of 100 herds providing data for four prospective years. More than 100 herds were recruited to allow for natural wastage of herds over this period. Herds were initially recruited in 2017 from the list of clients using the milk recording services of

QMMS, and herds that had been involved in research projects with QMMS and UoN. Selection criteria were: willingness to participate, previous reliable electronic records of clinical mastitis cases and regular (at least quarterly) testing of the whole herd for Individual Cow Somatic Cell Count (ICSCC) in 2016. This provided 114 herds. All the selected farmers agreed to participate. The geographical locations of the herds were then mapped and compared with the distribution of the national dairy herd (in England and Scotland). To improve the match with the national distribution, veterinary practitioners in under-represented regions (Cumbria and Scotland) were approached and asked to suggest suitable herds for participation, using the same criteria. This provided a further 11 herds, reaching a total of 125. No Welsh herds with suitable records could be recruited.

No information was collected on any mastitis investigations or prevention measures taken on the farms, whether related to the DMCP, or not.

Farmers, or veterinary practitioners on their behalf, submitted electronic data either 1) in the "common data layer" (cdl) format used by all three GB milk recording organisations, or 2) from farm software that could provide the same information, or 3) as output from the TotalVet programme (QMMS Ltd and SUM-IT Computing, © AJ & KJ Bradley), created as a result of processing one or both of the previously mentioned data sources.

In order to account for seasonal variation, herd 12-month means were calculated for ten chosen summary indicators of clinical and subclinical (using ICSCC data) mastitis. The parameters (calculated using TotalVet) were selected to give the ability to detect changes in certain aspects of the epidemiological patterns of disease and are defined in Table 1. Data were collated for each year retrospectively to 2012 and prospectively up to and including 2021. Contact with participating farmers was maintained with at least two emails annually, one to request the previous year's data, and one reporting benchmarked results once analysis had been completed. Telephone calls were made when necessary to request or clarify data, and to discover the reasons for non-return of data.

Exclusion criteria

Where clinical mastitis rates lower than 5 cases per 100 cows per year were reported, the herd's clinical data were not included in the analysis, based on the assumption that mastitis cases were under-reported. This aligns with the NMR method [10]. In cases where there were large discrepancies from previous years the farmer was contacted, and where it was discovered that recording practices had changed, the farm was excluded. If a farm had fewer than four milk recordings in a calendar year, or no recordings in the last 6 months of the year, the herd was excluded from that year's analysis of SCC parameters. Where subclinical mastitis analysis returned unusual or implausible figures (e.g. 0 or 100 percent for cure rate or infection rate across the dry period) the calving pattern, recording pattern and timing of recordings in relation to calving periods were examined. Figures of 0 or 100 percent that were clearly related to the denominator because of block calving (no cows being dried off or calving) were excluded. For these reasons, the number of herds in the analysis showed some variation between parameters.

Analysis

The mammary gland health indicators were calculated for each farm for each calendar year from 2016 to 2021 inclusive, and retrospectively for each year back to 2012. Some farms lacked data for one or more of these years, therefore the number of farms that could be compared year to year was variable.

To assess progress over time, the key mammary gland health parameters in 2012 and 2021 were compared for those farms with a robust dataset for both years (based on the exclusion criteria above), using the Wilcoxon signed rank test. A non-parametric test was used to reduce the effects of outliers.

To check whether surviving herds were representative of the initial group, the Mann Whitney test was used to determine whether there were differences in the 2012 herd descriptors or mastitis parameters, between herds that were retained in the study sample and those that were lost.

RESULTS

Study population of farms recruited and available for the analysis

Table 2 details the farms that were lost from the sample between the initial recruitment in 2017, on the basis of 2016 data, and the final year of analysis in 2021, and the reasons for the attrition. Between 2017 and 2021, six dairy herds were sold and one was amalgamated with another, seven herds ceased milk recording, five produced insufficient or incomplete clinical mastitis data, four changed to an incompatible recording system, and five farmers lost contact or failed to supply data. Milk recording became too infrequent for two herds in 2021. A total of 95 farms provided data throughout the years 2016 – 2021.

Table 2 also enumerates the surviving farms that were excluded from the nine year comparison because they were found to have incomplete historical data for 2012. Five had poor quality clinical mastitis records, or none; eight had no, or insufficient ICSCC records, and one herd had an atypical herd size in 2012, as a result of culling for bovine TB. As a result of these losses a total of eighty-one herds were available for analysis over the nine year period. Missing data on either clinical or subclinical mastitis reduced the number of herds for analysis for some individual parameters to as low as 72 (Table 2).

The Mann Whitney test showed no significant differences in any of the 2012 herd descriptors or mastitis parameters, between the herds that were lost from the study, and those that were retained. This suggests that the surviving herds were representative of the initial group recruited.

Changes over time 2012 – 2021

For the herds involved in the comparison, in 2012, the mean herd size (Figure 1a) was 259 (median 201, IQR 124 - 281); in 2021 this had increased to 362 (median 287, IQR 189 - 372). Median 305-day yield (Figure 1b) increased from 8921 (IQR 7960 – 9512) to 9385 litres (IQR 8113 – 10770 litres).

All mammary gland health parameters improved significantly between 2012 and 2021. Box and whisker plots showing the median values for each parameter in 2012, 2016 (as recruited) and 2021, and the results of Wilcoxon Rank tests of differences between 2012 and 2021 are presented in Figure 1c-l. Calculated weighted BMSCC (Figure 1c) fell from 169,000 to 160,000 cells/ml ($P = 0.046$). Median clinical mastitis incidence rate (Figure 1d) decreased from 40.0 cases/100 cows/year in 2012 to 21.0 cases/100 cows/year in 2021 ($P < 0.001$). Reductions were achieved in cases of both lactation origin (Figure 1e) (2.06 to 1.51 cows in 12 affected, $P < 0.001$) and dry period origin

(Figure 1f) (0.90 to 0.49 cows in 12 affected, $P < 0.001$). Lactation new infection rate, as measured by SCC (Figure 1g), reduced from 8.75 % to 5.95% ($P < 0.001$) and dry period new infection rate (Figure 1h) from 16.8% to 14.1% ($P = 0.037$). Apparent dry period cure rate (Figure 1i) increased from 76.5 to 79.7 ($P = 0.034$) and fresh calver infection rate (Figure 1j) fell from 19.5 % to 14.9% ($P = 0.002$). The percentage of the herd over 200,000 cells/ml (Figure 1k) fell from 20.0% to 14.3% ($P < 0.001$) and the proportion of the herd chronically infected (Figure 1l) fell from 12.3% to 7.4% ($P < 0.001$).

Annual changes in selected ICSCC parameters and their relationships are illustrated in Figure 2. All the ICSCC parameters showed a general downward trend over time, with some slight year to year fluctuations. Annual medians for percentage of the herd chronically infected are plotted alongside lactation new infection rate in Figure 2a. The proportion of chronically infected cows fell from 12.3% in 2012 to 7.4% in 2021 – more steeply than the lactation new infection rate (8.75% to 5.95%). The ratio of median lactation origin infection rate to median dry period infection rate is plotted on an annual basis in Figure 2b. The ratio of median lactation new infection rate to median dry period new infection rate was 0.52:1 in 2012, and 0.42:1 in 2021. This indicated a slight shift to greater prominence of new infections (as measured by cell count) acquired in the dry period, as opposed to during lactation.

Annual mean and median values for the clinical mastitis incidence rate are illustrated in Figure 3a, and show a steady decrease over time. The relative contributions to index (first) cases of clinical mastitis from lactation and the dry period from 2012 to 2021 (annual medians across all herds) are illustrated in Figure 3b. The ratio of median measures of lactation origin cases to dry period origin cases was 2.3:1 in 2012 and

3.1:1 in 2021, indicating a slight shift of the predominant risk time away from the dry period towards lactation (less of the clinical mastitis associated with the dry period).

DISCUSSION

The study achieved the objective of providing data on key performance indicators for mammary gland health in a consistent cohort of well recorded dairy herds over a nine year period. Following national trends in mastitis is important to monitor progress over time. At the time of writing, this is the only peer reviewed study following a large and consistent cohort of UK dairy herds over such a long period. This cohort monitoring exercise demonstrated a clear improvement over a nine year period in this consistent group of herds in England and Scotland.

Comparison with other industry figures over the same period

Four other sources of information on UK mammary gland health measures are available: reports on 500 NMR herds [10] and on Kingshay Dairy Consultants' clients' data [12] are published annually. Figures provided by Kite Consulting and the milk recording organisation CIS have been included in a series of reports by the Cattle Health and Welfare Group (CHAWG) [19] but these are not available for every year, and not for the years 2012 or 2021. Although sample sizes are larger, none of the reports include as many indicators as this study, and none are peer reviewed. These sources all show an improvement during the period in question and the figures are similar for most parameters. Some comparisons are tabulated in Appendix 1. NMR reports [10] show the median BMSCC reducing from 199,000 in 2012 to 173,000 cells/ml in 2021, slightly higher figures than from these sentinel herds. Kingshay Dairy Consultants reported mean figures which are very close to those from the sentinel herds, at 181,000 cells/ml in 2012 and 161,200 cells/ml in 2021 [12]. NMR herds were smaller than the sentinel herds (NMR median 125 in 2012 and 177 in 2021, compared with 201 and 287 for the sentinel herds). However, the sentinel herd dataset did not show any relationship between herd size and mammary gland health parameters (data not shown).

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The Kingshay Dairy Costings Report, collated from farm records of Kingshay consultancy clients [12], showed a mean clinical mastitis rate of 58 and 32 cases per 100 cows per year for years ending 31 March 2012 and 2022 respectively, higher than the sentinel herds where means were 44 cases per 100 cows per calendar year for 2012 and 25 for 2021; however, the lower quartiles compare quite closely for the two sources. NMR did not publish a clinical mastitis rate until 2016, due to inconsistent or non-existent records in the initial set of 500 herds; in 2012 nearly half the 500 did not report mastitis at all. NMR began analysis of 112 identical herds with reliable clinical mastitis records in 2016. In this subset, median clinical mastitis incidence has dropped, from 43 cases per 100 cows in milk per year in 2016 to 29 in 2021 [10]. Use of the denominator “cows in milk” in the NMR calculations, rather than all cows in the herd, prevents a direct comparison with the sentinel herds; nonetheless an improving trend is demonstrated. Kite and Kingshay figures reported by CHAWG show a steady reduction in clinical cases from 2013 to 2020 [19] – see also Appendix 1.

Calculating a variety of parameters beyond a simple incidence rate of clinical cases and summary measure of BMSCC as sold gives a better understanding of epidemiological patterns and the capacity to target future interventions more appropriately. Sentinel herd data indicated a reduction in clinical case rate for index (first) cases arising in both lactation and the dry period (Figure 1e and 1f). In 2021, NMR introduced a parameter separating “cows with index case of mastitis in the first 30 days of lactation” and “index rate after 30 days in lactation” [10]. Temporal changes in these parameters are yet to be demonstrated.

Both sentinel herds and NMR herds have demonstrated a reduction in the proportion of chronically infected cows, as determined by ICSCC. Although their definitions of chronic infection differ, the figures are very similar and show the same trend. NMR used "*the percentage of all milk samples that originated from cows where the current and previous milk sample both had SCC of 200,000 or more*"*).* The definition used for chronically infected cows in the sentinel herds was recommended in 2005; using two of the last three test-day cell counts improves sensitivity of detection for cows likely to be infected with a major pathogen [17]. Both populations also show a parallel and similar reduction in the proportion of cows tested with over 200,000 cells/ml.

Both study groups demonstrate an improvement in the dry period cure rate, as measured by SCC, again with figures in quite close agreement. There has been considerable emphasis across the industry on improving dry cow management over the past nine years and this appears to have been successful. At the same time, there has been a reduction in dry cow antibiotic use, due to a more selective approach to dry cow therapy [20]. Withholding antibiotics from uninfected cows has not led to an increase in dry period new infections, suggesting that this selective approach to dry cow therapy has been successful.

Overall, industry figures indicate that between 2012 and 2021 there has been a reduction of approximately 44% in the mean reported rates of clinical mastitis, and between 11 and 13% in the national mean SCC, whether calculated from individual cow SCC, or samples of bulk milk as sold. This clear improvement is an excellent achievement by the industry. It is likely to be at least partially a result of increased focus on a structured approach to prevention of mastitis on farms. There appears to have been more progress in reducing clinical cases of dry period origin than those of lactation origin (Figure 3b). This may be linked to increased understanding of the importance of the dry period in maintaining mammary gland health, increased use of teat sealants [21] and/or the ease of altering the management of groups of dry cows compared with cows in lactation.

The balance of new infections as measured by SCC in fact shifted slightly the other way, with a trend for dry period new infections to become more evident compared with lactation new infections (Figure 2b). This could reflect changes in the pathogen profiles, with a shift towards pathogens that are more likely to cause subclinical infections during the dry period. It could also reflect better transition management and healthier cows, since subclinical mastitis could be considered a more controlled immune response compared with clinical symptoms. The differing trends in clinical and subclinical infections is a reminder that these may be due to different pathogens, have different risk factors, and/or respond differently to interventions.

Implications

These findings of improved milk quality and cow health are encouraging for the industry as a whole; producers, processors and consumers will all be benefitting from lower SCCs and levels of clinical mastitis. A reduction in clinical cases will result in less antimicrobial use; lower SCCs and fewer clinical cases will have improved production efficiency, as both clinical and subclinical mastitis are known to reduce yields. [2,3] Another outcome will be greater production per cow, which in turn will reduce greenhouse gas emissions per unit of milk produced [22].

How the improvement might have been achieved

Influential drivers over the last nine years include pressure from milk buyers, pressure to reduce antibiotic use, and economic pressures to produce milk more efficiently. Better control of cell counts and clinical mastitis is likely to have been achieved, at least partly, as a result of steadily increasing awareness that improvements in mammary gland health require a farm specific approach, based on an understanding of SCC dynamics, the origin of clinical cases, and the epidemiological “mastitis pattern” in the herd. Such an approach has been advocated, and a structured method available, in the form of the Dairy Mastitis Control Plan since 2009 [13]. Since 2020 an accessible mammary gland health monitoring framework and related advisory resources have been promoted under the QuarterPRO initiative [18] and this may also have played a part in raising awareness of relevant control measures and the importance of monitoring mammary gland health.

It is possible that the reliability of recording of clinical cases varied between 2012 and 2021. Some farms may have improved their recording, while on others the quality of records may have deteriorated. The direction of any possible bias introduced by these possibilities cannot be determined. In the industry as a whole, an increasing emphasis has been put on recording, by milk buyers and assurance schemes. The imposition of a ceiling level of mastitis incidence for suppliers to certain milk pools may have encouraged some under-reporting, but it is considered unlikely that a deterioration in recording would have been great enough to cause a reduction in incidence of the magnitude demonstrated.

To achieve further progress will require continuing reduction in both the incidence of new infections (based on an understanding of the origin of these infections), and the proportion of chronically infected cows, through cure or culling.

Comparisons with long-term monitoring exercises in other countries

There are a limited number of other reports of monitoring mastitis at a national level over a number of years. In The Netherlands, Lam and others [23] reported cell count and clinical mastitis measures from a cohort of 116 dairy herds before and after the introduction of a national mastitis control plan. The incidence rate of clinical mastitis fell significantly from 33.5 to 28.1 quarter cases per 100 cow years at risk between 2004 and 2009. However, the prevalence of subclinical mastitis (average annual percentage of herd with SCC > 200,000 cells/ml, estimated using negative binomial models) did not alter significantly (23.0 in 2004 and 22.2 in 2009). Australia has had a national mastitis control campaign (Countdown Downunder) running since 1998 [24] but there are no publications reporting its impact other than a reference to SCC levels in milk supplied to dairies 2000 to 2019 [25, 26]. Scandinavian countries have been implementing udder health improvement schemes and centralising data for many years, and SCC data and incidence rate of treatments for clinical mastitis for 1990 – 2018 are summarised by Rajala-Schultz and others [27]. Graphical data suggest that in 2012 clinical mastitis treatment rates ranged from 0.32 cases per cow year at risk in Denmark to 0.15 cases per cow year at risk in Finland. By 2018, the latest year reported on in this paper, treatment rates had dropped to approximately 0.19 cases per cow year at risk in Denmark, and 0.1 in Finland. This incidence rate is lower than for our sentinel herds, but these figures specifically report treatments and there has been a strong Scandinavian campaign for reducing treatment [27]. In Canada a national cohort of dairy farms was established to provide a “data collection platform" for epidemiological data. Ninety-one farms provided samples and data, but only for a two-year period. Farms participating in Dairy Health Improvement (DHI) recording were selected to give an appropriate national representation of BMSCC strata – (low, medium and high), and housing systems [28]. The US Council on Dairy Cattle Breeding publish annual statistics on SCC from DHI herds online [29] and report steady progress. Average ICSCC was 200,000 cells/ml in 2012 and 179,000 cells/ml in 2021 (a reduction of 10.5%), but no other udder health measures are reported.

Limitations

It is possible that the data included information bias related to the accuracy of reporting of clinical mastitis in the electronic datasets. The most likely situation would be under-reporting, although over-reporting could occur if treatments of subclinical cases were included as “mastitis events”. Exclusion of reports of fewer than five cases of clinical mastitis per hundred cows per year was intended to guard against extreme under-reporting. The evidence of progress provided by this study is limited to a well recorded population. Farms with contact with QMMS / UoN might possibly be more likely to make progress as a result of receiving specialist advice or input from research projects. However, ten percent of the herds were recruited via veterinary practitioners and had no direct contact with these two organisations. Farms that do not record may be poorer performers - but this can never be proven. For this reason, the sentinel herd study was not designed to quantify an absolute value for UK annual mastitis metrics, but rather a trend over time. There are national figures that suggest that BMSCC (as sold) has been reducing steadily over the last nine years. Figures collated on milk collected from farms by dairies representing two-thirds of UK production show an average SCC (measured on bulk milk at point of collection) of 186,000 cells/ml in 2012 and 164,000 cells/ml in 2021, a reduction of 11.8% [30].

It is possible that receipt of the benchmarked results stimulated some farmers into actions to improve mastitis control measures, but we have no evidence of this. Only a very few farmers acknowledged receipt of the results or contacted the study team having received them.

Study population

The herds in the sentinel group were larger than the UK averages reported by AHDB, of 125 in 2012 and 160 in 2021 [30]. This could be explained by very small herds being less likely to milk record regularly. There was a tendency for larger herds to survive and surviving herds to have been higher yielding in 2012 (2012 median 305 day yield for "lost herds" =8578 kg, for survivors 8921). However, this did not appear to introduce a selection bias for survival in terms of clinical mastitis rates. Statistically, no mastitis parameters differed between the herds that were lost from the cohort and those that survived. For example, the 2012 median clinical mastitis rates for lost farms and surviving farms were very similar - clinical mastitis for "lost herds" 38.5 cases/100 cows /year; for survivors 40.0. Surviving herds did have a numerically lower median calculated BMSCC in 2012 ("lost" herds 200,000 cells/ml; survivors 169,000 cells/ml).

Loss of farms from the study

Herds were lost from the initial cohort largely due to sale, or deterioration in quality of records. Figures from AHDB suggest that the national UK population of dairy herds reduced by 17 percent between 2014 and 2021 (figures for 2012 are not available). The study cohort therefore showed a better survival rate than the UK population as a whole. Four herds were lost as a result of transferring to recording systems from which the necessary data could not be easily extracted. This illustrates the benefits of compatibility between electronic recording systems and the drawbacks of exclusive "closed" recording systems. Particularly disappointing was the loss of farms through a deterioration in record keeping, frequently as a result of the adoption of a policy of not treating all cases of mastitis, and recording only treatments. Reasons for this included farms changing to “antibiotic free” production or using culture based algorithms to make treatment decisions, and/or withholding treatment from cows considered to have a poor chance of cure. Whenever making a change in treatment protocol, it is essential that farms continue to record all cases of clinical mastitis to enable robust monitoring of the consequences.

In conclusion, there has been encouraging progress in mammary gland health between 2012 and 2021 in this cohort of well-recorded herds, which we consider to be representative of the full population of milk recording herds. It is likely that at least some of this progress has been as a result of focussed individual approaches to tackling problems, guided by the DMCP and latterly by the QuarterPRO initiative. Other contributing factors include bonus and penalty payments based on BMSCC, targets for clinical mastitis imposed by some milk buyers, realisation of the financial implications of poor mammary gland health and pressure to reduce antimicrobial use.

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CONFLICT OF INTEREST

The authors declare they have no financial or non-financial conflicts of interest.

ETHICS STATEMENT

No specific Ethical and Welfare Committee approval was necessary because data were collected from existing farm records, requiring no interventions on animals. Written informed consent to use data for research purposes was obtained from all farmers at recruitment.

DATA AVAILABILITY STATEMENT

Data not shared – permission to publish individual farm data was not granted by farmers.

REFERENCES

1. Fitzpatrick CE, Chapinal N, Petersson-Wolfe CS, DeVries TJ, Kelton DF, Duffield TF, et al. The effect of meloxicam on pain sensitivity, rumination time, and clinical signs in dairy cows with endotoxin-induced clinical mastitis. J Dairy Sci [Internet]. 2013;96(5):2847–56. Available from: http://dx.doi.org/10.3168/jds.2012-5855
2. Rajala-Schultz PJ, Gröhn YT, McCulloch CE, Guard CL. Effects of clinical mastitis on milk yield in dairy cows. J Dairy Sci. 1999;82(6):1213–20.
3. Bobbo T, Cipolat-Gotet C, Bittante G, Cecchinato A. The nonlinear effect of somatic cell count on milk composition, coagulation properties, curd firmness modeling, cheese yield, and curd nutrient recovery. J Dairy Sci [Internet]. 2016;99(7):5104–19. Available from: http://dx.doi.org/10.3168/jds.2015-10512
4. Franceschi P, Faccia M, Malacarne M, Formaggioni P, Summer A. Quantification of cheese yield reduction in manufacturing Parmigiano reggiano from milk with non-compliant somatic cells count. Foods. 2020;9(2).
5. O.Neill J. Tackling drug-resistant infections globally:Final report and recommendataions. The Review on antimicrobial resistance. 2016. Available from: https://amr-review.org/sites/default/files/160518_Final paper_with cover.pdf
6. FAO and VMD. Tackling antimicrobial resistance and antimicrobial use [Internet]. 2022. Available from: https://doi.org/10.4060/cc0927en
7. Özkan Gülzari Ş, Vosough Ahmadi B, Stott AW. Impact of subclinical mastitis on greenhouse gas emissions intensity and profitability of dairy cows in Norway. Prev Vet Med. 2018;150(November 2017):19–29.
8. Bell MJ, Garnsworthy PC, Stott AW, Pryce JE. Effects of changing cow production and fitness traits on profit and greenhouse gas emissions of UK dairy systems. J Agric Sci. 2015;153(1):138–51.
9. von Soosten D, Meyer U, Flachowsky G, Dänicke S. Dairy cow health and greenhouse gas emission intensity. Dairy. 2020;1(1):3.
10. Hanks J, Kossaibati M. Key Performance Indicators for the UK national dairy herd: A study of herd performance in 500 Holstein/Friesian herds for the year ending 31st August 2021. 2021;(August):1–48. Available from: https://www.interherdplus.com/wp-content/uploads/2022/02/NMR500Herds-2021Final.pdf accessed 22/8/2023
11. Rowland K. Impact of milk prices on mastitis costs. Proc Br Mastit Conf. 2022;21–2.
12. Kingshay. Dairy Costings Focus Annual Report [Internet]. 2021. Available from: https://www.kingshay.com/wp-content/uploads/Dairy_Costings_Focus_Report_-2021_2325_300621.pdf
13. Bradley AJ, Breen JE, Hudson CD, Green MJ. The DairyCo Mastitis Control Plan:current progress with implementing a national mastitis control scheme. Cattle Pract. 2009;17(3):184–9.
14. Bradley, A. J.,Green, M.J., Breen, J.E.., Hudson CD. DairyCo Mastitis Control Plan – three year report 2008 - 2012. Final report on the delivery of the DMCP,

training events and farm impact of plans [Internet]. 2012. Available from: https://www.mastitiscontrolplan.co.uk/images/Public/final_dmcp_report_2012.pdf

15. Green MJ, Leach KA, Breen JE, Green LE, Bradley AJ. National intervention study of mastitis control in dairy herds in England and Wales. Vet Rec. 2007;160(9):287–93.

16. Green MJ, Green LE, Medley GF, Schukken YH, Bradley AJ. Influence of dry period bacterial intramammary infection on clinical mastitis in dairy cows. J Dairy Sci [Internet]. 2002;85(10):2589–99. Available from: http://dx.doi.org/10.3168/jds.S0022-0302(02)74343-9

17. Bradley A, Green M. Use and interpretation of somatic cell count data in dairy cows. In Pract. 2005;27(6):310–5.

18. Green M., Breen JE, Leach KA, Bradley AJ. “Quarter PRO”: a new initiative for optimising udder health. Cattle Pract. 2018;26(2):57–60.

19. GB Cattle Health and Welfare Group (CHAWG) 5th Report November 2020. https://projectblue.blob.core.windows.net/media/Default/Beef%20&%20Lamb/CHAWG2020-Report5_3613_171120_WEB.pdf Accessed 20/3/2023.

20. Responsible Use of Medicines in Agriculture Alliance. RUMA Targets Task Force 2: Two Years On [Internet]. 2022. Available from: https://www.ruma.org.uk/wp-content/uploads/2022/11/RUMA-TTF-Report-2022-FINAL-FINAL.pdf

21. McCubbin KD, de Jong E, Lam TJGM, Kelton DF, Middleton JR, McDougall S, et al. Invited review: Selective use of antimicrobials in dairy cattle at drying-off. J Dairy Sci. 2022;105(9):7161–89.

22. Mostert PF, Bokkers EAM, de Boer IJM, van Middelaar CE. Estimating the impact of clinical mastitis in dairy cows on greenhouse gas emissions using a dynamic stochastic simulation model: a case study. Animal [Internet]. 2019;13(12):2913–21. Available from: http://dx.doi.org/10.1017/S1751731119001393

23. Lam TJGM, Van Den Borne BHP, Jansen J, Huijps K, Van Veersen JCL, Van Schaik G, et al. Improving bovine udder health: A national mastitis control program in the Netherlands. J Dairy Sci. 2013;96(2):1301–11.

24. Penry JF. Countdown Downunder: development led innovation in a national mastitis control program. In: Hogeveen H, Lam TJGM, editors. Udder Health and Communication [Internet]. 2011. p. 33–42. Available from: https://doi.org/10.3920/978-90-8686-742-4_2

25. Brightling P, Dyson RD, Hope AF, Penry JF. A national programme for mastitis control in Australia: Countdown Downunder. Ir Vet J. 2009;62:S52–8.

26. Morton J. National Bulk Milk Cell Count (BMCC) Statistics 2000 - 2019. 2021. Available from: https://cdn-prod.dairyaustralia.com.au/-/media/project/dairy-australia-sites/national-home/resources/2021/12/22/national-bulk-milk-cell-count-2000-19/national-bulk-milk-cell-count-bmcc-statistics-2000-to-2019.pdf?rev=151682da789345e4a46c6669efbc3f3c. Accessed 30/8/2023

27. Rajala-Schultz P, Nødtvedt A, Halasa T, Persson Waller K. Prudent use of antibiotics in dairy cows: the Nordic approach to udder health. Front Vet Sci. 2021;8(March).

28. Reyher KK, Dufour S, Barkema HW, Des Côteaux L, DeVries TJ, Dohoo IR, et al.

The National Cohort of Dairy Farms - A data collection platform for mastitis research in Canada. J Dairy Sci [Internet]. 2011;94(3):1616–26. Available from: http://dx.doi.org/10.3168/jds.2010-3180

29. Norman, HD, Guinan, FL, Megonigal, JH, Durr J. Milk somatic cell count from Dairy Herd Improvement herds during 2021. Counc Dairy Cattle Breed Res Reports [Internet]. 2022;2. Available from: https://queries.uscdcb.com/publish/dhi/current/sccrpt.htm

30. AHDB milk hygiene figures https://ahdb.org.uk/dairy/gb-milk-hygiene accessed 2/5/2023.

Table 1 Mammary gland health parameters used in monitoring

Cow clinical mastitis incidence rate (/100 cows per year): The incidence rate of all cow-cases of clinical mastitis per 100 cow years (all cows in the herd in lactation 1 or above, i.e.including lactating and dry cows)
Dry period origin clinical mastitis rate (in 12): The proportion of cows affected with a new (first or 'index') case of clinical mastitis **within 30 days of calving**, out of every 12 cows that are 'at-risk' (*i.e.* cows that are eligible)
Lactating period origin clinical mastitis rate (in 12): The proportion of cows affected with a new (first or 'index') case of clinical mastitis **after 30 days of lactation**, out of every 12 cows that are 'at-risk' (*i.e.* cows that are eligible)
Calculated bulk milk somatic cell count (SCC) ('000/ml): The herd weighted average SCC at each milk recording - calculated from Individual cow somatic cell counts and yields
% of the herd 'chronically infected': percentage of cows in the herd that remain above a threshold of 200,000 cells/ml on more than one occasion in the last three recordings
% of the herd >200,000 cells/ml: percentage of cows in the herd that are above a threshold of 200,000 cells/ml at the milk recording
Lactation new intra-mammary infection (IMI) rate (%): The rate of new infection as measured by an increase in somatic cell count for lactating cows from below to above a 200,000 cells/ml threshold between successive milk recordings
Dry period new intra-mammary infection (IMI) rate (%): The rate of new infection (as measured by an increase in somatic cell count from below to above a 200,000 cells/ml threshold) across the dry period (*i.e.* 'low' cell count at drying-off but 'high' cell count (>200,000 cells/ml) after calving – calculated for cows where the first recording occurred within 30 days after calving)
'**Apparent' dry period cure rate (%):** The rate of cure of intramammary infection as measured by a decrease in somatic cell count across the dry period (*i.e* >200,000 cells/ml at drying-off but 200,000 cells/ml or below, after calving - calculated for cows where the first recording occurred within 30 days after calving)
Fresh calver infection rate (%): The proportion of cows and heifers with SCC >200,000 cells/ml at the first recording after calving, where this occurred within 30 days after calving

Table 2 Reasons for loss of herds from the cohort of 125 recruited in 2017 on the basis of 2016 data

Year of loss	Reasons for loss	Herds lost	Herds remaining
2012	Not milk recording in 2012	8	
	Poor quality data in 2012	5	
	Unrepresentative year in 2012	1	
	Total	14	111
2017	Lost contact	2	
	Total	2	109
2018	Poor quality data	1	
	Stopped recording all clinical cases	2	
	Total	3	106
2019	Ceased milk recording	1	
	Incompatible new herd data system	2	
	Poor quality data	1	
	Sold herd	4	
	Total	8	98
2020	Ceased milk recording	3	
	Incompatible new herd data system	2	
	Lost contact	3	
	Merged two herds	1	
	Sold herd	1	
	Stopped recording all clinical cases	1	
	Total	11	87
2021	Ceased milk recording	3	
	Insufficient milk recording	2	
	Sold herd	1	
	Total	6	81
	Reasons for reductions in this number below 81 for individual parameters		
	Lacking yields to calculate Bulk Milk Somatic Cell Count	5	76
	Had reliable clinical mastitis data but lacked regular Individual Cow Somatic Cell Count (SCC) data	9	72
	Had Individual Cow SCC data but lacked reliable clinical mastitis data	3	78
	Lacking robust dry period SCC data due to timing of milk recordings in relation to calving pattern.	6	75

LIST OF FIGURES

APPENDIX 1

Other reports of Key Performance Indicators for clinical and subclinical mastitis

Abbreviations:

CIS – Cattle Information Service (UK)

DHIA – Dairy Herd Improvement Association (US)

ICSCC – individual cow somatic cell count

NMR – National Milk Records (UK)

SCC – somatic cell count

SH – Sentinel Herds (UK)

Kingshay and Kite Consulting figures taken from summary in the Fifth CHAWG Report https://ahdb.org.uk/knowledge-library/gb-cattle-health-welfare-group-fifth-report-2020 or direct from Kingshay Costing Focus Reports reports https://www.kingshay.com/dairy-costings/dairy-costings-focus/

NMR figures taken from annual reports on 500 herds e.g. Hanks & Kossaibati 2022 https://www.interherdplus.com/wp-content/uploads/2022/02/NMR500Herds-2021Final.pdf accessed 22/8/2023

Bulk milk somatic cell count (cells/ml) as sold or calculated from individual cow recordings of yield and individual cow somatic cell count (ICSCC)

Bulk milk SCC	2012	2021
Sentinel herds (from ICSCC weighted by yield)	Mean 184,900, Median 169,000, IQR 127,000 - 229,000	Mean 161,200, Median 160,000, IQR 119,500 - 190,000
NMR bulk milk SCC (from ICSCC)	Median 199,000, IQR 162,000 - 239,000	Median 173,000 IQR 136,000 – 219,000
Kingshay - Bulk milk as sold	Mean 181,000	Mean 161,000
AHDB figures – Bulk milk as sold	186,000	164,000
USDA DHIA herds (mean ICSCC)	200,000	179,000

Other subclinical mastitis Key Performance Indicators from other sources for selected years (as available) in comparison with Sentinel Herd (SH) figures.

Dry period new infection rate (%)

	NMR median (n = 500)	CIS mean (n = 2500)	SH mean (n = 75)	SH median
2021			15.2	14.3
2019	15	14	14.4	13.2
2018	15	13	15.5	14.6
2017	14	14	15.1	14.5
2012			17.5	16.6
2010	16	10		

Dry period cure rate (%)

	NMR median (n = 500)	CIS mean (n = 2500)	SH mean (n = 74)	SH median
2021	77		79.4	79.8
2019	77	71	74.6	76.9
2018	76	72	78.7	78.9
2017	77	75	80.2	80.4
2012	73		76.1	76.5
2010	74	75	76.5	

Lactation new infection rate (%)

	NMR median (n = 500)	CIS mean (n = 2500)	SH mean (n = 78)	SH median
2021			6.4	5.6
2019	6	7	6.6	6.0
2018	7	7	6.2	6.0
2017	7	8	6.7	6.7
2012			8.8	8.7
2010		8		

Lactating period chronic infections (%)

	NMR median (n = 500)	CIS mean (n = 2500)	SH mean (n = 77)	SH median
2021	8		8.4	7.4
2019	9	15	8.5	7.8
2018	10	15	8.9	8.1
2017	10	10	8.9	7.7
2012			12.9	12.3
2010	14	18		

Clinical cases of mastitis 2012 – 2021 (cases per 100 cows per year)

	Kingshay	**Kite Consulting**	**Sentinel Herds**		**NMR between 252 and 262 herds**	**NMR 112 identical herds**
	mean	mean	mean	median	median	median
2021	32		25	21	27	29
2020	36	26	30	26	28	
2019	39	28	30	26	30	
2018	39	31	30	26	31	
2017	41	31	34	28	32	
2016	49	36	39	37	36	43
2015	50	36	40	36		
2014	52	42	42	35		
2013	58	43	41	38		
2012	58		45	40		