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Culling from the herd's perspective—Exploring herd-level management factors and culling rates in Québec dairy herds

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ABSTRACT

The relationship between cows' health, reproductive performance or disorders and their longevity is well demonstrated in the literature. However these associations at the cow level might not hold true at the herd level, and herd-level variables can modify cow-level outcomes independently of the cows' characteristics. The interaction between cow-level and herd-level variables is a relevant issue for understanding the culling of dairy cows. However it requires the appropriate group-level variables to assess any contextual effect. Based on 10 years of health and production data, the objectives of this paper are:(a) to quantify the culling rates of dairy herds in Québec; (b) to determine the profiles of the herds based on herd-level factors, such as demographics, reproduction, production and health indicators, and whether these profiles can be related to herd culling rates for use as potential contextual variables in multilevel modelling of culling risk. A retrospective longitudinal study was conducted on data from dairy herds in Québec, Canada, by extracting health information events from the dairy herd health management software used by most Québec producers and their veterinarians. Data were extracted for all lactations taking place between January 1st, 2001 and December 31st, 2010. A total of 432,733 lactations from 156,409 cows out of 763 herds were available for analysis. Thirty cow-level variables were aggregated for each herd and years of follow-up, and their relationship was investigated by Multiple Factor Analysis (MFA). The overall annual culling rate was 32%, with a 95% confidence interval (CI) of [31.6%,32.5%]. The dairy sale rate by 60 days in milk (DIM) was 3.2% [2.8%,3.6%]. The annual culling rate within 60 DIM was 8.2% [7.9%,8.4%]. The explained variance for each axis from the MFA was very low: 14.8% for the first axis and 13.1% for the second. From the MFA results, we conclude there is no relationship between the groups of herd-level indicators, demonstrating the heterogeneity among herds for their demographics, reproduction and production performance, and health status. However, based on Principal Component Analysis (PCA), the profiles of herds could be determined according to specific, single, herd-level indicators independently. The relationships between culling rates and specific herd-level variables within factors were limited to livestock sales, proportion of first lactation cows, herd size, proportion of calvings occurring in the fall, longer calving intervals and reduced 21-day pregnancy rates, increased days to first service, average age at first calving, and reduced milk fever incidence. The indicators found could be considered as contextual variables in multilevel model-building strategies to investigate cow culling risk.

1. Introduction

In the dairy cow production cycle, a cow will eventually reach a point where she is no longer an economic asset for the producer, and a decision will have to be made whether to keep or remove her from the herd. Culling is the removal of a cow from the herd, most often replacing her with another one, probably a first-lactation heifer (Hadley et al., 2006). Culling rates greater than 30% are common in American and Canadian dairy herds (Fetrow, 1987; Radke and Lloyd, 2000; Smith et al., 2000), despite common recommendations to lower cull rates. These higher cull rates can sometimes be viewed, wrongly or not, as a sign of management failure (Eicker and Fetrow, 2003).

A great deal of the literature on the culling of dairy cows looks at the cow-level relationship between longevity and either health (Beaudeau

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et al., 1994, 2000; Gröhn et al., 1998; Rajala-Schultz and Gröhn, 1999a) or reproductive performance and disorders (Rajala-Schultz and Gröhn, 1999b; Schneider et al., 2007; De Vries et al., 2010), demonstrating their effects on cow culling risk. However, these cow-level associations may not hold true at the herd level, i.e. herd-level disease rates, production, or reproduction performance, might not illustrate the same relationships with culling events as seen at the cow-level. Indeed, group-level variables can affect or modify individual-level outcomes independently of the characteristics of the individuals (Diez Roux, 1998). Therefore there is an interest in integrating the population context into individual-level analyses to untangle the relationships between the variables on various levels (Guthrie and Sheppard, 2001). Multilevel models can achieve this goal by decomposing the variability across hierarchical levels (Stryhn and Christensen, 2014).

Even though a large herd effect on the risk of being culled has been mentioned by a few studies (Beaudeau et al., 1995; Emanuelson and Oltenacu, 1998; Gröhn et al., 1998), we could find only three studies that assessed the association between herd culling rates and some herd-level management factors (Batra et al., 1971; Smith et al., 2000; Mohd Nor et al., 2014). While all three studies found a positive relationship between the culling rate and average herd production, the results were discordant regarding the association with herd size, from no effect (Batra et al., 1971), to increased cull rates in larger herds (Smith et al., 2000), or in smaller ones (Mohd Nor et al., 2014). Mohd Nor et al. (2014) also found higher cull rates in herds with worse reproduction performance parameters and higher average somatic cell counts (SCC). But several more herd characteristics can potentially modify the cow culling risk, such as the availability of heifers, milk quotas, the farmer's attitude towards risk and uncertainty, the milk and beef market, etc. (Beaudeau et al., 2000) The combination of cow- and herd-level factors is a relevant issue for the understanding of the culling of dairy cows. However, it requires the appropriate group-level variables to assess any contextual effect.

Demographics, reproduction, production, and health factors are, together, determinants in the administration of a farm enterprise. Susser (1994) defined a contextual variable as an aggregate-level variable derived from a compilation of individual attributes having an effect that is beyond the sum of their parts. We hypothesize that contextual variables grouped into the four domains above (demographics, reproduction, production, health) could define certain types of herds and be related to herd culling rates. Many variables can be constructed within these domains, but the domains might not provide the same number of variables, and they can potentially be correlated. Multiple Factor Analysis (MFA; Escofier and Pagés, 1994), which identifies the relationship between several groups of variables, can be used in such a context. It is a generalization of Principal Component Analysis (PCA) applied to all variables, within which each group of variables is weighted, thus resulting in a reduced number of uncorrelated variables. Principal Component Analysis is a suitable method to determine a parsimonious set of factors that describe the structural relationships among variables. In MFA, common factors are generated for both variables and groups of variables, allowing the MFA to take into account the heterogeneity of the groups of variables (Abdi et al., 2013). MFA represents observations (here, herds) in the Euclidian space according to their variables. These variables are reduced to fewer latent variables (i.e. factors) which best capture the amount of variance (i.e. inertia) between the original variables (Bécue-Bertaut and Pagès, 2008; Gorsuch, 2014). A factor is therefore a linear combination of the variables, characterized by its eigenvalues indicating the variance of the data it represents. The main variables and groups of variables that differentiate herds can therefore be identified, and their commonalities and discrepancies analysed. The identification and characterization of different contextual profiles of herds would help the understanding of farm management and decision-making in the context of the culling decision, providing information on the required group-level variables to include in multilevel analysis.

Based on 10 years of retrospective dairy cow health and production data, the objectives of this paper are: (a) to quantify the culling rates of Québec dairy herds; (b) to determine the profiles of herds based on herd-level factors such as demographics, reproduction, production and health indicators, and whether these profiles can be related to herd culling rates for use as potential contextual variables in multilevel modelling of culling risk.

2. Materials and methods

2.1. Dataset

A retrospective longitudinal study was conducted on data from dairy herds in the Province of Québec, Canada, by extracting health information events from *DSA Laitier* (DSAHR Inc., Saint-Hyacinthe, QC, Canada), the dairy herd health management software used by more than half of producers in Québec and their veterinarians.[1] This program uses clearly defined health definitions, ensuring that producers and veterinarians record the same health conditions, using the same definitions. Veterinarian enters health conditions into the herd DSA database, as well as producers for which data are then reviewed by their veterinarian at the herd visit. All information is transferred into the centralized DSA database by the herd veterinarian, which is then validated. Veterinarians are therefore closely involved in the diagnosis of the disease conditions, as well as their recording and reporting. Treatments are only available through the herd veterinarian, even if it can be provided to the animals by the dairy producer. A purposive sample was created by extracting data for all lactations taking place between January 1st, 2001 and December 31st, 2010, keeping herds that had data for a minimum of three consecutive years with *DSA Laitier* within the study period and for which at least one culling was recorded in order to remove herds with gross under-reporting (see flowchart in Fig. 1). Production data were obtained from the only Québec dairy herd improvement (DHI) service provider (Valacta, Sainte-Anne-de-Bellevue, QC, Canada). The health and production data were matched based on herd- and cow-level identification. If not successful, further matching was tried based on birth date, calving dates, and health and production history. Only herds for which at least 95% of the lactations from the health dataset could be matched with data from the production dataset were kept. Herds with less than 30 animal-years for a given year were removed for that year of follow-up. Cows were included for their full interval from calving to subsequent calving, or culling. Cows with calving intervals, or interval between last calving and the end of data, longer than 580 days were censored at their last calving date. If this censoring resulted in their first calving date, the cow was dropped. Cows leaving their herd on their calving date were assigned one day of follow-up.

The following herd-level variables were created from the cow-level data, for each herd and year of follow-up, and defined under the following groups of indicators:

Demographics indicators. Mean annual herd size by farm was computed as animal-years. Proportion of first lactation cows in herd was calculated as the ratio between the animal-years of first lactation cows and the total animal-years. The difference between the incidence of sales (reported culling reason: sale for milk) and the incidence of animals purchased gave the livestock sale indicator. Proportion of calvings occurring in the fall was computed as the ratio between the number of calvings between August and November and the total number of calvings for the year. Additional milk can be produced during these months despite the regulation imposed by the milk quota system in place in Québec.

Reproduction performance indicators Herd calving intervals were determined as the median time for the interval between a calving and the

[1] http://www.dsahr.ca.

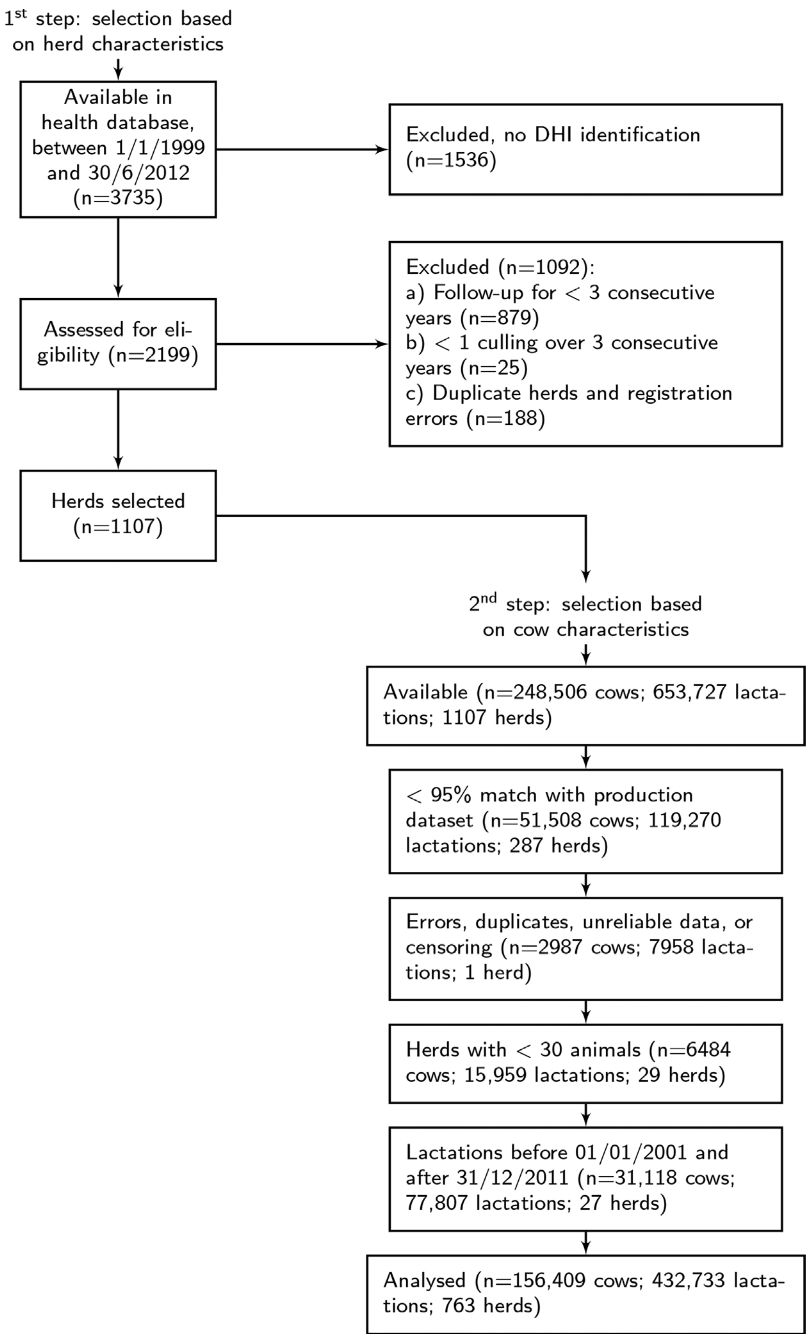

Fig. 1. Flowchart of herds and cows selection.

next one. Median days to first service was counted as the time between calving and first insemination. The 21-day pregnancy rate was computed as the incidence of pregnancies per 21 days (making allowance for a 50-day voluntary waiting period). For heifers, the one measure of reproductive performance was the mean age at first calving.

Production indicators. Median real 305-day milk production (fat-protein corrected), fat, and protein yields from the production dataset were used. Peak milk production for heifers and cows was derived from monthly tests, as the maximum production within 90 days in milk. Milk production persistence was computed from the Wilmink equation (Wilmink, 1987) for primiparous and multiparous cows separately. Peak variation was defined as the coefficient of variation (CV) of peak production for heifers and cows separately. Persistence variation was defined as the difference between the 75th and the 25th percentiles of the persistence indicators determined above for heifers and cows separately.

Health indicators. Health indicators were calculated as proposed by Kelton et al. (1998): the ratio between the number of lactations with one (or more) cases of the disease and the number of lactations at risk. The incidences of the following diseases were computed: milk fever (MF; for all parities and parity 3 and greater), retained placenta (RP), endometritis (MET, as a reproductive health event occurring between 21 and 120 days after calving), displaced abomasum (DA, ratio of the number of lactations with first diagnosis of DA to the number of lactations by cows without a previous diagnosis of DA), cystic ovaries disease (COD), lameness, clinical mastitis, and dystocia (as the number of calvings with dystocia over the number of calvings). To get an appraisal of the sub-clinical cases present in the herd, an udder health index was created as the proportion of cows with a geometric mean of somatic cell count over 200,000 cells for their lactation. The somatic cell count was made available from the monthly test in the production dataset coming from the DHI. The mortality incidence was determined

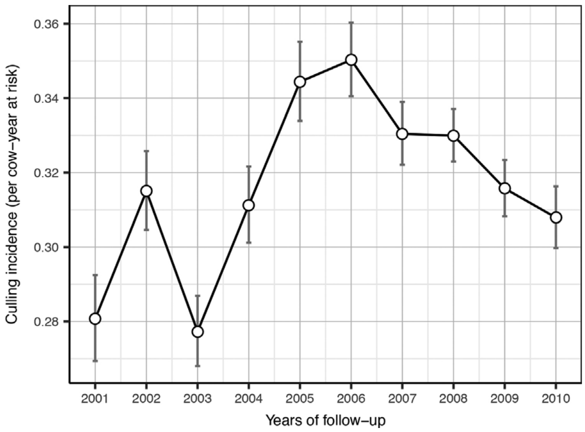

Fig. 2. Culling incidence (and 95% confidence interval) for each year of follow-up from generalized estimating equation (GEE) model.

as well.

Culling rate indicators. Three culling indicators were calculated for each herd and each year of follow-up, as the number of events per animal-year at risk. These three indicators were the overall culling rate (CR), culling rate by 60 days in milk (DIM; CR60), and dairy sale rate by 60 DIM (DS60). The rates were divided into the following groups: < 25%, 25–30%, 30–35%, and > 35% for CR; < 5%, 5–10%, and > 10% for CR60; and no dairy sales, > 0–3%, and > 3% for DS60.

2.2. Data analysis

All statistics were computed with R version 3.3.2 (R Core Team, 2015); packages geepack (Højsgaard et al., 2006) and FactoMineR (Lê et al., 2008).

Culling events and time at risk were counted by year, between 2001 and 2010. Culling incidences (overall, by 60 DIM, dairy sales by 60 DIM) for the entire cohort were estimated using a generalized estimating equation (GEE) analysis (Hanley et al., 2003; Yan and Fine, 2004; Zou, 2004) with Poisson distribution, log link function, exchangeable correlation structure, and robust sandwich estimator, to take into account repeated measures within the herd.

The relationship between various herd indices separated into different groups was assessed with a Multiple Factor Analysis (MFA; Escofier and Pagés, 1994). All groups of indicators were defined as above, with culling rate indicators used as supplementary variables, i.e. they were not used to calculate the factors, but were projected onto the active space (Lebart et al., 2006).

The MFA was done first with the groups of indicators clustered by year. The same MFA was then done while imputing missing values (Josse and Husson, 2012; Husson and Josse, 2013). If no difference between the two models and no effect of the year were present, the computed indices were averaged for each herd over their follow-up period and the final MFA was performed (mean for rates, weighted mean for proportions, and weighted medians for median based indicators). The number of factors used for the interpretation was determined based on a scree plot and the eigenvalues for each group (Cattell, 1966; Horn and Engstrom, 1979).

The relationship between groups of indicators were checked with the Lg (Escofier and Pagés, 1994; Pagés, 2014) and RV (Escoufier, 1973) coefficients. The Lg coefficient is an indicator of multi-dimensionality: the larger Lg is, the more the two groups compared share a common inertia. RV is the Lg coefficient 'normalized' in [0,1], where 0 indicates orthogonality between the two groups and 1 homothety. The interest in representing simultaneously the groups was also assessed by looking at the ratio of the inter-inertia to the total inertia (Lebart et al., 2006). Close to 1, it confirms the 'common' character of a factor. If no relationship was found between the group of variables, a separate PCA was performed for each group of indicators. Largest values of PCA loadings were used to select variables in case of collinearity (Jolliffe, 1972).

The association between culling rates supplementary variables and a factor was evaluated by calculating test-values (Morineau, 1984). Test-value is a criterion that allow to quickly assess if a category of a supplementary variable has a 'significant' position on an axis (i.e. factor) (Lebart et al., 2006). This test-value is the conversion of the coordinates of this variable on the axis into a standard normal distribution under the assumption of independence. This assumption implies a test-value has 95 chances over 100 to belong to the interval $[-1.96, +1.96]$ (that can be rounded to an absolute value of 2). However this value of 2 is very liberal in the presence of multiple testing, as we have here. No satisfying values are available though, and test-values should rather be seen as a way to classify supplementary variables (or categories of these variables) by order of decreasing interest (Lebart et al., 2006). The eventual association found is purely descriptive and not implying any causal pathway.

3. Results

A total of 432,733 lactations from 156,409 cows (> 95% Holsteins) from 763 herds were available for analysis. The overall annual culling incidence of the 763 herds was 0.32 cullings per cow-year at risk, 95% confidence interval (CI) [0.316, 0.325]. The dairy sale incidence was 0.032 sales per cow-year at risk [0.028, 0.036], and the culling incidence by 60 DIM was 0.082 cows culled per cow-year at risk [0.079, 0.084]. The variation in the overall annual culling incidence is shown in Fig. 2. Descriptive statistics for the 30 indices and the culling rates are presented in Table 1. The annual herd culling rates ranged from 11% to 53%.

3.1. Multiple factor analysis

There was no effect of the year of observation nor of the imputation of missing values. Hence, the computed indices were averaged for each herd over their follow-up period. After examination of the scree plot and eigenvalues, a two factor solution was chosen.

The explained variance for each axis from the MFA was very low (Table 2: 13.7% for the first axis and 12.6% for the second). *Demographics* and *Production* groups of indicators had the largest inertia on the first axis (eigenvalues of 0.65 and 0.4, respectively), *Health* and *Reproduction* groups contributing little to this axis. On the other hand, *Reproduction* had the largest inertia on the second principal component (eigenvalue of 0.48) while *Production* and *Health* contributed equally to this axis (eigenvalues of 0.31 and 0.33, respectively) while *Demographics* had a low contribution to this axis. Neither were the different groups well projected on each axis, as evidenced by the groups' relative contribution (squared cosines) ranging from 0.02 to 0.15 on the first factor (0.01–0.18 on the second).

The four active groups and the supplementary one, *Culling*, are displayed in the two-dimensional space defined by the MFA's first two factors (according to their squared loadings, i.e. the importance of their association with the factor) (Fig. 3). The groups' coordinates, between 0 and 1, indicate the percentage of inertia explained by the first factor (first dimension, horizontal axis) and the second factor (second dimension, vertical axis). *Demographics* and *Production* are found on the first axis, but none are strongly common to the first factor. Of the two, *Demographics* is the more discriminating between farms, especially according to their proportion of first lactation cows and their livestock sales (contributions of, respectively, 24.8% and 19.1% on the first axis). The other two active groups make a small contribution to this factor. The second factor results mainly from the group *Reproduction*. The illustrative group, *Culling*, is not linked to the second factor and only weakly to the first one. The inertia of the 5 groups of variables in relation to the first and second factors were low. Therefore the herds were

Table 1
Descriptive statistics (percentiles) of 763 herds for yearly indices (see description in text).

Variables	p5	p25	p50	p75	p95
Demographics indicators					
Herd size (animal-years)	32.6	39.3	48.9	62.3	100.4
Proportion of first lactation cows (%)	26.1	31.3	34	36.7	41.2
Proportion of livestock sales[a]	−7.1	−1.4	0.2	2.8	11.7
Proportion of calvings in the fall (%)[b]	28.4	32.8	35.4	38.4	43.1
Reproduction performance indicators					
Median calving interval (months)	12.3	12.6	12.9	13.2	13.7
Median days to first service	65	72.5	78	83.5	96.9
21-day pregnancy rate (calvings per 100 cows-21 days)	12.8	15.6	18	20.5	24.5
Mean age at first calving (months)	25	25.9	26.6	27.4	29.1
Production indicators					
Median 305-day milk production (kg)	7344.9	8559.8	9197.5	9780.8	10,742.2
Median 305-day fat production (kg)	282.6	325	347	370.5	408
Median 305-day protein production (kg)	238.6	277	298	316	347
Peak milk production[c] (kg)—Heifers	26.1	30	31.9	33.8	36.3
Persistency[d]—Heifers	94.3	95	95.5	96	96.4
Peak milk production variation coefficient (%)—Heifers	11.7	13.4	14.7	16.4	19.4
Milk production persistence variability[e]—Heifers	1.6	2	2.3	2.6	3.1
Peak milk production[c] (kg)—Cows	33.9	38.7	41.7	44.3	48.3
Persistency[d]—Cows	92.4	93.2	93.5	93.9	94.4
Peak milk production variation coefficient (%)—Cows	12.9	14.6	15.9	17.4	21
Milk production persistence variability[e]—Cows	1.9	2.2	2.4	2.7	3.2
Health indicators					
Milk fever incidence[f]—All parities	0	1.2	2.4	4.6	8.7
Milk fever incidence[f]—Parities 3+	0	2.4	5	9.4	17.9
Retained placenta incidence[f]	0.4	2	4.1	6.8	11.6
Metritis incidence[f]	0.5	1.7	3	5.1	10.9
Displaced abomasum incidence[f]	0	1.3	2.7	4.6	8.3
Cystic ovaries disease incidence[f]	2	5.7	9.1	13.8	20.6
Lameness incidence[f]	0	1	3	6.8	20.1
Mastitis incidence[f]	0.8	3.7	7.8	16	31.5
Dystocia incidence[f]	0	0.5	1.6	3.8	8.9
Mortality[g]	0.9	2.5	3.9	5.9	11.2
Udder health index (%)[h]	10.4	15.7	20.1	25.3	33.3
Culling rate (%)	21.2	27.3	31.1	35.3	42.7
Culling rate by 60 DIM[i] (%)	2.7	5.2	7.3	9.6	14
Dairy sales by 60 DIM[i] (%)	0	0	0.3	1.3	6

[a] Sales minus purchase per 100 cow-years.
[b] From August to November.
[c] Maximum production within 90 days in milk.
[d] Percent milk decline by month.
[e] 75 to 25 percentile.
[f] Affected lactations per 100 lactations at risk.
[g] Per 100 cow-years.
[h] Proportion of cows over 200,000 cells.
[i] Days in milk.

poorly differentiated based on the common information provided by these groups of variables. Both the Lg and RV coefficients were very close to zero. The ratio of the inter-inertia to the total inertia is quite low on each axis as well (0.38 for first and 0.36 for the second axis).

The MFAs with the merged groups *Demographics/Production* and *Reproduction/Health* returned the same result of no relationship between the groups of variables. Hence, PCAs on each separate group were run to get more insight into each of these groups separately.

Table 2
Eigenvalues and explained variances (%) decomposed on the first two factors and by group of indicators, for Principal Component Analyses on each group of indicators (top) and for Multiple Factor Analysis (bottom).

	Global inertia	Factor 1		Factor 2	
		Eigenvalue	% variance	Eigenvalue	% variance
PCA demographics	4	1.24	30.93	1.07	26.67
PCA reproduction	4	2.15	53.86	0.87	21.76
PCA production	11	5.59	50.82	1.69	15.34
PCA health	11	3.21	29.16	1.35	12.28
MFA	10.49	1.43	13.65	1.32	12.55
Demographics	3.23	0.65	45.05	0.19	14.79
Reproduction	1.86	0.20	13.96	0.48	36.54
Production	1.97	0.40	28.15	0.31	23.34
Health	3.43	0.18	12.84	0.33	25.33

PCA, Principal Component Analysis; MFA, multiple factor analysis.

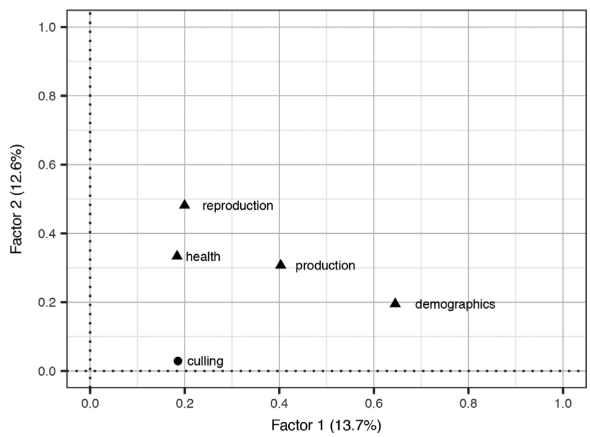

Fig. 3. Contribution of groups of indicators to the first two factors of the Multiple Factor Analysis (MFA), according to their squared loadings (triangles, active groups; circle, supplementary group).

3.2. PCA

From the separate analyses by groups (PCA, Table 2), we could see that all groups are uni-dimensional, i.e. their inertia is mainly on a single axis (variables are collinear), with the exception of *Demographics*, resulting in the factor being summarized by its variable. The component loadings, i.e. the position of the variables in the two-dimensional space, are shown in Fig. 4 for each PCA.

Demographics. The first factor has an eigenvalue of 1.2 (explained variance of 30.9%). This first axis is made of the two variables *Proportion of first lactation* (largest factor loading) and *Livestock sales*, while the second factor is made of *Proportion of calvings in the fall* and *Herd size*. We can note that both are orthogonal to each other. The first factor can be summarized as *Herd dynamics*, i.e. representing a modification in herd structure, and the second factor being the *Herd management*.

According to the test-value, only the highest CR category (i.e. higher cull rate) was associated with the second axis (Table 3; a smaller herd size and lower proportion of calvings in the fall with a higher cull rate). But they are all strongly associated with the first axis, except the medium rate 30–35%. The culling rate is associated with *Herd dynamics*, and the highest culling rates are also negatively associated with *Herd management*.

CR60 is associated with the first axis for the lowest and highest levels; and for all levels on the second axis but the lowest one.

DS60 is associated with the first axis, at all levels; and with the second axis for the lowest and highest rates.

Reproduction. The first factor has an eigenvalue of 2.2 (explained variance: 53.9%). From Figure 4, the first axis is made of *Calving interval*, *Days to first service*, and *21-day pregnancy rate*; the second axis by *Age at first calving*. Largest factor loadings were equivalent for *Calving interval* and *Pregnancy rate*. *Calving interval* and *21-day pregnancy rate* go in opposite directions, i.e. herds with higher 21-day pregnancy rates had shorter calving intervals. They also serviced the cows earlier. However, it is orthogonal with *Age at first calving*.

Regarding culling practices, the lowest and highest culling rates are associated with the first and second axis, i.e. lowest culling rates are found in herds with a delayed age at first calving, the highest 21-day pregnancy rate, the shortest calving interval, and vice versa (Table 4).

The lowest CR60 is associated with the first axis only (lowest rates linked to longer calving intervals and lower pregnancy rates). The same can be said for DS60, but only for the second axis (no dairy sales associated with older age at first calving; more dairy sales with earlier age at first calving).

Production. The first factor had an eigenvalue of 5.6 (explained variance of 50.8%). The first axis is made of *305-day milk* (largest factor loading), *fat*, and *protein*, and *Peak heifer* (L1) and *cow* (L2+) production; and the second axis of *Peak heifer* (L1) and *cow* (L2+) *covariance* (but their quality of representation is not strong: low squared cosines of 0.52 and 0.5, respectively). Our focus is then mainly on the first axis, where herds can be distinguished based on their level of production (Figure 4).

The overall culling rates are weakly associated with the first axis. The highest and lowest 60 DIM rates are associated with this axis, with lower rates found in lower producing herds and higher rates in higher producing herds (Table 5).

Health. The first factor has an eigenvalue of 3.2 (explained variance: 29.2%). The first axis is made of *MF* (all parities and parities 3 and greater, L3+), *DA*, *Lameness*, *RP*, and *Mastitis*. The second axis is made of *Metritis*, *COD*, and *Mortality*. We can note that *RP* and *Metritis/COD* are orthogonal: the highest RP incidence is not linked to the highest incidence of metritis and/or COD. However, only *MF* had a good quality of representation on the axes (squared cosine = 0.68).

The medium overall culling rate (30–35%) was associated with the first axis (highest MF incidences). The lowest CR60 was associated with lower MF incidences (Table 6).

4. Discussion

This study found an average culling rate of 32% over the 2001–2010 decade, a CR60 of 8.2%, and a DS60 of 3.2%. This overall culling rate is similar to the rates commonly found in North America (Radke and Lloyd, 2000). Lower culling rates are often reported in Europe (between 20% and 25%) (Sol et al., 1984; Esslemont and Kossaibati, 1997; Whitaker et al., 2004; Mohd Nor et al., 2014) but Oler et al. (2012) recorded a 32% culling rate in Poland. In the United States, while Gardner et al. (1990) reported a 25% culling rate in California dairy herds in 1990, more recent studies by De Vries et al. (2010) as well as Dechow and Goodling (2008) found culling rates comparable to this study (32% and 30.7%, respectively). On the other hand, the US National Animal Health Monitoring System (2007) reported lower culling rates, ranging from 25% to 31.3% between 2001 and 2006. Culling rate definitions can vary across studies, and comparisons should be made with care. However, the large variation of culling rates between herds is constantly found across studies, and ours is no exception, with culling rates as low as 11% and as high as 53%. Still, the present study is the first to compute culling rates on such a large observational cohort, followed for 10 years. CR60 was similar to what was reported by Dechow and Goodling (2008), 7.6%. The dairy sale rate was also in the range reported in the literature (3% in Dechow and Goodling (2008), 4.1% in Mohd Nor et al. (2014), and 5.5% in US National Animal Health Monitoring System (2007)). The evolution of the culling rate over time showed a sharp decline in 2003. While Canada experienced its second bovine spongiform encephalopathy case in May 2003, it is hard to impute this rate drop solely to that event. Without data before 2001, it is difficult to determine whether the 2002 increase in culling was a trend or just a blip due to particular conditions. Nevertheless, we have to recognize that cull cattle prices were considerably reduced in 2003, potentially creating a positive environment for decreased culling rates.

We could not demonstrate the presence of specific profiles of herds based on reproduction, production, demographics, and health indicators but, on the contrary, we show the heterogeneity among Québec dairy herds for these contextual factors. By considering each domain separately, profiles of herds emerged according to their population dynamics, population management, reproduction indicators, production, and milk fever incidence. Lower and higher cull rates could be linked to demographics and reproduction factors, but not to the production and health ones. Production indicators however were associated with CR60 and DS60. The relationships between disease incidences and culling rates were weak. Variables within these factors were collinear, allowing to summarize the factors by a specific variable.

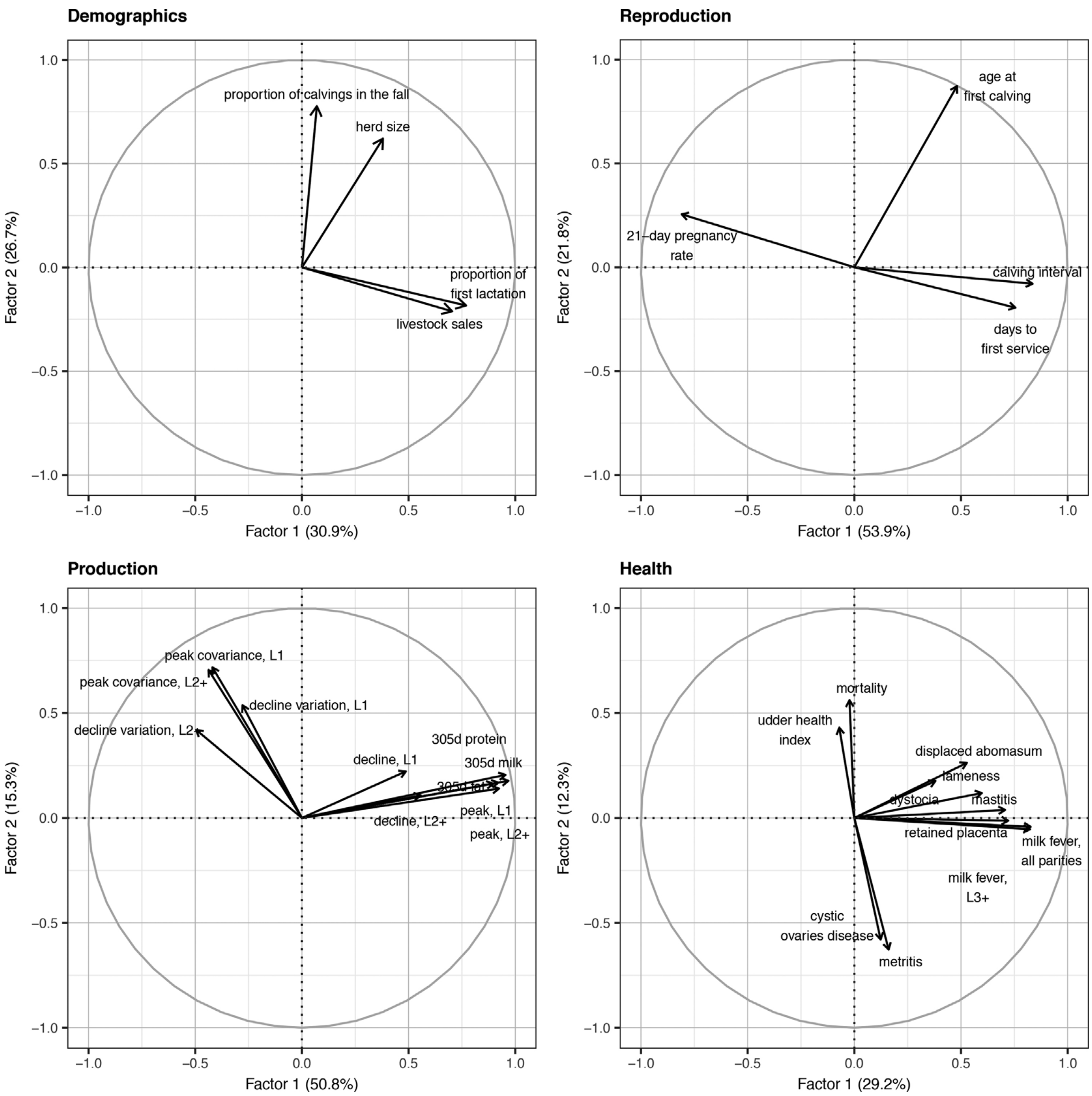

Fig. 4. First two factors of Principal Component Analyses (PCA) on each group of indicators. Arrow in direction of the highest value of the variable. 305d: 305 days; L1: heifers; L2+: cows; L3+: parities 3 and greater.

Table 3
Test-values for supplementary variables *Culling*—Principal Component Analysis on *Demographics* indicators. * $p < 0.05$ for the test-value.

		Factor 1	Factor 2
Culling rate (%)	< 25	−5.83	1.88
	[25,30)	−4.31*	0.83
	[30,35)	1.20	0.81
	> 35	7.86*	−3.24*
Culling rate by 60 DIM (%)	[0,5)	−4.62*	−0.40
	[5,10)	−1.62	2.20*
	> 10	6.63*	−2.24*
Dairy sales by 60 DIM (%)	none	−12.39*	3.73*
	[0,3)	3.68*	−0.05
	> 3	12.52*	−4.88*

DIM, days in milk.

Table 4
Test-values for supplementary variables *Culling*—Principal Component Analysis on *Reproduction* indicators. * $p < 0.05$ for the test-value.

		Factor 1	Factor 2
Culling rate (%)	< 25	−2.22*	5.30*
	[25,30)	−2.74*	0.26
	[30,35)	0.77	−1.20
	> 35	3.78*	−3.33*
Culling rate by 60 DIM (%)	[0,5)	2.45*	0.82
	[5,10)	−0.91	0.08
	> 10	−1.39	−0.93
Dairy sales by 60 DIM (%)	none	−1.21	2.29*
	[0,3)	0.44	−0.98
	> 3	1.13	−1.99

DIM, days in milk.

Multiple factor analysis handles tables in which a set of observations is described by several sets of variables, each set having distinct meanings. The present results of the MFA demonstrate the heterogeneity among herds for the four groups of variables evaluated. The eigenvalues from a MFA are linkage indices between the associated factor and all the groups, where the maximum value, 4 (i.e. the number of groups, *J*), is obtained when one factor from the global analysis is confounded with the first factor from the separate analysis of each

Table 5
Test-values for supplementary variables *Culling*—Principal Component Analysis on *Production* indicators. * $p < 0.05$ for the test-value.

		Factor 1	Factor 2
Culling rate (%)	< 25	−1.22	−2.10*
	[25,30)	−2.11*	−1.95
	[30,35)	1.56	−0.05
	> 35	1.49	3.74*
Culling rate by 60 DIM (%)	[0,5)	−2.75*	−3.88*
	[5,10)	0.24	0.92
	> 10	2.49*	2.82*
Dairy sales by 60 DIM (%)	none	−7.03*	1.74
	[0,3)	2.06*	−1.36
	> 3	7.13*	−0.88

DIM, days in milk.

Table 6
Test-values for supplementary variables *Culling*—Principal Component Analysis on *Health* indicators. * $p < 0.05$ for the test-value.

		Factor 1	Factor 2
Culling rate (%)	< 25	−1.40	−3.58*
	[25,30)	−1.17	0.70
	[30,35)	2.52*	0.61
	> 35	−0.34	1.58
Culling rate by 60 DIM (%)	[0,5)	−3.35*	−1.91
	[5,10)	2.05*	0.37
	> 10	0.94	1.50
Dairy sales by 60 DIM (%)	none	1.49	4.18*
	[0,3)	−1.10	−1.73
	> 3	−0.81	−3.72*

DIM, days in milk.

group. If the first eigenvalue is close to *J*, the first factor is common to all groups and is an important direction of inertia for each of them. This was clearly not the case here, and we could conclude there was little relationship between the groups. Each group's inertia being very low, the information provided by each group is very different. Previous studies already demonstrated that farmers' management style and attitude were more important then herd-level characteristics for farm performance (Bigras-Poulin et al., 1985; Tarabla and Dodd, 1990). We have shown here that herds could not be clustered based on the combination of multiple selected herd-level variables. No relationships between groups of indicators could be highlighted and each group had to be considered separately. From the separate PCAs, descriptive relationships between culling rates and factors were limited to factors represented by livestock sales, proportion of first lactation cows, herd size, proportion of calvings occurring in the fall, longer calving intervals and reduced 21-day pregnancy rates, increased days to first service, average age at first calving, and reduced milk fever incidence. Some of these relationships are self-explanatory due to their direct relationship, such as the relations between cull rate, CR60, DS60 and livestock sales and proportion of first lactation cows. Others are easily explained, for example, higher cull rates in herds with longer calving intervals, lower 21-day pregnancy rates, and higher average days to first service. Herds comprising of too many cows with low reproductive performances were more likely to remove their problematic animals. We also found that cull rates were associated with the herd's average age at first calving, i.e. higher cull rates were found in herds with early first calving and vice versa. The only contextual health variable associated with CR60 was the MF incidence (all parities, and third lactation and over), where herds with lower MF incidence had lower CR by 60 DIM.

For a cow, being fertile (Schneider et al., 2007; De Vries et al., 2010) and healthy (Gröhn et al., 1998; Rajala-Schultz and Gröhn, 1999a; Beaudeau et al., 2000) would generally allow her to stay longer in the herd. These associations were made at the cow-level and cannot be generalized to a collective relationship. Doing so would result in an atomistic fallacy (Duncan et al., 1993; Diez Roux, 1998). This bias arises from the presence of multiple levels of organization in the dataset, where a variable defined and measured at one level may belong to a different construct than its counterpart at another level. For example, regarding milk production performance, if herds can be distinguished based on these, it is not related to the herd culling rate despite milk production being a protective factor against culling for the cow (Gröhn et al., 1998; Rajala-Schultz and Gröhn, 1999c). Other factors are at play when considering herd-level as opposed to cow-level associations (LeBlanc, 2010). In particular, a human variable is introduced by the herd manager who's making economically-driven herd management decisions, resulting in a given herd culling rate. These decisions can result in a different cow-specific culling risk. Hence, constructs from a higher level can be important to understand variability at a lower level and vice versa, thus the appeal of multilevel modeling to explore the hierarchical structure in the data. These multilevel models make use of random slopes, contextual variables, or both (Stryhn and Christensen, 2014). Although a synthetic, composite, variable could not be identified to summarize the herds, we were able to determine several potential contextual variables of interest for dairy cow multilevel modelling, i.e. herd dynamics (herd size, proportion of first lactation cows, proportion of calvings in the fall), reproduction indicators (average age at first calving, 21-day pregnancy rate, calving interval), herd average 305-day milk production, and MF incidence. Additional variables not available in the data sets used would be interesting to consider as contextual variables and would require further research, like economic and socio-economic information, farm infrastructure, land use, crops, etc.

The herds were representative of Québec dairy herds using a monthly DHI service for individual cow milk recording, and a computerized data management system for reproduction and health management. Compared to Québec statistics on dairy herds,[2] study herds had the same characteristics in terms of size, with slightly better milk production—200 kg over 305-day—and reproductive performance—shorter calving intervals and fewer days to first service in study herds. Compared to the *DSA Laitier* database, our study herds had also better 21-day pregnancy rate (18 vs 16). However our study herds followed exactly the same trends for each of the indices over the 10 years of follow-up as those from DHI and *DSA Laitier*. By using aggregated data, we assumed that we will have reduced measurement errors in the covariates, as they are based on averages (Prentice and Sheppard, 1995; Guthrie and Sheppard, 2001; Richardson and Monfort, 2001). Also, it has been demonstrated that the effect of measurement errors on the PCA results in an increase in variability, not in bias (Hellton and Thoresen, 2014). Beyond measurement error, the construct referenced on the group-level data could be distinct from the one at the individual-level (Firebaugh, 1978; Schwartz, 1994). With aggregated, group-level data we provided information on true group-level constructs, not just summaries of individual-level constructs (Morgenstern, 1995; Diez Roux, 2004). The validity of the aggregated data is also related to the sample size of the data used to create them. By selecting herds larger than 30 animal-years, followed for three years, we increased our confidence in the validity of the aggregation.

5. Conclusion

This study provided the first description of Québec herd culling rates using 10 years of follow-up data, with a culling incidence of 0.32 cullings per 100 cow-year. It demonstrated the heterogeneity of Québec dairy herds according to demographics, reproduction, production, and health indicators. However, it allowed determining profiles of herds

[2] Available online at http://www.valacta.com/FR/Nos-publications/Pages/evolution-de-la-production-laitiere.aspx.

according to specific domains independently. The culling risk associations usually seen at the cow-level are not entirely transposed at the herd level, calling for the inclusion of herd-level variables into the modelling of cow culling risk. Herd size, proportion of first lactation cows, proportion of calvings in the fall, average age at first calving, 21-day pregnancy rate, average calving interval, herd average 305-day milk production, and MF incidence can be used as potential contextual variables in the multilevel modelling of culling risk.

Conflict of interest

None.

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