Exploring the characteristics and dynamics of Ontario dairy herds experiencing increases in bulk milk somatic cell count during the summer

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ABSTRACT

Regionally aggregated bulk milk somatic cell count (BMSCC) data from around the world shows a repeatable cyclicity, with the highest levels experienced during warm, humid seasons. No studies have evaluated this seasonal phenomenon at the herd level. The objectives of this study were to define summer seasonality in BMSCC on an individual herd basis, and subsequently to describe the characteristics and dynamics of herds with increased BMSCC in the summer. The data used for this analysis were from all dairy farms in Ontario, Canada, between January 2000 and December 2011 ($n \approx 4,000$ to 6,000 herds/yr). Bulk milk data were obtained from the milk marketing board and consisted of bulk milk production, components (fat, protein, lactose, other solids), and quality (BMSCC, bacterial count, inhibitor presence, freezing point), total milk quota of the farm, and milk quota and incentive fill percentage. A time-series linear mixed model, with random slopes and intercepts, was constructed using sine and cosine terms as predictors to describe seasonality, with herd as a random effect. For each herd, seasonality was described with reference to 1 cosine function of variable amplitude and phase shift. The predicted months of maximal and minimal BMSCC were then calculated. Herds were assigned as low, medium, and high summer increase (LSI, MSI, and HSI, respectively) based on percentiles of amplitude in BMSCC change for each of the 4 seasons. Using these seasonality classifications, 2 transitional repeated measures logistic regression models were built to assess the characteristics of MSI and HSI herds, using LSI herds as controls. Based on the analyses performed, a history of summer BMSCC increases increased the odds of experiencing a subsequent increase. As herd size decreased, the odds of experiencing HSI to MSI in BMSCC increased. Herds with more variability in daily

BMSCC were at higher odds of experiencing MSI and HSI in BMSCC, as were herds with lower annual mean BMSCC. Finally, a negative association was noted between filling herd production targets and experiencing MSI to HSI in BMSCC. These findings provide farm advisors direction for predicting herds likely to experience increases in SCC over the summer, allowing them to proactively focus udder health prevention strategies before the high-risk summer period.

Key words: somatic cell count, seasonality, dairy herd

INTRODUCTION

Mastitis is among the most pervasive and economically important diseases faced by the dairy industry (Hogeveen et al., 2011). At the cow level, an elevated SCC is a sign of inflammation in the udder, the cause of which is most likely a bacterial IMI (Dohoo and Meek, 1982). Cows with higher SCC produce less milk with altered processing characteristics, namely reduced shelf life, and altered protein content (Le Marechal et al., 2011; Hand et al., 2012). As such, bulk milk SCC (BMSCC) is a commonly used gauge of milk quality, with dairy processors and regulators worldwide placing regulations on acceptable levels.

It is a well-established and globally widespread finding that regionally aggregated BMSCC means shows a repeatable, cyclic seasonal pattern (Green et al., 2006b; Olde Riekerink et al., 2007). Typically, BMSCC levels are highest during the warm months of the year, from July through October, in the northern hemisphere. Studies in Ontario, Canada, have found BMSCC averages are lowest in April and highest in October, a trend consistent over a 6-yr period (Sargeant et al., 1998). In Ontario, monthly provincial mean BMSCC levels typically ranged from a nadir of less than 200,000 cells/mL in the winter to their highest levels of 300,000 cells/mL in the summer (Sargeant et al., 1998).

This seasonal compromise in milk quality is concerning for several reasons. Producers with elevated BMSCC experience decreased milk production (Hand et al., 2012) and face financial penalties when they exceed

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the SCC regulatory thresholds (Dekkers et al., 1996). It has been shown that increased BMSCC in summer poses a significant challenge for producers to comply with such regulatory standards (Lukas et al., 2008). Historically, a positive association between external pressure to lower BMSCC and inhibitor penalties (antibiotic residues in milk), likely due to increased use of intramammary antibiotic treatment (Schukken et al., 1992a; Sargeant et al., 1998).

Several factors contribute to the seasonal pattern in BMSCC. The increased heat and humidity of summer provide optimal environmental conditions for bacterial growth, increasing infection pressure and, ultimately, the incidence of clinical mastitis during the summer (Hogan et al., 1989). In addition, the summer increase in BMSCC is also associated with an increase in the proportion of cows with a chronically high SCC (2 consecutive tests greater than 200,000 cells/mL), with these cows accounting for 71% of the increase in BMSCC over the summer (Green et al., 2006b).

There are also potential animal-level risk factors associated with the summer, potentially leading to increases in IMI and, thus, BMSCC. Animals experiencing heat and humidity could develop heat stress and subsequent immune suppression, potentially increasing the risk of IMI (do Amaral et al., 2011). Also, the incidence of metabolic disease is often elevated in the summer (Duffield et al., 1998), which could further contribute to immune suppression and an increased IMI risk (van Straten et al., 2009).

Milk is a supply managed commodity in Canada, whereby the amount of milk sold by individual dairy farmers is controlled through a quota system, expressed in kilograms of butterfat per day, and hereafter referred to as milk quota (**MQ**), to match the domestic demand. Milk quota is designed to be filled and reconciled monthly, with limited ability to compensate for over- or under-production in 1 mo by offsetting production in another month. Producers are typically allotted the right to sell additional milk, over and above their allotted MQ, in the face of supply and demand mismatch, termed as incentive days (**ID**). Typically, the summer and fall periods are times where demand for milk outstrips supply. Producers aim to temporarily increase milk production, either to attain fall or summer ID or to increase production levels after periods of under-production. Temporary increases in production are primarily achieved by maintaining higher-lactating cow numbers through cow retention, acquisition, or targeted breeding. This could become a risk factor for summer BMSCC increases when facilities are inadequate in size or capacity to accommodate such temporary fluctuations, leading to higher stocking densities with potential

increased levels manure accumulation (Magnusson et al., 2008) or higher levels of social stress with potential immune suppression (Herskin et al., 2007). Producers who retain cows destined for culling could inadvertently keep cows with chronic IMI in the herd, contributing to higher levels of BMSCC and acting as a source of new IMI (Zadoks et al., 2002). The effects that the supply management system has on udder health have not been studied.

Studies evaluating seasonal SCC trends in entire regional populations of herds over extended periods are few in number. Also, there are no published studies that have described the characteristics and BMSCC dynamics of the seasonal phenomenon at the individual herd level. The objectives of the present study were to define summer seasonality in BMSCC on an individual herd basis, and, subsequently, to describe the characteristics and BMSCC dynamics of herds with increased BMSCC in the summer in the context of the Canadian dairy industry.

MATERIALS AND METHODS

Farms

The data used for this analysis were from the complete population of licensed dairy farms in Ontario, Canada, from January 2000 to December 2011. The number of farms and cows decreased from 6,100 herds and 380,000 milking cows in 2000 to approximately 4,000 herds and 319,000 milking cows in 2011. The average farm size (milking and dry cows) over this period ranged from approximately 40 in 2000 to 70 in 2011. For each year, only herds selling milk for a complete year (>90% of milk pickup data available) were retained for analysis. The Holstein breed accounts for greater than 90% of the cows milked in Ontario (CanwestDHI, 2012). All milk sold in the province is evaluated for component content and milk quality at 1 laboratory (University of Guelph, Laboratory Services Division). All milk is marketed to processors through the Dairy Farmers of Ontario (**DFO**; Mississauga, ON, Canada).

Data

The data used in the current study were obtained from the DFO and consisted of bulk milk production, components (fat, protein, lactose, other solids), and quality (BMSCC, bacterial count, inhibitor presence, freezing point), farm MQ, and MQ and ID fill percentage from every farm in Ontario. Between January 1, 2000, and May 31, 2010, bulk tank milk samples from each farm were analyzed 4 times per month. Subse-

quently (June 2010 onward), a sample from every bulk tank pickup (typically every other day) from each farm was analyzed.

Statistical Analysis

The seasonality of BMSCC was assessed using a mixed linear model using random slopes and intercepts with autocorrelated errors for repeated measures (PROC MIXED; SAS software version 9.3; SAS Institute Inc., Cary, NC). Natural logarithmic transformations of BMSCC were performed to approximate the normal distribution of the data. Sine and cosine terms with a yearly period and daily frequency were included in the model to estimate seasonality (Stolwijk et al., 1999). Random intercepts and slopes were calculated for each herd. To correct for year effects, separate parameters were estimated for each year. The model used to approximate seasonality was

$$\begin{aligned} \ln \text{BMSCC}_{ij} = & \beta_0 + \beta_1 \sin(2\pi \times \text{day}_{ij}/365.25) \\ & + \beta_2 \cos(2\pi \times \text{day}_{ij}/365.25) + u_{0i} + u_{1i} \sin(2\pi \\ & \times \text{day}_{ij}/365.25) + u_{2i} \cos(2\pi \times \text{day}_{ij}/365.25) + \varepsilon_{ij}, \quad [1] \end{aligned}$$

where $\ln \text{BMSCC}$ = natural logarithm of BMSCC; β_0 = intercept; β_1 , β_2 = regression coefficients for fixed effect; u_{0i} = random effect for herd i ; u_{1i} , u_{2i} = random coefficient for herd i ; ε_{ij} = residual error term. Repeated measures were modeled using a first-order autoregressive autocorrelation structure. In our analysis, the first-order autoregressive correlation structure had a lower Akaike information criterion compared with the autoregressive moving average; therefore, this model was used. The size of the data set prohibited model convergence with the incorporation of more complex structures.

Herd-level seasonal variability was described using random intercepts and regression coefficients generated by applying equation 1. Briefly, the seasonality in herd BMSCC is expressed through the cosine function:

$$f(t)_i = \alpha_i \times \cos [(2\pi \times \text{day}/365.25) - \sigma_i], \quad [2]$$

where t = time period (e.g., January = 1), α = the amplitude of the cosine function, and σ = the horizontal phase shift of the cosine function in radians (Stolwijk et al., 1999). From this equation, the predicted yearly dates of maximal and minimal BMSCC were calculated for every herd and for the population. For each year, herds could be placed into 1 of 12 categories based on the season and severity of their BMSCC increase for that year. Seasons were defined as summer (June 21

to September 22), fall (September 23 to December 20), winter (December 21 to March 20), and spring (March 21 to June 20). Based on thirds of the distribution for each year, herds were classified on the height of the amplitude of their fitted cosine curve as having low, medium, or high degrees of increase in BMSCC for the season. For example, herds whose predicted BMSCC increase in 2011 occurred in the summer and the amplitude of the increase was in the highest third were classified as a high summer increase (**HSI**) herd. The classification frequency and dynamics of BMSCC seasonality across years were also assessed. Figures were constructed of monthly BMSCC from select individual herds versus model-fitted BMSCC to illustrate the seasonality categories.

To assess the contribution of each farm to the overall provincial summer BMSCC, a variable was created that used the number of somatic cells produced over the acceptable milk quality target of 200,000 cells/mL (Schukken et al., 1992b). This parameter is influenced by the BMSCC and the volume of milk produced. It is calculated as

$$\begin{aligned} \text{Summer BMSCC contribution}_{ijk} = & \frac{\sum_{i=7}^{n=3} (\text{BMSCC}_{ijk} - 200,000) \times \text{Production}_{ijk}}{\text{Mean summer milk production}_k}, \quad [3] \end{aligned}$$

where i = summer month indicator (7,8,9); BMSCC_{ijk} = the BMSCC for herd j in month i of year k ; Production_{ijk} = total milk production (in kilograms) for herd j in month i of year k ; $\text{Mean summer milk production}_k$ = the mean milk production (in kilograms) for all Ontario herds over the summer months (July through September). A farm whose production over the summer months of year k , whose BMSCC in July was 300,000 cells/mL, had a BMSCC contribution of 100 for that period.

Descriptive statistics were generated for the final data set. The variables MQ and ID fill percentage are a representation of the proportion of MQ and ID that the producer was able to fill over the entire season (kilograms of butterfat produced per kilogram of MQ or ID available to fill). For example, a producer with 3,700 kg of MQ to fill in the summer, who actually shipped 3,440 kg, had an MQ fill percentage of 93% over that period. Histograms were created to visually inspect variables for normality. Variables for MQ, MQ and ID fill percentage, and summer BMSCC standard deviation did not approximate the normal distribution. Therefore, median and interquartile ranges were calculated for each variable. Univariable comparison of cen-

Table 1. Description of yearly variables for herd level analysis of seasonality over 12 yr (2000 to 2011) of regulatory bulk milk SCC (BMSCC) data for Ontario dairy herds

Variable	Description
Herd size	Based on kilograms of butterfat under the herd daily quota holdings (i.e., a herd of 40 cows, with each cow producing 1.1 kg of butterfat daily would have a 44-kg quota).
MQ ¹ fill (%)	Variables are based on the percentage of milk quota (based on daily kilograms of butterfat) the producer has filled for each season (i.e., producers that produced 5% less than their milk quota during the entire summer months would have a milk quota fill percentage of 95%).
Summer	
Fall	
Winter	
Spring	For each season and herd, the percentage of over-quota production that the herd was able to fill (i.e., fall incentives in the year of 2010 gave the producers an added 3 d of production for the entire season). A herd with 44 kg of milk quota per day would have the right to ship 132 kg (3 × 44) additional butterfat for that period, over and above their normal milk quota.
ID ² fill (%)	
Average BMSCC (×1,000 cells/mL)	Over 12 mo, arithmetic average monthly weighted BMSCC for the year.
BMSCC threshold breach (yes/no)	3 or more monthly BMSCC values >500,000 cells/mL (regulatory limit)
Bacterial count threshold breach (yes/no)	1 or more monthly Bactoscan level >121,000 bacterial count/mL
Transitional variables for previous years classification	Previous 2 yr classifications used as risk factors in transitional model; 12 in total – season (summer, fall, winter, spring) × severity (low, medium, high)

¹MQ = milk quota.²ID = incentive days.

tral values was accomplished through nonparametric methods, namely the Kruskal-Wallis one-way ANOVA (Proc NPAR1WAY, SAS Institute Inc.).

Using the seasonality definitions, 2 transitional repeated measures logistic regression models were built to assess the characteristics of herds experiencing summer increases in BMSCC. Control herds were defined as herds experiencing low levels of summer BMSCC increase (**LSI**). Case herds for each model were defined as herds experiencing either a medium (**MSI**) or high (**HSI**) level of summer BMSCC increase. Variables considered for analysis were herd size (based on kilograms of butterfat quota holdings), seasonal quota and incentive fill percentage, year, yearly mean BMSCC, milk bacteria count, milk components (fat, protein, lactose, TS), within-summer BMSCC standard deviation, and transitional variables for the herd seasonality classification in each of the previous 2 yr. Initial analysis was performed using univariable logistic regression, with *P*-values <0.2 used as the criterion for inclusion in the multivariable models. Variables identified as associated with SCC seasonality (*P* < 0.2) were assessed for collinearity using Spearman rank-order correlation (ρ). High correlation coefficients (ρ > 0.6) were found between summer MQ fill percentage and summer ID fill percentage (ρ = 0.72), and between fall MQ fill percentage and fall ID fill percentage (ρ = 0.82). The MQ fill percentage variables were preferentially retained and used in subsequent analysis, as the number of ID offered to producers varied by years. Continuous vari-

ables were assessed for linearity with the inclusion of a quadratic term in the model. In the case of nonlinear relationships (i.e., quadratic term with *P* < 0.05), the quadratic term was included in the model, otherwise the variable remained as continuous. Complete variable descriptions are presented in Table 1.

Manual backward elimination was used to build the final multivariable, repeated measures logistic model using PROC GLIMMIX in SAS (version 9.3; SAS Institute, Inc.). A partial F-test with a *P*-value <0.05 was required for the inclusion of any variable in the final model. Several correlation structures were assessed, all resulting in similar (<10% difference) coefficient values and levels of significance. The final model included random effect for residuals by herd using the first-order autoregressive correlation structure to account for repeated measures over time, as this method resulted in the lowest Akaike information criterion value.

RESULTS

Seasonality Classification

Table 2 presents the final mixed linear model of the seasonality in BMSCC for Ontario dairy herds over 12 yr of data. There was seasonal variation in all 12 yr of analysis. Figure 1 shows examples of representative LSI, MSI, and HSI herds classified based on thirds of the distribution of the amplitude of the cosine function for 2011 annual BMSCC for the herd.

Table 2. Results from final mixed model evaluating seasonal variation for ln(bulk milk SCC) over 12 yr for dairy herds in Ontario

Year	Effect	Estimate	SE	P-value	No. of herds
2000	Intercept	5.3966	0.0046	<0.0001	6,095
	Sine	-0.0610	0.0025	<0.0001	
	Cosine	-0.1034	0.0021	<0.0001	
2001	Intercept	5.3369	0.0051	<0.0001	5,824
	Sine	-0.0833	0.0027	<0.0001	
	Cosine	-0.1086	0.0022	<0.0001	
2002	Intercept	5.3359	0.0052	<0.0001	5,560
	Sine	-0.0877	0.0027	<0.0001	
	Cosine	-0.0858	0.0022	<0.0001	
2003	Intercept	5.2963	0.0055	<0.0001	5,300
	Sine	-0.1714	0.0028	<0.0001	
	Cosine	-0.1081	0.0022	<0.0001	
2004	Intercept	5.3058	0.0056	<0.0001	5,137
	Sine	-0.0623	0.0027	<0.0001	
	Cosine	-0.0608	0.0022	<0.0001	
2005	Intercept	5.3515	0.0059	<0.0001	4,886
	Sine	-0.1275	0.0027	<0.0001	
	Cosine	-0.0858	0.0023	<0.0001	
2006	Intercept	5.3703	0.0059	<0.0001	4,614
	Sine	-0.1087	0.0028	<0.0001	
	Cosine	-0.0532	0.0023	<0.0001	
2007	Intercept	5.3949	0.0058	<0.0001	4,428
	Sine	-0.0950	0.0029	<0.0001	
	Cosine	-0.0578	0.0023	<0.0001	
2008	Intercept	5.4138	0.0060	<0.0001	4,306
	Sine	-0.0987	0.0028	<0.0001	
	Cosine	-0.0602	0.0024	<0.0001	
2009	Intercept	5.4060	0.0060	<0.0001	4,206
	Sine	-0.0674	0.0029	<0.0001	
	Cosine	-0.0577	0.0024	<0.0001	
2010	Intercept	5.4334	0.0058	<0.0001	4,150
	Sine	-0.1105	0.0028	<0.0001	
	Cosine	-0.1066	0.0024	<0.0001	
2011	Intercept	5.4336	0.0058	<0.0001	4,106
	Sine	-0.0981	0.0027	<0.0001	
	Cosine	-0.0736	0.0022	<0.0001	

Figure 2 illustrates the yearly distribution of herd BMSCC increase by season. Overall, summer was the season in which the most herds experienced an appreciable increase, with 48 to 71% of herds experiencing summer BMSCC increases in a given year. Fall and spring were the next most frequent seasons in which herds experienced BMSCC increases, with roughly 20 and 15% of herds experiencing increases in these seasons, respectively. Figure 3 illustrates the positive relationship between whole-province seasonal amplitude in BMSCC and the proportion of herds increasing in the summer.

Within herds, the transition dynamics of seasonality classification between years was also variable. Of all herds considered over the 12 yr of available data, 26% experienced summer increases in BMSCC in most (>75%) of their years of operation. Furthermore, 71% of herds experienced summer increases in 50% or greater of their years of operation.

BMSCC Contribution of Summer Seasonal Herds

Analysis of the contribution of summer-seasonal BMSCC increasing herds to the provincial summer BMSCC is presented in Figure 4. The LSI herds contributed the least amount of SCC to the provincial BMSCC in 8 out of 12 yr of analysis. In 2004, LSI were actually the greatest contributors to provincial summer BMSCC. Interestingly, HSI herds had only 1 yr out of 12 in which they were the greatest contributors to the provincial BMSCC. This result was likely due to their smaller average herd size, based on daily MQ, relative to LSI and MSI herds (Table 3). For the remaining 10 out of 12 yr of study, MSI herds were the predominant contributors to Ontario's summer BMSCC levels.

Descriptive Statistics

Table 3 describes differences among herds in the 4 seasonality categories over 12 yr. Milk quota was sig-

Figure 1. Herd classified as experiencing a low (a), medium (b), or high (c) summer increase in bulk milk SCC (BMSCC) in 2011. Solid line represents model prediction for the herd, and (•) represents actual BMSCC.

nificantly different among all seasonality categories, with smaller herds experiencing greater summer BMSCC increase. Herds experiencing summer increases in BMSCC filled approximately 2% less of their MQ over the summer period relative to herds with low, nonsummer seasonality. Added ID are typically allotted in the months of July through November, when producers are permitted to ship the equivalent of between 0.5 and 4 additional days of milk during the month, depending on the year. Summer-increasing herds filled 3 to 5% less of their added ID over the summer period. Within-month summer BMSCC standard deviation also significantly increased as the severity of summer BMSCC increased. Annual BMSCC was different among all groups. Although the magnitude was small, a significant trend

existed, where HSI herds had the lowest annual BMSCC (228,000 cells/mL), followed by low nonsummer (238,000 cells/mL), MSI (239,000 cells/mL), and LSI (245,000 cells/mL) herds (Table 3).

Characteristics of Summer Seasonal Herds

In univariable analysis, 11 variables were associated with seasonality classification, and 10 remained significant in the final multivariable model (Table 4). Herds experiencing medium to high increases in BMSCC in the spring or summer of the previous year had increased odds of being classified as an HSI herd in the subsequent year. Similarly, an MSI or HSI classification in the summer 2 yr previous (i.e., summer of 2004 if the

Figure 2. Distribution of the season in which the highest bulk milk SCC occurred in all herds in Ontario, Canada: summer (black), fall (gray), spring (striped), and winter (white).

current year is 2006) were again positively associated with classification as HSI in the current year. The odds of being classified as an HSI herd were significantly higher for herds filling less of their MQ. This relationship was reversed when considering winter MQ fill percentage, where the higher the percent of MQ filled, the greater the odds of classification as HSI. Based on MQ, smaller herds had greater odds of classification as HSI relative to larger herds. As the average annual BMSCC decreased, the odds of experiencing HSI increased. Herds that had violative bulk milk bacterial counts were less likely to be HSI herds. Herds that recorded 3 or more monthly BMSCC greater than the regulatory threshold (until 2012) of 500,000 cells/mL had higher odds of experiencing an HSI. All of the herds that experienced BMSCC levels above the limit had annual BMSCC greater than 275,000 cells/mL (473 out of 8,022 herd-years).

For the analysis of MSI versus LSI herds, 11 variables were significant in the univariable analysis, of which 6 variables remained in the final model (Table 5). The MSI or HSI classification in either of the previous 2 yr was associated with higher odds of experiencing an MSI in the current year. Herds experiencing medium fall increases in the previous year had lower odds of an MSI

in the current year. Herds filling lower amounts of their MQ over the summer had higher odds of experiencing an MSI, although the strength of this association was also less than that observed in herds experiencing HSI classification. In addition, herds that had lower annual BMSCC throughout the year had higher odds of experiencing MSI. When controlling for other significant variables, herd size was not associated with classification as an MSI herd (relative to LSI herds).

DISCUSSION

The first objective of our study was to characterize the seasonal variability in BMSCC at the herd level. Although BMSCC for Ontario followed a consistent and predictable sinusoidal pattern, herds that contributed to this phenomenon experienced a diversity of seasonal fluctuations.

The current approach to describe summer seasonality in BMSCC was not without some drawbacks. There were areas of the yearly time series that were not adequately described by the model (Figure 1a; January and February 2011, for example). Assigning 1 sinusoidal function per herd per year was specifically employed to distill major trends in herd BMSCC levels, where

Figure 3. Comparing the proportion of herds experiencing their highest bulk milk SCC levels in the summer months (bars) with the provincial amplitude (severity) of the increase in bulk milk SCC (line).

Figure 4. Contribution to Ontario summer bulk milk (BMSCC) from 2000 to 2011 for low (black), medium (gray), and high (white) summer increasing herds.

Table 3. Comparison of median (and IQR¹) production characteristics among seasonality categories over 12 yr of analysis

Item	Low nonsummer seasonality	LSI ²	MSI ²	HSI ²
Total herd-years (n)	6,494	8,736	8,022	8,021
MQ ³ (kg of butterfat)	43.3 ^a (29.2–66.9)	46.9 ^b (31.7–74.1)	44.8 ^c (30.6–70.94)	38.4 ^d (26.3–57.4)
MQ fill (%)				
Summer	97.3 ^a (92.2–100.4)	96.7 ^b (91.4–100.0)	96.1 ^c (90.9–100.0)	95.5 ^d (89.9–99.6)
Fall	100.1 (95.8–103.2)	100.2 (95.9–103.3)	100.3 (96.1–103.5)	100.3 (95.8–103.7)
Winter	101.8 (97.3–106.4)	102.5 (98.7–107.2)	102.6 (98.8–107.5)	102.9 (99.2–108.0)
Spring	100.4 ^a (97.1–104.5)	100.2 ^b (99.9–104.0)	100.0 ^c (96.9–103.7)	100.0 ^d (96.6–103.8)
ID ⁴ fill (%)				
Summer	12.2 ^a (0–62.7)	5.78 ^b (0–53.1)	1.89 ^c (0–50)	0 ^d (0–50)
Fall	49.4 (0–89.6)	48.1 (0–89.1)	48.3 (0–90.2)	49.5 (0–90.4)
Summer SD bulk milk SCC (×1,000 cells/mL)	68 ^a (47–97)	71 ^b (48–102)	78 ^c (54–112)	90 ^d (63–128)
Mean annual bulk milk SCC	238 ^a (180–315)	245 ^b (186–321)	239 ^a (180–311)	228 ^c (176–294)

^{a–d}Values in same row with differing superscripts denote statistically differing values ($P < 0.05$).

¹IQR = interquartile range.

²Low, medium, and high summer increase in bulk milk SCC, respectively.

³MQ = milk quota.

⁴ID = incentive day.

such minor, transient increases in BMSCC appear as areas of poor model fit. Overall, the modeling strategy provided a logical, objective, and systematic method of classifying overarching herd-level trends in yearly pick-up BMSCC.

The major contributors to Ontario summer BMSCC were the 50 to 70% of herds that experienced BMSCC increases in the summer. Specifically, herds that experienced an MSI contributed the highest proportion of cells over and above the 200,000 cells/mL milk quality target. Although, by definition, there was no difference in the proportion of herds in MSI versus HSI categories, herds in the MSI group tended to be larger, producing relatively more milk than HSI herds. Similar trends in monthly SCC contributions have been in other studies (Schukken et al., 1992b; Sargeant et al., 1998; Berry et al., 2006).

Results of the current study support the observation that the summer BMSCC increase is a repeatable event within a herd. Herds that have experienced an increase in BMSCC during the summer of either of the previous 2 yr had higher odds of being classified as an HSI herd in the current year. The severity of BMSCC increase was a strong influencing factor in predicting the occurrence of summer increases in BMSCC. Herds experiencing high-amplitude BMSCC increases in the spring, summer, or fall of previous years had higher odds of experiencing an MSI to HSI in the current summer. This is not surprising, given the strong positive relationship between mean BMSCC and variability (as measured by standard deviation; Schukken et al., 1992b; Lukas et al., 2008). The LSI herds tended to have slightly, though significantly, higher levels of monthly BMSCC throughout the year, potentially leading to lower variation in

BMSCC levels throughout the summer, as seen in their lower summer BMSCC standard deviation. Nevertheless, low levels of variation in BMSCC are linked with a consistent application of best management practices for mastitis control; whereas herds that experience high levels of variation in BMSCC are likely to be smaller herds and have inconsistent management procedures (Reneau and Lukas, 2006). Management practices (or lack thereof) are highly dependent on farmer mindset and beliefs, which can be difficult to alter (Jansen and Lam, 2012), potentially leading to an increased likelihood of repeated summer BMSCC increases over time in a herd.

Although a formal supply management system for milk production exists in several countries, results of the current study uncovered potential determinants of seasonal BMSCC increase severity. Milk quota is designed to be filled and reconciled monthly, with the DFO limiting the producer's ability to compensate for over- or under-production in 1 mo by offsetting production in another month. Herds that experienced MSI and HSI filled significantly less MQ in the summer than LSI herds. There is a question of cause and effect in this situation. Increases in SCC are consistently associated with reduced milk production (Durr et al., 2008; Hand et al., 2012). High summer SCC could limit milk production and, therefore, hamper ability to fill MQ. However, herds filling a lower proportion of MQ during the summer might retain or purchase more animals to bring production back in line with quota allotment. In the face of finite facilities, this action may result in increased stocking densities that, in late gestation and early lactation, could result in a significant increase in SCC (Green et al., 2008), potentially due to increased

Table 4. Results from final multivariable logistic regressing model for comparison between LSI¹ (referent) and HSI² herds in Ontario over 12 yr of analysis

Item	Subset	Estimate	SE	P-value	OR ³
Intercept		1.49	0.36	<0.0001	4.44
Seasonality	Medium summer	0.44	0.06	<0.0001	1.56
Previous year	High summer	0.69	0.06	<0.0001	1.98
	Low fall	-0.11	0.09	0.192	0.89
	Medium fall	-0.13	0.09	0.131	0.88
	High fall	0.05	0.09	0.531	1.05
	Low spring	0.04	0.09	0.693	1.04
	Medium spring	0.33	0.09	0.0003	1.40
	High spring	0.52	0.09	<0.0001	1.69
	Low winter	0.09	0.16	0.5668	1.09
	Medium winter	-0.08	0.16	0.6299	0.92
	High winter	-0.04	0.17	0.8376	0.97
	Low summer (referent)	0			
Seasonality	Medium summer	0.14	0.06	0.025	1.15
2 years previous	High summer	0.28	0.06	<0.0001	1.32
	Low fall	0.03	0.08	0.68	1.04
	Medium fall	0.05	0.08	0.56	1.05
	High fall	0.25	0.08	0.003	1.28
	Low spring	-0.17	0.10	0.08	0.84
	Medium spring	-0.04	0.10	0.67	0.96
	High spring	0.06	0.09	0.52	1.06
	Low winter	-0.16	0.16	0.30	0.85
	Medium winter	-0.06	0.17	0.71	0.94
	High winter	-0.33	0.18	0.06	0.72
	Low summer (referent)	0.00			
Summer bulk milk SCC SD ($\times 1,000$ cells/mL)		0.02	0.001	<0.0001	1.02
Quota fill (summer)		-0.02	0.003	<0.0001	0.98
Quota fill (winter)		0.01	0.002	<0.0001	1.01
Size (kg quota)		-0.002	0.000	<0.0001	0.99
Average annual bulk milk SCC ($\times 1,000$ cells/mL)		-0.010	0.000	<0.0001	0.99
Year	2002	-0.36	0.09	<0.0001	0.69
	2003	-0.25	0.08	0.002	0.77
	2004	-2.09	0.10	<0.0001	0.12
	2005	-0.08	0.08	0.36	0.92
	2006	-0.15	0.08	0.07	0.85
	2007	-0.93	0.09	<0.0001	0.39
	2008	-0.94	0.09	<0.0001	0.38
	2009	-0.47	0.09	<0.0001	0.62
	2010	0.07	0.08	0.42	1.06
	2011 (referent)	0.000	—	—	
No. of monthly bacterial counts >121,000 cfu/mL per year	0	0.15	0.05	0.003	1.16
	1+	0.00			
Bulk milk SCC Threshold	fewer than 3 mo >500	-0.59	0.11	<0.0001	0.56
	3+ months >500	0.00			

¹LSI = low summer increase in bulk milk SCC.²HSI = high summer increase in bulk milk SCC.³OR is the odds ratio (the odds of being classified as HSI relative to LSI).

pathogen challenge from higher levels of manure contamination (Magnusson et al., 2008).

Herds experiencing MSI and HSI could have warmer farm-specific microclimates, leading to higher rates of clinical and subclinical mastitis when compared with low increasing BMSCC herds (Green et al., 2006b; Olde Riekerink et al., 2007). Indeed, Olde Riekerink et al. (2007) found the incidence of clinical mastitis due to *Streptococcus uberis* and *Escherichia coli* mastitis was highest in the summer months for pasture-based and completely confined herds, respectively. Higher rates of clinical mastitis, especially when undetected, could

exert a significant upward pressure on BMSCC, thus contributing to an increase during the summer. Further research is necessary to confirm this assertion. In addition, lack of effective heat abatement could increase the effects of summer heat stress in a herd, with concomitant production losses (West, 2003), increased rates of metabolic disease (Duffield et al., 1998), immune suppression (do Amaral et al., 2011), and lower reproductive success (Scheffers et al., 2010). Unabated summer heat might in HSI and MSI herds might also reduce conception success during the summer, which would manifest in the subsequent year with fewer cows calving

Table 5. Results from final multivariable logistic regressing model for comparison between LSI¹ (referent) and MSI² herds in Ontario over 12 yr of analysis

Item	Subset	Estimate	SE	P-value	OR ³
Intercept		0.98	0.24	<0.0001	2.68
Seasonality	Medium summer	0.28	0.05	<0.0001	1.33
Previous year	High summer	0.23	0.06	<0.0001	1.25
	Low fall	-0.11	0.07	0.115	0.89
	Medium fall	-0.26	0.08	0.001	0.77
	High fall	-0.02	0.08	0.784	0.98
	Low spring	0.07	0.08	0.382	1.07
	Medium spring	0.15	0.08	0.076	1.16
	High spring	0.16	0.08	0.075	1.17
	Low winter	-0.29	0.15	0.052	0.75
	Medium winter	-0.11	0.15	0.470	0.89
	High winter	-0.22	0.16	0.181	0.80
	Low summer (referent)	0.00			
Seasonality	Medium summer	0.06	0.05	0.26	1.06
2 years previous	High summer	0.14	0.06	0.01	1.15
	Low fall	-0.06	0.07	0.43	0.94
	Medium fall	-0.06	0.08	0.39	0.94
	High fall	0.11	0.08	0.14	1.12
	Low spring	-0.10	0.08	0.20	0.90
	Medium spring	-0.03	0.08	0.76	0.98
	High spring	-0.12	0.09	0.17	0.89
	Low winter	-0.21	0.14	0.14	0.81
	Medium winter	0.01	0.15	0.92	1.02
	High winter	-0.005	0.16	0.97	0.99
	Low summer (referent)	0.00			
Summer bulk milk SCC SD ($\times 1,000$ cells/mL)		0.01	0.001	<0.0001	1.01
Quota fill (summer; %)		-0.01	0.002	0.0002	0.99
Annual BMSCC ($\times 1,000$ cells/mL)	Average	-0.004	0.000	<0.0001	0.99
	2002	-0.03	0.08	0.68	0.97
	2003	-0.04	0.07	0.58	0.96
	2004	-0.84	0.07	<0.0001	0.43
	2005	0.08	0.07	0.26	1.09
	2006	-0.03	0.08	0.84	0.98
	2007	-0.44	0.08	<0.0001	0.64
	2008	-0.40	0.08	<0.0001	0.67
	2009	-0.08	0.08	0.32	0.92
	2010	0.09	0.07	0.24	1.09
	2011 (referent)	0.00			

¹LSI = low summer increase in bulk milk SCC.²MSI = medium summer increase in bulk milk SCC.³OR is the odds ratio (the odds of being classified as MSI relative to LSI).

in the spring and lower summer production. Further research is necessary to determine the importance and relative contribution of each of these potential risk factors in driving the summer increase in BMSCC.

Winter MQ fill percentage was also associated with severity of summer BMSCC increase. The HSI and MSI herds filled a higher percentage of MQ in the subsequent winter relative to LSI herds. This situation could also be associated with calving patterns, as herds that have had suboptimal reproductive success the previous summer could experience a rebound in conception rate over the fall. This could result in a situation where a higher proportion of cows reaching peak milk production over the late fall and early winter period of the following year, thus filling a higher proportion of their MQ. Finally, it is possible that a proportion of the increase in BMSCC occurring over the summer

could be due to a concentrating effect associated with a decrease in average daily milk production per cow. Daily milk production per cow also follows a seasonal pattern, with nadir levels occurring in the late summer and fall months (Hoving, 1998), coinciding with the highest levels of BMSCC in summer increasing herds. As milk production increases, this could produce a minor concentrating effect on SCC levels (Green et al., 2006a). Further research to confirm this hypothesis is necessary.

Smaller herds were at significantly increased odds of experiencing an HSI relative to larger herds. In all models, a higher degree of summer standard deviation in BMSCC was highly associated with experiencing classification as MSI or HSI. This finding is in agreement with other research that has found a strong positive correlation between mean and standard deviation in

BMSCC (Schukken et al., 1992b). Specifically, smaller herds are at an increased risk of exceeding BMSCC regulatory thresholds relative to larger herds, and this increased risk could be explained through higher levels of variability of BMSCC experienced by smaller herds (Lukas et al., 2008). In smaller herds, 1 cow with an increase in SCC contributes a higher proportion of cells to the BMSCC than would a single cow in a larger herd. This acts to increase BMSCC variability in smaller herds. Interestingly, when BMSCC variability (summer BMSCC standard deviation) is controlled, herd size remained associated with high summer BMSCC increases. Much of this remaining effect of herd size could be related to differences in management practices that vary with herd size (Dong et al., 2012). In that study, larger herds tended to practice stricter biosecurity, had fewer off-farm commitments, were more diligent in culling high-SCC cows, and followed hazard analysis and critical control point (HACCP) protocols. When these variables were controlled in that study, herd size had no bearing on BMSCC.

Herds that produced milk with low average annual BMSCC tended to have greater odds of experiencing an HSI relative to LSI herds. Herds whose annual average BMSCC was less than 150,000 cells/mL had the highest likelihood of experiencing an MSI and HSI relative to herds that had a monthly BMSCC greater than 275,000 cells/mL. Herds with low annual BMSCC have, on average, a higher proportion of animals with low SCC and, hence, more cows at risk of experiencing new IMI causing an increase in BMSCC over the summer. Another possible explanation could be that, as average BMSCC decreases, the relative importance of environmental pathogens increases. Several studies have reported that the incidence of mastitis due to environmental pathogens is higher in herds that maintain low SCC (Erskine et al., 1988; Barkema et al., 1998, Olde Riekerink et al., 2007).

Milk quality differed between LSI and MSI or HSI herds. Herds experiencing 1 or more months with bacterial counts above the regulatory threshold were actually less likely to be HSI herds. There is a positive association between average monthly BMSCC and bacterial count in milk (Schukken et al., 1992a). The LSI herds had higher annual BMSCC averages; however, when this was controlled, LSI herds still had slightly higher odds of experiencing high monthly bacterial counts. Elevated bacterial counts in milk are associated with a variety of factors, such as poor milking practices, improper cooling of milk, unclean or unsanitized milking equipment, and mastitis (Jayarao and Wolfgang, 2003). It is possible that including the annual BMSCC variable in the multivariable logistic model did not adequately

control for the association that higher BMSCC has with higher bacterial counts. Though the association between violative bacterial count and LSI classification had a *P*-value of 0.003, the magnitude of the odds ratio is quite low (1.16), leading one to question the practical significance of this finding. It is also possible that this is a spurious relationship. Further on-farm studies focusing on high bacterial count risk factors would be necessary to understand this relationship.

CONCLUSIONS

Summer is a period of increased risk for BMSCC increases. The proportion of herds that experience BMSCC increases in the summer poses a challenge to the maintenance of consistently high-quality milk. Herds that are smaller or produce low average BMSCC were at an increased risk for experiencing an HSI. Herds that had a recent history of high seasonal variability also had higher odds of an HSI. There was a significant association between the degree of summer seasonality and the ability to maintain milk production at farm-specific targets (MQ). These factors provide farm advisors with some direction for predicting herds that are most likely to experience significant increases in BMSCC over the summer period and, therefore, can inform targeted and specific intervention strategies that focus on the promotion of udder health practices in these herds.

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