Prevalence of and risk factors associated with skin lesions and lameness in dairy cattle in the Maritime Provinces of Canada and the use of benchmarking to motivate reductions in the herd-level prevalence of these conditions

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Abstract

Animal-based measurements, such as skin lesions and lameness, are often included in on-farm assessments for dairy cow welfare and quality assurance programs, for example proAction® in Canada. Following the introduction of proAction® in Canada in 2017, the prevalence and risk factors for these animal-based measurements for dairy cattle were studied to evaluate whether there were specific risk factors in the Maritime Provinces that could be identified and used to provide a basis to assist producers to meet the acceptable targets defined by proAction®. Using an assessment protocol that was the basis for proAction®, 79 herds housed in both tie-stall (n=33) and free-stall (n=46) barns within the Maritime provinces were evaluated twice, approximately one year apart. During these assessments numerous animal-, environmental-, and management-based measurements were collected and used to provide results and feedback to the study participants. Results were provided in both paper form and through a benchmarking website created using the data from this study, allowing for comparison of results to herds of similar size and facility type.

We found that the prevalence of hock lesions, knee lesions, neck lesions, and lameness were 39%, 14%, 1% and 21%, respectively for all free-stall cows. For the tie-stall cows assessed the prevalence of hock lesions, knee lesions, neck lesions and lameness were 39%, 17%, 5% and 15%, respectively. As management and the assessment protocol differed between facility types, risk factors for each animal-based measurement of interest were explored separately for free-stalls and tie-stalls using multivariable logistic regression. Numerous environmental-based factors, such as, stall design and management were associated with lesions on the hocks, knees, neck and

lameness in both free-stall and tie-stall facilities. An example of interest was that free-stalls with parallel type milking parlours had a lower odds of knees lesions compared to those with herringbone parlours. Free-stalls with feed barriers with partitions present at the feed-bunk had a lower odds of neck lesions. When tie-stalls had stall measurements >190cm and ≤200cm from tie rail to the rear curb, a lower odds of neck lesions was reported. When free-stalls reported having a total milking time ≥3 hours/day, with cows having the potential to have to wait in a holding area for this length of time, the odds of being lame was 2.11 times greater (P = <0.001) than those spending <3 hours a day. When bedding was classified as wet in tie-stalls, the odds of being lame was 2.66 times greater (P = 0.002) than when the bedding was dry. Numerous cow-level variables were associated with skin lesions and lameness, which included parity, daily milk production, stage of production, and body condition.

After providing producers with the prevalence of skin lesions and lameness within their herds as benchmarks, re-evaluation of the herds showed that the average reduction in herd level prevalence of hock lesions and lameness were from 42% to 37% and 19% to 16%, respectively. Although on average there were improvements between assessments, there were some herds that saw an increase in herd-level prevalence of these animal-based measurements between assessments. Changes that producers made that were associated with the reduction of within herd prevalence included: addition of barriers (i.e. partitions or locking headgates) at the feedbunk, changing the type of milking parlour (i.e. traditional parlours to AMS or rotary parlour), and increasing the number of times cows were fed a day (i.e. addition of robot feeders or feeding TMR 2-4 times daily from once daily). Changes that producers made which were associated with an increase in the within herd prevalence included: increasing the time spent observing lameness in the herd, viewing the benchmarking website and changing the type of bedding used in the stall.

The herd assessments performed on the study herds in the Maritime Provinces, showed that lesions to the hock, knee and neck and lameness were observed in dairy herds. Although differences were seen between facility types, in general, the results suggest that with improved design (i.e. meeting specific stall dimensions) and management of the stalls and feed-bunk, the number of dairy cattle with skin lesions and lameness could be reduced. Making producers aware of the prevalence within their herds is an important first step in helping in the reduction of these welfare concerns in dairy cattle. Showing producers that changes that are associated with a reduction in the within herd prevalence can be simple and easy to implement could also help motivate them to make improvements.

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LIST OF ABBREVIATIONS

AMS	Automated Milking System
AUC	Area Under the Curve
BCS	Body Condition Score
CS	Cluster Specific
DD	Digital Dermatitis
DIM	Days in Milk
HE	Heel Erosion
HT	Hoof Trimmer
K_W	Weighted Kappa
NB	New Brunswick
NS	Nova Scotia
PA	Population Average
PE	Prince Edward Island
SCC	Somatic Cell Count
SH	Sole Hemorrhage
SLS	Stall Lameness Scoring
SU	Sole Ulcer
USD	United States Dollar
WLD	White Line Disease

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Chapter 1: General Introduction

1.1 Animal-based measurements in on-farm assessments

Animal-based measurements are often used in farm animal welfare assessments. These measurements can be used to help evaluate animal welfare by using physical and physiological measurements (i.e. stress hormone metabolites (Palme, 2012)) (Veasey, 2017), in addition to observing animal behaviour (Heath et al., 2014). Animal-based measurements assessing the physical appearance of the animal are frequently used in assessing the welfare of dairy cattle, as they are reliable and repeatable between observers (Flower and Weary, 2006; Gibbons et al., 2012; Vasseur et al., 2013; Gibbons et al., 2014). Physical animal-based measurements can be used to indicate damage following an animal's interaction with the environment, allowing for comparison of cattle managed in different systems (i.e. free-stall vs tie-stall vs robotic) and cattle within the same herd. The focus of this thesis, skin lesions and lameness, are examples of physical animal-based measurements.

In order to promote good welfare and avoid animal suffering, the five freedoms were created as a guide for the use of farm animals. The five freedoms include: the freedom from thirst and hunger, freedom to express normal behaviours, freedom from pain, injury and disease, freedom from fear and distress, and freedom from discomfort (FAWC, 2009). All five of the above can be compromised when an animal is lame (Way and Shearer, 2017) and it is likely that skin lesions are associated with pain and discomfort (Kester et al., 2014). Another framework for animal welfare assessments is the Five Domains Models. The five domains being: nutrition, physical environment, health, behavioural interactions and mental state (Mellor et al., 2020). Animal-based measurements can be used as key welfare indicators to assess these domains for dairy cattle, for example skin lesions can assess the environment and lameness the health (Grandin, 2022). For the above reasons, these specific animal-based measurements are often used in animal welfare assessments for dairy cattle.

There are numerous on-farm assessment protocols designed for dairy cattle, an example in Canada is a quality assurance program implemented by the Dairy Farmers of Canada, known as proAction® (DFC, 2019). This program is required to be completed by all Canadian dairy producers in order to produce saleable milk for consumers. There are numerous aspects to proAction®, with one being on-farm animal assessments using animal-based measurements like BCS, lameness and skin lesions. An assessment of dairy cattle welfare described by Vasseur et al. (2015) is the basis for this aspect of proAction®. Vasseur et al. (2015) used the requirements and recommendations of the Canadian code of practice for care and handling of dairy cattle (NFACC-DFC, 2009) to create a scoring system for dairy producers. Examples of these requirements and recommendations include: "build stalls to minimize hock and knee injuries and allow cows to rise and lie down with ease" and routinely observe all cows for lameness (NFACC-DFC, 2009). In order to evaluate these requirements and recommendations physical animal-based measurements, for example skin lesions over the tarsal and carpal joints, BCS, and lameness scoring, along with environmental-, and management-based measurements (e.g. stall dimensions and management questionnaire) were used to develop their scoring systems. With proAction® evaluations, producers are required to meet certain thresholds for the animal-based measurements being assessed, for this reason it is of interest to broaden our knowledge on the prevalence and the risk factors of these measurements in order to help Canadian dairy producers meet the expectations for this assurance program.

The prevalence of skin lesions and lameness has been reported in other regions of Canada (Zaffino Heyerhoff et al., 2014; Solano et al., 2015; Nash et al., 2016), but little is known or reported about their prevalence in the Maritime region of Canada. For this reason, the focus of this thesis was to determine the prevalence of skin lesions and lameness on dairy herds within the Maritime Provinces of Canada and compare them with the other regions of Canada. As it was necessary to gather information in a similar manner to the previous studies and proAction®, a simplified version of the protocol described by Vasseur et al. (2015) was used. The other animal-based measurements (e.g. BCS and cleanliness), as well as the environmental-, and management-based measurements, such as stall dimensions, bedding type and stocking density, in this protocol were used to determine the risk factors for skin lesions and lameness. Previous Canadian studies explored the risk factors associated with these specific animal-based measurements for both tie-stall and free-stall housing independently (Zaffino Heyerhoff et al., 2014; Solano et al., 2015; Nash et al., 2016), but a comparison of the prevalence and associated risk factors for the two housing systems was not done. For this reason, we chose to determine the risk factors specific to free-stall and tie-stall facilities within the Maritime Provinces and compare the two housing systems.

1.2 Hock, knee and neck skin lesions

Non-accidental, chronic integumentary injuries commonly seen in dairy cows kept in stalls can present themselves in various forms, the three main ones being loss of hair, ulceration and swelling (Laven & Livesey, 2011; Gibbons et al., 2012). A full understanding of how these injuries develop is not yet known, however, it is hypothesized that there is likely a progression in development and severity from hair loss to ulcerations and major swelling (Kester et al., 2014). It is also possible that each type of injury has unique risk factors and their development is not progressive (Potterton et al., 2011). Even when injuries are scored as mild, signs of inflammation may be present. Injuries with hair loss alone, showing thickening of the epidermis on histological examination could be interpreted as an adaptive response to repeated friction to that area. When lesions are identified as ulceration and/or major swelling, signs of an inflammatory response can be noted, such as, heat and the presence of inflammatory cells in the epidermis on histological assessment (Haager, 2016). Lesions may be infected, and peri-arthritis, or hygromas can form on the affected joint, leading to limited mobility, lameness and pain. Herds with higher prevalence of severe hock lesions can have higher SCC, cull rates, death losses and lameness (Fulwider et al., 2007).

Ideally, a single standardized scoring system for skin lesions would be used to allow direct comparison between studies, however, there are several similar but slightly different scoring protocols described in the literature. These protocols all use a combination of hair loss, swelling and ulceration/breaks in the skin to assess lesions on the hock, knee or neck (Weary & Taszkun, 2000; Zurbrigg et al., 2005a; Rutherford et al., 2008; Potterton et al., 2011; Gibbons et al., 2012). Regardless of how the scores are assigned it is important that these scores are highly repeatable between and within observers.

Integumentary lesions on the limbs, specifically on the hock and knee, can have a high prevalence in dairy cows. Between 40 and 81% of cows evaluated in previous studies have injuries on one or both hocks (Kielland et al., 2009; von Keyserlingk et al., 2012; Chapinal et al., 2014; Zaffino Heyerhoff et al., 2014) and 1-43% have injuries to one or both knees (von Keyserlingk et al., 2012; Zaffino Heyerhoff et al., 2014; Nash et al., 2016). Integumentary lesions on the neck are not as commonly studied as those to the limbs. It has been reported that 9% of Canadian cows housed in free-stall facilities (Zaffino Heyerhoff et al., 2014) and 4% housed in tie-stall facilities (Zurbrigg et al., 2005a) have lesions on their necks. The prevalence at the herd-level varies, with some herds having very few to no lesions reported (von Keyserlingk et al., 2012; Zaffino Heyerhoff et al., 2014; Nash et al., 2016). Given the high level of within herd prevalence of these lesions, lowering or almost completely eliminating these injuries should be possible for dairy producers to accomplish. The prevalence of integumentary lesions is not well known in the Maritime Provinces of Canada; therefore, an aim of this thesis was to determine the prevalence of hock, knee and neck lesions in tie-stalls and free-stalls in this region. This goal will be addressed in Chapter 2.

1.2.1 Risk factors of skin lesions

It is unknown what the exact cause of integumentary lesions in dairy cattle are, but several studies have found numerous environmental-, animal- and management-based factors to be associated with them. Lesions on the limbs have been associated with the dimensions of the stall in both free-stall and tie-stall housing, for example, the odds of hock and knee lesions decreased with increasing bed length and stall width and the odds of neck lesions decreased with increased tie-rail height (Zurbrigg et al., 2005b; Keil et al., 2006; Zaffino Heyerhoff et al., 2014; Nash et al., 2016). The type of material used to form the base of the stall has also been associated with hock and knee skin lesions; the odds of observing hock lesions in free-stall facilities was higher when stalls had rubber mattresses as the base compared to deep-bedded sand stalls (Weary and Taszkun, 2000; Fulwider et al., 2007; Andreasen and Forkman, 2012; Zaffino Heyerhoff et al., 2014), whereas, in tie-stall facilities the odds of hock and knee lesions was lower on mattresses compared to mats and concrete (Nash et al., 2016). The type of bedding that is placed in the stalls can also be a risk factor for lesions on the limbs. Kielland et al. (2009) reported a higher odds of knee lesions when wood shavings were used as bedding compared to finer sawdust and Potterton et al. (2011) reported a lower odds of hock lesions when straw or sand was used compared to wood shavings/paper waste. The design and management of the stalls is important when trying to reduce the prevalence and severity or prevent hock and knee lesions.

The positioning and design of neck rails and barriers at the feedbunk have been associated with neck lesions in dairy cows (Zurbrigg et al., 2005b; Kielland et al., 2010; Zaffino Heyerhoff et al., 2014). In free-stalls post and rail barriers at the feedbunk increase the odds of neck lesions compared to barriers with partitions, such as, headlocks or diagonals (Kielland et al., 2010). These risk factors show how integumentary lesions could be reflective of the animal's interaction with their environment and whether it is appropriately designed and managed.

Characteristics of the animal themselves may also influence whether or not they will develop integumentary lesions. Cows in poorer body condition have a higher odds of lesions on their limbs compared to well-conditioned cows (Kielland et al., 2009; Nash et al., 2016). Aged cows have a higher odds of lesions on their limbs and neck compared to those in their first lactation (Kielland et al., 2009; Potterton et al., 2011; Zaffino

Heyerhoff et al., 2014; Nash et al., 2016). The stage of production has also been associated with integumentary lesions, where cows further in their lactation are at an increased risk (Kielland et al., 2009; Zaffino Heyerhoff et al., 2014; Nash et al., 2016). The latter two risk factors show that the longer the animal is exposed to the environmental risk factors, the more likely they will be to develop lesions.

In the current thesis, one goal was to explore what measurements collected during the on-farm assessments were associated with the presence of hock, knee and neck skin lesions, at both the cow and herd level. This would be done individually for tie-stall and free-stall housed cattle, looking for the similarities and differences which may exist between the two housing systems. This goal will be addressed in Chapter 2 of this study.

1.3 Lameness

Lameness is one of the most common conditions seen in cattle (Shearer et al., 2012), with up to 55% of cows showing signs of lameness in a North American study (von Keyerslingk et al., 2012). As seen in section 1.1 with integumentary lesions, variation in the prevalence exists between regions, housing/milking systems and herds. In a Canadian study only 15% of cows in AMS herds were visibly lame (Westin et al., 2016) compared to 21% found in free-stall parlour systems (Solano et al., 2015). Large variability can also be seen between herds, with reports of up to 69% and as low as 0% in Canadian free-stall herds (Solano et al., 2015). This shows that reducing the prevalence of lameness is an attainable goal for the dairy industry.

Lameness can impact the health and longevity of the animal in the herd. Lameness can lead to reduced reproductive performance (Garbarino et al., 2004; Bicalho et al., 2007) and has been associated with an increased risk of being culled from the herd early (Bicalho et al., 2007; Cramer et al., 2009), both of which result in added expenses for producers. Lameness can also have a large financial impact for producers directly through lost milk revenue from decreased production. One Canadian study found that lame cows in AMS herds produced 1.6 kg/d less than their non-lame herd-mates (King et al., 2017). Considering the above losses and the cost of treatment, each case of lameness is estimated to cost the producer $175 (USD) (Cha et al., 2010). Lowering the prevalence of lameness in dairy herds would be greatly beneficial for both animal health and profitability.

As with skin lesions, the prevalence of lameness in the Maritime Provinces of Canada are not well known. Another aim of this thesis was to determine the prevalence of lameness in Maritime dairy herds, using locomotion scoring in free-stalls and stall lameness scoring in tie-stalls. This goal will be addressed in Chapter 3.

1.3.1 Locomotion scoring

Cows tend to be quite stoic animals as they are a prey species, therefore, signs of pain may not be evident until it is severe (Anil et al., 2005; Nechanitzky et al., 2016). This can make identifying lame cows quite challenging. Observations of the posture and gait of the cow can be used to help make these identifications (Shearer et al., 2012). Visual locomotion scoring is one of the most common methods of assessing lameness. Cows are given a score on an ordinal scale, such as the five-point scale described by Sprecher et al. (1997) or the nine-point scale described by Flower and Weary (2006), based on posture, gait, presence of head bob and ability to bear weight (Shearer et al., 2012; Gardenier et al., 2021). A five-point scale is most commonly used, where a score of 1 is assigned for sound (non-lame) cows and a score of 5 for severely lame cows. This methodology of assessing cows for lameness allows for individual as well as herd-level evaluations to be executed (Shearer et al., 2012). One disadvantage of this methodology is that it is a subjective measurement, potentially affecting the validity and precision of the scores. Inter-rater reliability is typically measured using a kappa statistic (K_w) with moderate to good agreement, defined by Dohoo at al. (2009) as $K_w < 0.4$ to > 0.81, the goal when comparing scores between observers (Thomsen et al., 2008; Gardenier et al., 2021). Repeatability between observers can increase with experience and training (Flower and Weary, 2006; Thomsen et al., 2008), but intra-observer repeatability may decrease over time due to a gradual change in how observations are made, known as "observer drift" (Flower and Weary, 2006). This is a good reason why repeatability should be re-evaluated throughout a study.

1.3.2 Stall lameness scoring

When cows are restrained in their stalls in tie-stall facilities, observing cows for lameness using gait scoring is not as simple (Leach et al., 2009; Gibbons et al., 2014; Palacio et al., 2017). This is why Leach et al. (2009) reported a different methodology specifically for tie-stall housing, referred to as stall lameness scoring (SLS). This method allows observers to score cows for lameness while they remain tethered in their stalls, making it safer and less time consuming. While standing behind the animal to be scored, the observer watches for changes in the cow's behaviour which could be indicative of limb pain. These indicators are based on how the cow positions her feet in the stall when standing, as well as their weight distribution when standing and stepping from side to side. Based on the expert opinion of a veterinary surgeon, Leach et al. (2009) chose five behavioural indicators which may be demonstrated in lame cows: “regular, repeated shifting of weight from one foot to another; rotation of feet from the line parallel to the midline of the body; standing on the edge of a step; resting a foot (one foot more than another); and uneven weight bearing between feet when moving from side to side, demonstrated by more rapid movement by one foot to relieve another, or reluctance to bear weight on a particular foot”. A cow would be classified as lame if two or more of these indicators were present. Rotation of the hind claws alone was not an indication of lameness, as cows were equally likely to show this indicator when they were classified as sound using locomotion scoring (Leach et al., 2009). For this reason, Gibbons et al. (2014) adapted the methodology and chose to exclude this behaviour and provide more detailed descriptors of each indicator.

When SLS was compared to the reference standard of a five-point locomotion scoring system, where cows are classified as lame (score ≥ 3/5) or sound (score < 3), the sensitivity (Se) for classification of lameness (SLS ≥ 2 behavioural indicators) ranged from 54-68% and the specificity (Sp) was between 77% and 96% (Leach et al., 2009; Gibbons et al., 2014; Palacio et al., 2017). Not all cows identified as lame by locomotion scoring are identified as lame with SLS, likely due to them being able to tolerate pain better when standing still but not while walking. When cows were more severely lame (score ≥ 4/5) the ability to identify them using SLS improved, and the sensitivity increased to 80-90% (Leach et al., 2009).

The results from previous studies show that SLS can be used in place of locomotion scoring to provide an estimate in the prevalence of lameness in the herd for welfare assessment or research, however, this value may be over- or under-estimated depending on the number of lame cows in the herd and how many behavioural indicators are used to classify cows as lame (Leach et al., 2009; Gibbons et al., 2014). The prevalence of lameness based on the same cows in the same herd can range from 6-74%, depending on the number of observed behavioural changes that are used to classify a cow as lame (Gibbons et al., 2014). When comparing the prevalence of lameness based on locomotion scoring to the prevalence based on SLS, using only one behavioural indicator to classify lameness could lead to an overestimation, whereas, using three or more indicators could lead to an underestimation (Leach et al., 2009; Gibbons et al., 2014).

As with locomotion scoring, SLS is a subjective measurement and repeatability between observers is important. Excellent agreement (kappa coefficient ≥ 0.81) (Dohoo et al., 2009) between and within observers when classifying cows as lame based on ≥ 2 behavioural indicators has been reported (Leach et al., 2009; Gibbons et al., 2014). The percentage of exact agreement for each individual behaviour was ≥95% within observers and ≥81% between observers (Gibbons et al., 2014). SLS was previously validated by scoring video recordings of the cows (Gibbons et al., 2014). Palacio et al. (2017) validated the methodology described by Gibbons et al. (2014) by comparing scores given during live assessments to those from video recordings, reporting a Se and Sp >80% for the four behavioural indicators. Performing SLS live is a simple and efficient manner to assess lameness in tie-stalls (Palacio et al., 2017).

1.3.3 Risk factors of lameness

Lameness is a multifactorial condition with numerous environmental-, management- and animal-based risk factors which have been identified for dairy cattle. Spending more time standing idle, either in their stalls (Cook et al., 2004) or the holding area at milking time (Espejo and Endres, 2007), can increase the probability of cattle becoming lame. Providing softer surfaces to stand, such as, deep-bedded sand stalls (Chapinal et al., 2013; Solano et al., 2015; Cook et al., 2016) and rubber covered alleys in free-stalls (Vanegas et al., 2006) can help reduce the risk of lameness. Lying behaviours have also been associated with lameness and can be used to help identify individuals who are lame. Cows with longer total lying times (>14 hours/day) and longer (>90 mins/bout) and fewer lying bouts have higher odds of being lame compared to their sound herd mates (Ito et al., 2010; Solano et al., 2016).

The odds of a cow becoming lame has been found to increase with parity (Vanegas et al., 2006; Randall et al., 2015; Solano et al., 2015) and their stage of lactation (Onyiro et al., 2008; Solano et al., 2015). As with integumentary lesions, a longer exposure time to environmental conditions associated with lameness puts them at a higher risk of becoming lame. Thin cows have higher odds of lameness than those with better body condition (Randall et al., 2015; Solano et al., 2015). A fat pad known as the digital cushion is located in the bovine hoof to help absorb forces applied to the hoof when weight bearing. The thickness of this digital cushion decreases with lowering BCS, therefore, thinner cows would have less protection within their hoof increasing their risk of lameness (Bicalho et al., 2009).

As noted above, integumentary lesions on the limbs and lameness have similar risk factors. Previous studies have found that lesions on the hock and lameness are associated with one another (Potterton et al., 2011; Zaffino Heyerhoff et al., 2014). It is unknown whether cows with hock lesions subsequently become lame or if lameness leads to greater risk of lesions, however, when hock lesions are severe or infected the cow may also be classified as severely lame. If a hock lesion were to progress to arthritis and/or a hygroma, the mobility of the joint would be compromised and may be painful making the cow lame (Kester et al., 2014). When cows are lame they may spend more time lying down (Ito et al., 2010; Solano et al., 2016), and depending on the stall base could increase their risk of hock lesions.

As with skin lesions, one goal of the current thesis was to explore the cow- and herd-level measurements collected during the on-farm assessments to determine their association with lameness. There is little known or reported about the risk factors specific to tie-stall housed cattle, so for this reason, risk factors would be determined separately for tie-stall and free-stall housing to allow for comparison between the two systems. This goal will be addressed in Chapter 3 of this study.

1.4 Hoof lesions and association with locomotion scoring

In dairy cattle, lesions within the hoof are associated with 90% of lameness cases (Murray et al., 1996; van Huyssteen et al., 2020). Lesions within the hoof have been found to be a common cause of lameness in beef cattle (Newcomer & Chamorro, 2006), swine (Wang et al., 2018) and equids (Bras & Redden, 2018). In cattle these lesions are categorized based on whether the etiology of the lesion is infectious or non-infectious. Sole ulcers (SU), white line disease (WLD), and sole hemorrhage (SH) are examples of non-infectious lesions, whereas, DD, HE and interdigital dermatitis (i.e. foot rot) are examples of infectious type lesions (Cramer et al., 2009; Potterton et al., 2012; Solano et al., 2016; van Huyssteen et al., 2020). Herd-level factors that have been associated with the presence of these lesions include: herd size (Solano et al., 2016; van Huyssteen et al., 2020), milking frequency (van Huyssteen et al., 2020), access to an outdoor exercise area

(Cramer et al., 2009; Solano et al., 2016), amount of bedding and frequency that alleys are scraped down (Cramer et al., 2009). As expected, hoof lesions are also more common in older cows and those later in lactation (Solano et al., 2016; van Huyssteen et al., 2020).

When examining the hoof during routine hoof trimming, 26-46% of Canadian dairy cattle have at least one hoof lesion present. As with studies on general lameness, differences in the prevalence of hoof lesions are shown between regions, herds and housing types (Cramer et al., 2008; Solano et al., 2016; van Huyssteen et al., 2020). For example, the odds of cows having WLD or SU was lower in bedded packs and tie-stall barns when compared to free-stall barns (Solano et al., 2016) and some herds have no lesions noted during hoof trimming (Solano et al., 2016; van Huyssteen et al., 2020). Infectious type lesions, specifically DD, are one of the most commonly seen lesions in Canadian dairy herds (Cramer et al., 2008; Solano et al., 2016; van Huyssteen et al., 2020) with hoof trimmers noting up to 74% of cows being trimmed in a herd having DD (Solano et al., 2016).

If hoof lesions are the leading cause of lameness, it would be expected to see them on almost every lame cow, yet cows classified as sound based on their locomotion score may have a lesion present and vice versa (Manske et al., 2002; Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010). While studies have found that increased locomotion scores (Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010; Thomsen et al., 2012) and changes in duration and number of lying bouts (Chapinal et al., 2009; Ito et al., 2010; Thomsen et al., 2012) are associated with hoof lesions, the type and severity of the lesion can influence whether these changes are evident. van Huyssteen et al. (2020) found that only 20% of cows with DD were classified as lame, compared to

54% with SU and 58% with WLD. To date there have not been any studies looking at the relationship between hoof lesions and lameness classification based on SLS (Gibbons et al., 2014). It would be of interest to know whether certain behavioural indicators used to evaluate lameness with this methodology could help identify cows with hoof lesions. For this reason, an objective of this study was to determine the relationship between hoof lesions identified during routine hoof trimming with the behavioural indicators of SLS. This objective will be addressed in Chapter 4.

1.5 Benchmarking to motivate change

Once a herd is evaluated what can be done to increase producer’s awareness and encourage improvements to be made? Allowing producers to compare data to their peers through benchmarking is one method which could help influence producers to implement changes to their management (Chapinal et al., 2014; Atkinson et al., 2017; Sumner et al., 2018). Having access to this data can help shift the mindset of the producer away from the social norms of herd management, doing things a certain way because that is how it has always been done. A producer’s pride and identity as a farmer, along with their perception of the value of their animals can be linked with their motivation to change their management (Sumner et al., 2018). When producers are motivated to make improvements, the changes they implement resulted in reduced lameness and hock lesions (Chapinal et al., 2014) and improved udder health (Tremetsberger et al., 2015) in dairy cows. For dairy calves, changes in management after benchmarking resulted in increased growth rates and improved transfer of passive immunity (Atkinson et al., 2017). Benchmarking has also been shown to help improve animal-based measurements in swine welfare (Pandolfi et al., 2017).

Providing producers with results from on-farm assessments can help increase producer awareness of what problems might exist in their herds (Vasseur et al., 2015). Quite often the prevalence of animal-based measurements, for instance lameness, are underestimated by the producers (Higginson Cutler et al., 2017). This underestimation shows that the producers may not recognize that there is a problem that needs to be addressed, therefore, no strides are made toward improving their management. Producers may also be aware that there is a problem that needs to be addressed but feel there is a lack of time or labour to implement the necessary changes. It is also possible that producers view other health concerns on their farm with higher priority, focusing their efforts on improving that problem first (Leach et al., 2010). Even if the producers are aware of the problem, it could be difficult to determine how to manage these challenges to make improvements. Benchmarking is a way that social networking could be set up (Sumner et al., 2018). This enables producers to get ideas from those producers who are excelling. Another objective for this study was to increase awareness of the prevalence of animal-based measurements in their herd using an on-farm welfare assessment tool. These results would be used as a benchmarking tool to motivate study participants to implement changes, resulting in a reduction of integumentary lesions and lameness. This objective will be addressed in Chapter 5.

1.6 Objectives

The objectives of this thesis were to:

1. Determine the prevalence of hock, knee, and neck skin lesions and the associated risk factors in both free-stall and tie-stall facilities in Maritime Provinces of Canada. Addressed in Chapter 2.

2. Determine the prevalence of lameness and the associated risk factors in both free-stall and tie-stall facilities in Maritime Provinces of Canada. Addressed in Chapter 3.
3. Determine the prevalence of hoof lesions in tie-stalls and associations with behavioural indicators of lameness. Addressed in Chapter 4.
4. Determine whether an online benchmarking system and increased awareness of current herd prevalence of skin injuries and lameness motivate producers to improve animal welfare in their herds. Addressed in Chapter 5.

Hypothesis: The prevalence of skin lesions and lameness in the Maritime Provinces would be comparable to those in other regions of Canada. Allowing study participants to benchmark their herd assessment results with their peers would provide motivation to reduce the prevalence of skin lesions and lameness in their herds.

1.7 References

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Chapter 2: Prevalence of hock, knee and neck skin lesions and associated risk factors in dairy herds in the Maritime Provinces of Canada

Jewell, M.T., Cameron, M., Spears, J., McKenna, S.L., Cockram, M.S., Sanchez, J., Keefe, G.P., 2019. Prevalence of hock, knee, and neck skin lesions and associated risk factors in dairy herds in the Maritime Provinces of Canada. Journal of Dairy Science 102, 3376–3391.

2.1 Abstract

Skin lesions are commonly seen in dairy cattle and have been associated with animal-, environmental-, and management factors. These lesions are not only a welfare concern, but they also affect profitability. Three areas on the cattle were examined for skin lesions, the hock, knee and neck. Previous Canadian studies estimating the prevalence of lesions and the risk factors associated with them have not included the Maritime Provinces. In this study, 73 herds in the Maritime Provinces were chosen voluntarily to participate, with both tie-stalls (n=33) and free-stalls (n=40) represented. Within each herd, 67-90% of the lactating cows were selected and assessed for potential animal-, environmental-, and management-based risk factors. As the within herd prevalence of these lesions can be quite high, increasing producers' awareness of the potential risk factors, could help them reduce the prevalence in their herd. Leg lesions were scored on a four-point scale (0-3), based on hair loss, swelling and scabs, with a lesion defined as a score of 2 or 3 on at least one hock or knee. Necks were scored on a 3-point scale (0-2), with a lesion defined as score 2. For free-stalls, lesion prevalence (95% CI) for each region was: 39% (29-49%) for hocks, 14% (11-18%) for knees and 1% (<1-2%) for necks. Similarly, for tie-stalls the prevalence (95% CI) of: hock lesions was 39% (33-46%), knee lesions was 17% (13-22%) and neck lesions was 5% (3-8%). Due to differences in management and methods of assessment between facility types, tie-stalls and free-stalls were analyzed separately. Due to dichotomization of cows as having a skin lesion or not, random effects multivariable logistic regression was used to determine the risk factors for each lesion and facility type. Several environmental-based measurements, such as, the stall base, the type and dryness of bedding, and type of milking parlour were

associated with leg lesions. An environmental-based measurement that was associated with neck lesions was the design of the feed-rail barrier in free-stalls and the dimensions of the tie-rail in tie-stalls. Animal-based risk factors, such as, stage of lactation, parity, and body condition were also associated with all three types of lesions. This study showed that lesions to the hock, knee and neck were common in the Maritime Provinces of Canada. Although differences were seen between facility types, in general, the results suggest that if producers improved stall design and management and feed-bunk design, this would help reduce the number of skin lesions seen in dairy cattle.

2.2 Introduction

Skin lesions of the hock, knee and neck are common problems seen in commercial dairy operations. These types of lesions, even when mild, show inflammatory changes when assessed with histology and thermography and this suggests that they might cause pain or discomfort (Haager, 2016). Over the past decade, the global prevalence of lesions to the hock joints of dairy cattle has been reported to be 40-81% (Kielland et al., 2009; von Keyserlingk et al., 2012; Chapinal et al., 2014; Zaffino Heyerhoff et al., 2014). Studies conducted in North America reported that between 1-43% of cows had knee lesions (von Keyserlingk et al., 2012; Zaffino Heyerhoff et al., 2014; Nash et al., 2016). Although not as often studied as leg lesions, neck lesions are also of interest in terms of dairy welfare. Two Canadian studies found a prevalence of neck lesions of 4% in tie-stall facilities (Zurbrigg et al., 2005a) and 9% in free-stall facilities (Zaffino Heyerhoff et al., 2014). The overall prevalence of hock and knee lesions reported in these studies are quite high, however within individual herds the prevalence of these lesions can be very low to none (von Keyserlingk et al., 2012;

Zaffino Heyerhoff et al., 2014; Nash et al., 2016), demonstrating that reducing lesions is an achievable goal for producers.

Skin lesions to the legs of dairy cows have been associated with environmental-based measures, such as, dimensions of the stalls (Zurbrigg et al., 2005b; Keil et al., 2006; Zaffino Heyerhoff et al., 2014; Nash et al., 2016), type and amount of bedding provided (Kielland et al., 2009; Potterton et al., 2011), and the type of material used for the base of the stall (Weary and Taszkun, 2000; Andreasen and Forkman, 2012; Zaffino Heyerhoff et al., 2014; Nash et al., 2016), making them an indicator of how well the animal is interacting with their physical environment. Animal-based measures that have been associated with leg lesions include: body condition (Kielland et al., 2009; Nash et al., 2016), cleanliness of the cow (Potterton et al., 2011), the stage of production (Kielland et al., 2009; Zaffino Heyerhoff et al., 2014; Nash et al., 2016), and parity (Kielland et al., 2009; Potterton et al., 2011; Zaffino Heyerhoff et al., 2014; Nash et al., 2016).

Previous studies have found that hock lesions are associated with lameness (Potterton et al., 2011; Zaffino Heyerhoff et al., 2014). Although the causal relationship between the two is unclear, severe lameness can be seen when hock lesions are accompanied by severe swelling or infection. Hock lesions can lead to the development of arthritis and hygromas, which can limit the range of motion in the joint and cause pain (Kester et al., 2014). Hock lesions have also been associated with risks of reduced health and productivity, such as increased SCC and higher culling rates (Fulwider et al., 2007).

Although the direct cost of hock lesions is unclear, their presence can have an economic impact on the industry. Due to their association with lameness, one of the most costly health concerns in the dairy industry (Dolecheck and Bewley, 2018), hock lesions would be expected to contribute to these losses (Kester et al., 2014). It is important that producers are aware of the prevalence of lesions in their herd and what areas of management could be modified to improve the welfare of their animals and increase the profitability of their farm.

There is currently little information about the prevalence of lesions on dairy farms in the Maritime region of Canada. The goals of the current study were to establish the prevalence of skin lesions to hocks, knees and necks on dairy cattle in the Maritime Provinces of Canada, and determine associated animal-, environmental- and/or management-based risk factors.

2.3 Materials and Methods

2.3.1 Herd selection

Of a possible 588 farms available for participation from NB, NS and PE, Canada (CDIC, 2016), 80 herds (13.6%) were chosen to participate in this study based on voluntary interest. To reflect the population of herds, we aimed to have the participation of approximately 50% tie-stall and 50% free-stall herds (CDIC, 2016). Herds were eligible for inclusion in the study if they were enrolled in the regional milk recording service provided by Valacta Inc. (Sainte-Anne-de-Bellevue, Quebec, Canada) and were milking primarily Holstein cows (>80%). Enrollment of herds was based on voluntary interest in the study through advertisements in provincial dairy board newsletters, Valacta Inc. seminars on cow comfort, and through recruitment by regional veterinarians.

2.3.2 Cow selection

The number of cows assessed from each herd or management group within a herd (free-stall facilities) was determined using a sample size calculation for proportions based on the herd/group size, an estimated prevalence of 10%, a precision of 5% and an accuracy of 95%. When assessing free-stall herds with multiple groups of lactating cows, the number of cows to be assessed was calculated based on the size of each group separately when groups were: 1) not in contact with one another (e.g. separated by the feed alley) or 2) had distinctly different designs (e.g. flooring type, stall base or feed bunk rails). This would allow for the comparison of different design features within herds. However, this meant that more cows would be assessed per herd. To help decrease the time spent on-farm to perform the assessment, if management groups were in contact with one another (e.g. separated by a gate) and had similar design features, the number of cows to assess was calculated based on the total size of both groups. Cows were chosen proportionately from each group.

In tie-stalls, cows were selected for the assessment using a systematic random sampling scheme. However, in free-stall herds, a random sampling scheme was not as easily achievable, due to the assessment being completed while the cows were freely moving around. In order to compensate for this, the observers took care to select animals from different areas of the pen and animals performing different behaviours, such as lying, feeding, walking, and drinking and not just those in the proximity of the observers. Animals were selected as the observers walked through the herd until the required number of animals had been assessed. Due to the large proportion of the herd being sampled (67%-90%), this required multiple trips around the entire pen in order to achieve this. Cows were uniquely identified to ensure they were not scored multiple times throughout the process. When locking head gates were present at the feed-bunk, or assessment had to be completed during milking, cows were selected using a systematic random sampling scheme, similar to tie-stall facilities.

2.3.3 On-farm assessment

An assessment consisting of animal- and environmental- based measurements, as well as a management questionnaire as described below, were completed on-farm. Each on-farm assessment was completed by two assessors, with one always being the first author (MJ) and the other a trained research assistant from the Atlantic Veterinary College (Charlottetown, PE, Canada). A total of three observers were trained between April 2015 and May 2016 and were required to achieve an acceptable level of inter-rater agreement ($K_w > 0.6$) for skin lesions, BCS and cleanliness scoring, in order to perform on-farm assessments. This level of agreement was achieved and maintained throughout the project. Assessments on the participating farms took place between September 2015 and July 2016. Tie-stall herds that pastured their cattle were assessed in late spring, prior to the beginning of pasture season, to ensure observations reflected the effects of the housing facility on the cows as much as possible. All methods used to collect the data were approved by the Animal Care Committee at the University of Prince Edward Island (Charlottetown, PE, Canada; protocol #15-015).

Cows selected within the study were assessed for skin lesions on the hock, knee, and neck using the scoring system described by Gibbons et al. (2012). Hock and knee lesions were scored on a 4-point scale and neck lesions on a 3-point scale as described in Table 1. The BCS was assigned following the scoring chart developed by Vasseur et al. (2013) based on the Elanco Animal Health BCS for dairy cattle (Elanco Animal Health, 1996). Animals were finally assessed for cleanliness of leg, flank and udder as described in Table 2. The leg cleanliness was evaluated on the lateral aspect of the right leg, focusing on the area between the lower half of the tarsal joint and the coronary band. The flank cleanliness was evaluated on the right side of the animal focusing on the area from the upper half of the tarsal joint to the area between the hook and pin bones. Udder cleanliness was evaluated on the lower 50% of the udder, not including the teats (Vasseur et al., 2015). In tie-stall herds, these assessments took place while the animals were in their stalls. In free-stall herds, these assessments occurred in various locations within the pen, such as, standing in a stall, at the feed-bunk, and occasionally in the parlour. Regardless of the location, one observer was located behind the animal and the other in front of the animal, to ensure that all areas were fully viewed.

Another measurement collected was the height of the cow at the rump and the width at the hook bones, as described by Nash et al. (2016). In tie-stalls, this measurement was collected on all of the animals entered into the study and used to determine whether the dimensions of their stall were appropriate for their size. In free-stalls, since the cows do not have designated stalls, six of the larger animals were measured to determine whether the average stall size was appropriate for the larger animals in the group, following previously described recommendations (Vasseur et al., 2015).

Both qualitative and quantitative measurements of the environment were collected. The qualitative measurements taken during the assessment included: the type and dryness of bedding, and floor cleanliness (at the feed-bunk). The middle two stalls of each row were assessed for the quantity and quality of bedding as previously described

(Solano et al., 2015; Nash et al., 2016). The quantity of bedding was subjectively measured by visually assessing the amount of bedding covering the stall. This was assessed differently for different bedding types. For organic bedding material (e.g. straw, wood by-products) the quantity was considered to be deep if there was a layer of bedding >2 cm in depth and little if there was ≤2 cm. For sand bedded stalls the quantity of bedding was considered deep if the sand was at the level of the rear curb or higher and little if the level of the sand was below the rear curb. The herd was considered to have deep bedding if >50% of the assessed stalls were deep-bedded. The dryness of the bedding was also measured in two separate areas in these same stalls. A piece of paper towel, folded in four, was placed over the bedding sample and the observer applied pressure to the sample with their knee for three seconds. The quality of the bedding was determined to be dry, wet or very wet based on the number of layers and size of the area that absorbed moisture on the paper towel, with the highest score being the final score for that stall (Vasseur et al., 2015). The cleanliness of the floor at the feed-bunk was subjectively measured by walking up and down the area and assessing how much manure was present on the observer's boots, at least 20 minutes after the area had been cleaned. The floor was considered clean if ≤1 cm of manure was collected on the boots and dirty if there was >1 cm of manure (Vasseur et al., 2015).

Quantitative measurements that were taken during the assessment included: stall dimensions, height of feed-bunk rail and stocking density. The stall dimensions were assessed on the stalls at each end of each row and averaged across all stalls that were measured. The stall dimensions consisted of nine different aspects of stall design in free-stalls and four aspects in tie-stalls, as previously described (Zaffino Heyerhoff et al., 2014; Nash et al., 2016). The height of the feed-bunk rail was measured in free-stalls from the level of the floor on the cow-side to the bottom edge of the railing/barrier if present. The stocking density was calculated as the number of cows in the group/useable stalls.

To collect information about the general management on each farm, a questionnaire was administered by interview on-farm. The questionnaire was adapted from Vasseur et al. (2015) with the addition of questions to gain information not measured during the assessment such as: “What is the estimated time to milk the entire herd?: hh:mm”, “Do the lactating cows have access to pasture?” and “What type of facility are the dry cows kept in?”. The questionnaire consisted of 61 and 54 multiple choice and short answer questions, for free-stalls and tie-stalls, respectively.

2.3.4 Statistical analysis

All data were analyzed using Stata14 (StataCorp, College Station, TX). The experimental unit was the cow with the outcome of interest being whether the cow had a skin lesion on their hock, knee or neck or not, with outcomes being dichotomized as a lesion or not based on the scoring system described in Table 2.1. The prevalence, along with the 95% CI, of lesions to hock, knee and neck were determined at the cow- and herd-level, excluding those herds that were not included in the risk factor analysis (see results section for reasons for exclusion). The prevalence and 95% CI at the cow-level was determined from the inverse logit of the null model, in order to account for clustering within farms. Descriptive statistics (mean, standard deviation, minimum and maximum) were used to review the characteristics of the outcome variables, along with the cow- and herd-level explanatory variables. Explanatory variables for each outcome of interest were chosen based on the causal diagrams shown in Figures 2.1 & 2.2, with intervening variables being excluded from the model building process, e.g. lameness for hock and knee lesions. The unconditional association between each explanatory variable and each outcome was tested using a random effect logistic regression model, with herd as the random effect, for both facility types. If an explanatory variable was unconditionally associated with the outcome of interest ($P < 0.2$), the variable was carried forward to the multivariable regression model. The linearity of continuous variables was assessed graphically on a logit scale as well as through the use of fractional polynomials (Dohoo et al., 2009). If the explanatory variable did not have a linear relationship with the outcome it was transformed into a categorical variable, using categories based on quartiles or industry recommendations, and tested for its association with the outcome. The collinearity between the explanatory variables of interest was assessed and if any variables were highly correlated (correlation coefficient > 0.7) the most significant or biologically plausible was used for the multivariable analysis.

The final multivariable models were generated using a manual backwards step-wise process starting with all variables of interest included in the model and eliminating the most non-significant ($P > 0.05$) variable one at a time and reconsidering previously removed variables. If the removal of a variable resulted in a greater than 30% change in coefficient of a remaining variable, it was considered to be a confounder and left in the model. Biologically plausible interaction variables were tested for the remaining significant variables and kept in the model if $P \leq 0.05$ for the interaction term. Finally, diagnostics were performed on all models to assess the fit of the model. Residuals at the cow and herd-level were assessed for normality, visually with normality plots and statistically using a Shapiro-Wilk test.

The odds ratios of the risk factors of lesions to the hock, knee and neck presented in this study are CS estimates; these estimates are used to make comparisons of the odds of skin lesions within one particular herd. This type of estimate was used to compare the odds of lesions within one herd for cow-level factors, such as parity or DIM, because there is variability in these predictors within each herd. However, with herd-level predictors we wanted to compare cows within one herd to cows within another herd, therefore, CS estimates do not give us the most appropriate results. In order to correctly make comparisons between herds, a PA estimate was used. These PA estimates can also be used for cow-level variables. The cow- and herd-level predictors are shown in Figure 3 & 4. Estimates were converted from CS to PA estimates, using the following relationship: $\beta_k/\mathrm{sqrt}(1+0.346*\sigma^2_{herd})$, where – β_k is the regression coefficient from predictor "k" from the random effects model (e.g. cluster specific estimate) and σ^2_{herd}, is the herd level variance. The herd-level variance was determined using latent variables (Dohoo et al., 2009).

2.4 Results

2.4.1 Description of study population

A total of 80 herds were assessed during the study, of which 46 (58%) were free-stall and 34 (42%) were tie-stall facilities. The herds were distributed throughout the three Maritime Provinces of Canada, with 18 herds from NB, 32 herds from NS and 30 herds from PE. Within these herds, 1,523 tie-stall cows and 3,129 free-stall cows were assessed for skin lesions. There were four free-stall herds excluded from the analysis due to inconsistencies in the availability of their production data provided by Valacta Inc. Two other free-stall herds were excluded from the analysis due to their distinct differences in facility design and management, with one being the only herd not providing bedding and the other the only facility with concrete based stalls. One tie-stall herd was excluded from the analysis due to its distinct difference in facility design, as it was the only facility with cows secured in their stall by means of stanchions, where two vertical bars enclosed the neck of the cow.

The 33 tie-stall herds included in the analysis ranged in size from 26 to 148 cows, with a median herd size (interquartile range) of 60 cows (46 to 82 cows). These herds had an average milk production of 9,538 (993) kg/cow/year (mean (SD)). The 40 free-stall herds included in the analysis ranged in size from 22 to 255 cows, with a median (interquartile range) of 90 cows (51 to 121 cows). These herds had an average milk production of 10,112 (1,214) kg/cow/year (mean (SD)).

The facility design and management varied between herds. In the tie-stall herds included in the analysis, there were 19 (58%) herds that used straw or hay as bedding. There were 7 (21%) herds using a combination of straw and wood by-products, such as, shavings, sawdust or chipped construction waste and 7 (21%) herds using these wood by-products alone. For the purpose of the analysis, the latter two categories were combined as wood by-products and other. Under this bedding, the most common stall base was geotextile mattresses, which were present in 16 (48%) herds. The other types of stall bases observed in the study population were rubber mats in 11 (33%) herds and concrete in 6 (18%) herds.

In the free-stall herds included in the final analysis, we found an average stocking density of 0.97 (0.14) cows/stall. The height of the barrier present at the feed-bunk was on average 133.5 (12.0) cm, with one herd having no measurement as they had a tombstone style feed barrier. Another factor of interest about these herds is the type of milking system present on the farm. The most common milking systems were herringbone (50%) and parallel (23%) parlours. Other parlour types included parabone and flat parlours (15%). AMS were present on five farms (12%). Similarly to the tie-stall herds, the most common stall base present was geotextile mattresses, which were seen in 23 (58%) of the free-stall herds. Rubber mats were seen in 5 (12%) and a soil base was seen in 12 (30%); a soil based stall was defined as stalls with a sand or clay base. Looking at the material that was used to bed these stalls, wood by-products were used in 14 (35%) of herds, straw in 13 (33%) and sand in 7 (18%). There were six (15%) herds that were using chipped recycled construction waste, such as dry wall and lumber, as bedding.

2.4.2 Prevalence of hock, knee and neck skin lesions in tie-stalls

The cow-level prevalence of hock lesions across the 33 tie-stall herds was 39.3% (95% CI: 33.1-45.8), ranging from 11.7-75.0% within individual herds. Of the 1,477 cows initially selected, 22 were excluded from the analysis because the hock joints were too dirty to score accurately. Of the remaining 1,455 cows with complete records for hock lesions, 47, 13, 39 and 1% had a maximum hock score of 0, 1, 2, and 3, respectively. The cow-level prevalence of knee lesions across all herds was 16.6% (95% CI: 12.5-21.6), ranging from 2.2-78.2% within each herd. Of the 1,495 cows with records for knee lesions, 68, 13, 18 and 1% had a maximum knee score of 0, 1, 2 and 3, respectively. The cow-level prevalence of neck lesions across all herds was 4.7% (95% CI: 2.7-7.9), with the prevalence ranging from 0-31.4% within herds. Of the 1,500 cows with records for neck lesions, 87, 5 and 8% had scores of 0, 1 and 2, respectively.

2.4.3 Prevalence of hock, knee and neck skin lesions in free-stalls

The cow-level prevalence of hock lesions across the 40 free-stall herds was 38.7% (95% CI: 29.2-49.1). The within-herd prevalence ranged from 0-83.3%. Of the 3,108 cows assessed for hock lesions 40, 16, 42 and 2% had a maximum score of 0, 1, 2 and 3, respectively. The cow-level prevalence of knee lesions across all herds was 13.6% (95% CI: 10.5-17.6), ranging from 0-60% within each herd. Of the 3,118 cows assessed for knee lesions 73, 11, 16 and 1% had a maximum score of 0, 1, 2 and 3, respectively. The cow-level prevalence of neck lesions was 1.0% (95% CI: 0.4-2.3). The within-herd prevalence ranged from 0-21.2%. Of the 3,129 cows assessed for neck lesions 92, 4 and 4% had a score of 0, 1 and 2, respectively.

2.4.4 Factors associated with hock, knee and neck skin lesions in tie-stalls

All of the factors which were unconditionally associated with each outcome of interest were used in the multivariable analysis, as none were highly correlated. An outline of the hierarchical structure of the model, as well as the risk factors for all three outcomes, can be found in Figure 2.3. Risk factors that were significantly associated with hock lesions in tie-stall housed cows, as determined by multivariable analysis, are presented in Table 2.3. One of these factors was the type of bedding, where cows bedded with bedding material other than straw alone had 1.62 times the odds (P = 0.027) of hock lesions compared to those bedded with straw or hay alone. The proportion of random variation at the herd level explained by this model was 7%. Factors significantly associated with knee lesions in the final multivariable model are presented in Table 2.4. The proportion of random variation at the herd level was 17% in this model. Finally, the factors that were significantly associated with neck lesions in the final multivariable model are presented in Table 2.5. The proportion of random variation at the herd level explained by this model was 33%.

2.4.5 Factors associated with hock, knee and neck skin lesions in free-stalls

All of the variables unconditionally associated with the outcome of interest were used in the final analysis, as there were no highly correlated variables. The hierarchical structure of the models and their associated risk factors can be seen in Figure 2.4. The factors that were significantly associated with hock lesions in the final multivariable model are presented in Table 2.6. The proportion of random variation at the herd level explained by this model was 6%. The factors significantly associated with knee lesions in the final multivariable model are presented in Table 2.7. The proportion of random variation at the herd level explained by this model was 13%. The factors associated with neck lesions in the final multivariable model are presented in Table 2.8. The proportion of random variation at the herd level explained by this model was 38%.

2.5 Discussion

One limitation of this study was that enrollment in the study was voluntary. Therefore, the potential of selection bias exists. It is possible that herds with more lesions or poor management would not participate. Even though the study population was not randomly selected from the population, we still found a wide variation between herds for the prevalence of skin lesions to the hock, knee and neck, although the reported prevalence of lesions may be lower than if herds were randomly selected. The reported average herd size for Maritime tie-stalls was 60 cows and 120 cows for free-stall herds. The reported average yearly production across all Maritime herds was 10,187 kg/cow/year (CDIC, 2016). Due to the similarities between these average values and those found in our study population, we believe that they are representative of the farm demographics in this region.

As the management and environment of tie-stall and free-stall herds are very different, we looked at the risk factors for each facility separately. Despite these differences, similar levels of lesions were found in the two systems. In both facility types, the prevalence of hock lesions was estimated at 39%. As expected these results are comparable to previous Canadian studies using the same assessment protocols, where they found 47% of cows in free-stalls had hock lesions (Zaffino Heyerhoff et al., 2014) and 51% in tie-stalls (Nash et al., 2016), although our results are slightly lower. The prevalence of knee lesions found in the current study was 14% in free-stalls and 17% in tie-stalls. Again, our results are comparable but lower than the reported 24% in free-stalls (Zaffino Heyerhoff et al., 2014) and 43% in tie-stalls (Nash et al., 2016) in similar Canadian assessments. The prevalence of neck lesions in this study was 1% for free-stalls and 5% for tie-stalls. These results are lower than reported previously for free-stalls (9%) (Zaffino Heyerhoff et al., 2014) and equivalent to those reported for tie-stalls (4%) (Zurbrigg et al., 2005a). One potential explanation for the prevalence of lesions being lower in this study, when compared to earlier Canadian studies, could be due to the implementation of animal care assessments through proAction® (DFC, 2017). With the initiation of this program, producers have become more aware of these lesions, as they are a part of this assessment. The majority of tie-stall herds in the current study provided pasture access for their lactating cows, whereas, the previous studies selected herds with minimal access to pasture. This is potentially another reason why we found a lower prevalence of lesions in tie-stall herds, as grazing has been associated with minimizing hock and knee lesions (Haskell et al., 2006; Keil et al., 2006; Burow et al., 2013).

One risk factor that has been previously associated with hock lesions is whether the animal is obviously or severely lame (Rutherford et al., 2008; Zaffino Heyerhoff et al., 2014; Solano et al., 2015; Nash et al., 2016). As shown in the causal diagram in Figure 2.1, lameness and lesions to the hock and knee have a complex relationship, with many common risk factors. It was for this reason that lameness was excluded from the analysis in the current study, allowing us to determine the direct association that these risk factors had with leg skin lesions.

Focusing on the environmental- and management-based risk factors, in both tie-stall and free-stall facilities, we found that the lying surface was associated with hock lesions. A common choice for the stall base is mattresses, likely because they provide additional cushioning over a concrete base, in theory making it more comfortable to lie down. However, the textile covering that is placed over this cushioning can cause friction and heat to the hock joint (Weary and Taszkun, 2000), increasing the risk of lesions. In agreement with previous studies, we found that when compared to these mattresses, rubber mats were associated with more lesions in both facility types (Keilland et al., 2009; Nash et al., 2016). This could be because mattresses are more compressible compared to solid rubber mats (Fulwider and Palmer, 2004). In agreement with previous studies in free-stall facilities, soil-based stalls were associated with a lower odds of hock lesions compared to mattresses (Weary and Taszkun, 2000; Fulwider et al., 2007;

Potterton et al., 2011; Zaffino Heyerhoff., 2014). A soil-based stall, such as sand, has the ability to conform to the shape of the cow when they lie down, reducing pressure and friction to the hock joint and reducing the likelihood of a lesion. There were no tie-stall facilities with soil-based stalls in the study to make comparisons. We found that tie-stalls with a concrete stall base had a lower odds of hock lesions when compared to mattresses (Zaffino Heyerhoff et al., 2014; Lim et al., 2015). Although we did not identify the amount of bedding material as a significant risk factor, this finding might have been due to provision of adequate bedding. Perhaps producers with concrete stalls were aware of their discomfort and compensated with additional bedding. It has also been found that cows housed on concrete stalls had shorter total lying times and fewer lying bouts than cows housed on mattress based stalls (Haley et al., 2001), which would shorten their exposure time to the stall base. Comparison of these results with free-stalls was not possible, as herds with concrete base stalls were not included in our analysis.

Another factor to consider is the amount of time the cow has been exposed to the stall base. In this study, an interaction between the stall base and the stage of lactation was found for free-stall facilities, as shown in Figure 2.5. In agreement with previous studies, a trend that the odds of hock lesions tended to increase as the DIM increased was observed (Kester et al., 2014; Zaffino Heyerhoff et al., 2014; Nash et al., 2016) and as shown in the interaction plot, specifically when cows were housed on rubber mats or mattresses. The probability of hock lesions was statistically higher in this housing environment compared to soil-based stalls when cows were 100-199 DIM. At this point in the production cycle, the probability of hock lesions tended to peak when cows were housed on rubber mats and mattresses, then decreased or plateaued. This trend was not seen in soil-based housing systems. During the remainder of the production cycle there were no significant differences between stall types. These findings suggest that hock lesions are likely due to repeated trauma to the hock, over the first 100 DIM. Once an animal develops a lesion, it is likely to persist throughout their lactation. Further longitudinal studies would be required to explore this relationship.

The type of bedding material that is used to cover the base of the stall was also associated with hock lesions in both facility types. In free-stall facilities, deep-bedded sand stalls decreased the odds of lesions compared to other bedding products, such as shavings or sawdust, which can be more abrasive to the skin (Fulwider et al., 2007; Lombard et al., 2010; Andreasen and Forkman, 2012; Zaffino Heyerhoff et al., 2014). In tie-stall facilities, we found that wood by-products, such as shavings or sawdust, or a combination of these products with straw increased the odds of lesions when compared to straw alone. This agrees with previous work in both free-stalls and tie-stalls (Keil et al., 2006; Rutherford et al., 2008 Potterton et al., 2011), where straw bedding alone was found to provide a softer lying surface for the animals.

Another characteristic of the stall that was associated with hock lesions in both facility types was the length of the lying space (bed length). In tie-stalls, cows in shorter than recommended stalls had a higher odds of hock lesions than those in the recommended length stalls, which is consistent with other work focusing on tethered animals (Keil et al., 2006). Longer stalls allow the animal to stand comfortably and raise or lower smoothly, although, they can increase the risk of fecal and urine contamination (Bouffard et al. 2017). In free-stall facilities, we found an interaction between the length of the stall and the dryness of the bedding. When the bedding material was dry, the lowest probability of lesions was seen when stall length was between 186 and 207 cm, however, when the bedding material was wet, there were no significant differences between bed lengths, as shown in Figure 2.6. We would expect that having wet bedding material would increase the risk of lesions because the exposure of urine can be very irritating and reduce the barrier effect of the skin, allowing it to become damaged more easily and become colonized by bacteria (Kester et al., 2014). It is important that the bedding material provided to the animals is kept dry in order to decrease the risk of hock lesions.

Two animal-based measurements that were associated with hock lesions, that producers have the ability to influence in their herd, were the cleanliness of the cow and the BCS. In agreement with previous studies, there was a lower odds of lesions when the leg was dirty (Potterton et al., 2011). We found that the odds of hock lesions was lower when the flank region of tie-stall cows and the lower leg of free-stall cows were dirty. Although dirty animals are not desirable, the presence of dried, caked on manure could be act as a barrier for the skin, helping to prevent ulceration of the hock. It is also possible this finding could be a reflection of stall design and management. Supporting the results of other work, we found that thinner animals (<2.75) had higher odds of lesions in tie-stall facilities (Lim et al. 2015; Nash et al. 2016). Having more fat reserves would provide cushioning and additional protection over pressure points when lying down.

Focusing specifically on factors unique to tie-stall facilities, we found that the length of the tether was associated with hock lesions. In contrast to previous work, we found shorter chains decreased the odds of hock lesions (Zurbrigg et al., 2005b; Nash et al., 2016). It is uncertain why this contrasting result was found in this study. The manger wall is a stall design feature used to keep the cows from advancing in the stall, while separating their lying area from the feed-bunk. When manger walls were built 10-20 cm in height, there was a higher odds of lesions compared to those built shorter or taller than this. This measurement could be related to the type of material used for the construction of the wall, however, this information was not collected during these assessments. Future work on the stall design and construction material would be required to determine the relationship to lesions in tie-stalls.

Now focusing on lesions to the knee joint, there were no risk factors common between tie-stall and free-stall facilities. The reason for this could be due to unmeasured animal factors, such as lying duration or lying bouts or due to the differences in how these facilities are designed and managed, for example, stall dimensions. Providing stalls that are designed to fit the animal is important, especially in tie-stall housing, as the cows cannot choose which stall to lie in. In agreement with Nash et al. (2016), cows housed in narrow stalls compared with those in wider stalls had an increased odds of knee lesions in tie-stall facilities. When the cow does not fit in the stall properly, they are at a greater risk of coming into contact with design features of the stall when getting up and down. As with hock lesions, a manger wall height of 10-20 cm increased the odds of knee lesions compared with those that were higher and lower. Again, this could be influenced by the material used for the wall and further investigation into the relationship of this stall design feature and lesions on the extremities would be required. As seen with the hock lesions in this study, but in contrast to the work of Nash et al. (2016), shorter chains decreased the odds of knee lesions, but the reason for this is not clear.

As with hock lesions, the cleanliness of the cow was associated with knee lesions in tie-stall facilities. However, in contrast to the results for hock lesions in this study, cows with dirty flank regions had an increased risk of knee lesions. The reasons for a difference in the risk of hock and knee lesions based on the cleanliness of the cow were not readily apparent. This finding could be a reflection of the stall design and/or management.

When the cow lies down in the stall, the first thing her knee will come into contact with is the bedding. In contrast to hock lesions, we found that free-stall facilities bedded with shavings/sawdust had lower odds of lesions compared to other types of bedding. Sand bedded stalls usually have a large concrete curb at the front of the stall that may not be sufficiently covered. These stalls generally do not have brisket locators, therefore, allowing the cows to lie further forward in the stall, increasing the chance of their knees contacting the concrete curb. Another type of bedding that was used was recycled construction waste, which can contain very large and sharp pieces of wood that would be more traumatic to the knee joint compared to more finely processed by-products (shavings/sawdust). The type of bedding was not associated with knee lesions in tie-stall facilities. Perhaps, due to the lack of variability in the types of bedding materials that were provided in these facilities.

An interesting finding in this study was the association between the type of milking parlour and knee lesions in free-stall cattle. When compared to cows milked in herringbone parlours, cows milked in parallel parlours had lower odds of lesions and cows milked in other types of parlours had higher odds of lesions. Although focused on hock lesions only, a recent study in Sweden also found a higher odds of lesions when herringbone parlours were used compared to tandem parlours. This was believed to be due to the flow of cows through the parlour, as tandem parlours allowed for cows to enter and exit individually (Ekman et al., 2018). Although no tandem parlours were present in the current study, the flow of cattle through the parlour could be an important factor. The specific design of how cows were released from the parlour was not recorded, but most parallel parlours release all of the cows at once, rather than allowing them to leave in single file, which may reduce crowding and pushing amongst cows as they are exiting. It is also possible that this finding is a reflection of unmeasured differences in facility design and management between these herds.

One of the main factors that influences whether a herd has neck lesions or not is how the neck rail or feed-bunk is designed. By providing separation between cows at the feed-bunk, in the form of partitions or headlocks in free-stalls, the number of displacements at the feed-bunk is lowered (De Vries and von Keyserlingk, 2006; Huzzey et al., 2006). In tie-stall facilities, the location of the tie-rail is important to allow the animal to stand comfortably within the stall. We found an optimum distance of 190-200 cm from the tie-rail to the rear curb, where the lowest odds of neck lesions was seen. A stall within this size frame accommodates an average size cow comfortably and minimizes contact with the tie-rail while eating and getting up and down. Another aspect of the stall design associated with neck lesions in tie-stalls was manger wall height. When the height of the manger wall was between 10 and 20 cm high, there was a lower odds of neck lesions. The reasons for this finding are unknown and have not been noted previously. This finding could be associated with how the cow positions herself in the stall or how far she is required to reach for feed.

The parity of the cow was associated with all skin lesions, however, the pattern of the association differed between the locations. In agreement with previous work, older cows had a higher odds of knee and neck lesions compared to 1st lactation cows (Haskell et al., 2006; Zaffino Heyerhoff et al., 2014). In contrast to our findings for knee and neck lesions, we found that older cows had a lower odds of hock lesions compared to 1st lactation cows. This finding is the opposite of what other studies have found (Potterton et al., 2011; Zaffino Heyerhoff et al., 2014; Nash et al., 2016). This could be a reflection of the housing facility that the heifers are raised in. Heifers housed on straw yards (pack-bedding) had a lower prevalence of hock lesions after calving than those housed on rubber mats (Livesey et al., 2002). In our study, heifers and dry cows were housed in pack-bedded facilities in 65% of the herds, therefore, it is likely that the first exposure to a stall occurred when they joined the lactating herd. They would not be accustomed to lying within a confined space, with potentially new bedding materials, and may not fit in the stall properly. This could affect how a heifer gets up and down in the stall, increasing her risk of developing a hock lesion.

In future work, to assess the heifers and dry cows would be useful to determine if there are areas of management in these life stages that are associated with lesions. This would help determine when and where animals are most likely to develop lesions. More detailed and precise methods for recording stall management factors such as, stall cleanliness and bedding depth may have been beneficial in determining any potential associations between them and leg lesions. Additionally, looking at data from herds with activity monitoring would allow information about animal behaviour to be captured and determine their associations with lesions, for example lying times.

2.6 Conclusion

This study found that the prevalence of hock, knee and neck skin lesions can be high on dairy farms within the Maritime Provinces of Canada, however, many herds were able to achieve low levels of lesions. These results can be used as a benchmark in order to monitor changes over time and help motivate producers with higher levels of lesions to make improvements. There were several risk factors found to be related to the design of the barn and daily management which could help producers make better decisions on how to manage their herd to reduce the prevalence of skin lesions. Although similar areas of risk were identified for tie-stalls and free-stall, such as stall design and management, our study identified specific risk factors for each facility type. Having specific risk factors for each facility type can help better direct producers on where to implement changes. In general, providing soft and comfortable bedding in stalls with adequate space for cows to lie down and stand up with ease can reduce the odds of leg lesions. Designing tie-rails and feed barriers to reduce contact with the neck and decrease displacements at the feed-bunk can help lower the number of neck lesions. The animal-based factors, such as cleanliness and BCS, are other areas where producers can focus on making changes to reduce the number of lesions, as well as improving the overall welfare of their herd.

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Table 2.1. Description of scoring system used to assess hock, knee and neck lesions based on Gibbons et al., 2012.

	No Lesion		Lesion	
Score	0	1	2	3
Description for hock and knee	No swelling, no missing hair; some broken hairs present	Bald area or minor swelling (<1cm)	Moderate swelling (<2.5cm) or break in skin/scab present	Major swelling (≥2.5cm); may have bald area or break in skin
Description for neck	No swelling, no missing hair; some broken hairs present	No swelling, bald area	Swelling or break in skin/scab present	N/A

Table 2.2. Description of scoring system used to assess cleanliness of the leg, flank and udder based on Vasseur et al., 2015.

	Clean		Dirty	
Score	0	1	2	3
Description	Fresh manure splashes <50%[1] of area	Fresh manure splashes ≥50% of area	Dried on manure ≥50% of area	Dried manure on entire area

1- 50% of the area for the flank region was equivalent to standard letter sized paper for one single area of contamination.

Table 2.3. Final multilevel logistic regression model for hock lesions with cow and herd-level factors in 33 tie-stall farms in the Maritime Provinces of Canada (n= 1,314)

Variable	Category	**Herd/Cow n (%)**	Coefficient	SE	Odds Ratio	95% CI	Overall *P*-value
Stall base	Mattress	6 (18)	Referent	-	-	-	0.012
	Concrete	11 (33)	-0.96	0.33	0.38	0.20-0.73	
	Rubber mat	16 (49)	-0.11	0.27	0.90	0.53-1.51	
Bedding type	Straw/hay	19 (58)	Referent	-	-	-	0.027
	Other	14 (42)	0.52	0.24	1.69	1.06-2.68	
Manger wall height (cm)	< 10	341 (26)	-0.74	0.22	0.48	0.31-0.73	0.002
	10-19	652 (50)	Referent	-	-	-	
	≥ 20	321 (24)	-0.35	0.23	0.70	0.45-1.09	
Chain length (cm)	< 50	191 (15)	-0.58	0.24	0.56	0.35-0.89	0.019
	50-79	847 (64)	Referent	-	-	-	
	≥ 80	276 (21)	0.27	0.20	1.31	0.88-1.96	
Stall length (cm)	< 165	176 (13)	0.86	0.26	2.36	1.41-3.95	0.006
	165-174	558 (42)	0.09	0.17	1.09	0.77-1.53	
	175-184	415 (32)	Referent	-	-	-	
	≥ 185	165 (13)	0.15	0.24	1.16	0.73-1.85	
Parity	1st	441 (33)	Referent	-	-	-	<0.001
	2nd	351 (27)	-0.72	0.16	0.49	0.35-0.67	
	3rd	218 (17)	-0.68	0.19	0.51	0.35-0.74	
	4th +	304 (23)	-0.34	0.17	0.71	0.51-1.00	
DIM	<100	328 (25)	Referent	-	-	-	<0.001
	100-199	414 (31)	0.65	0.17	1.93	1.38-2.70	
	200-299	367 (28)	0.62	0.18	1.86	1.29-2.66	
	≥300	205 (16)	0.75	0.22	2.11	1.38-3.23	
Flank cleanliness	Clean	1,281 (97)	Referent	-	-	-	0.004
	Dirty	33 (3)	-1.65	0.57	0.19	0.06-0.58	
BCS	≤2.5	254 (19)	Referent	-	-	-	0.001
	2.75	513 (39)	-0.72	0.19	0.49	0.34-0.70	
	3	307 (23)	-0.38	0.21	0.69	0.46-1.03	
	≥3.25	240 (18)	-0.54	0.23	0.58	0.37-0.91	
Constant			-0.53	0.47			
Variance herd level			0.26	0.12			

Table 2.4. Final multilevel logistic regression model for knee lesions with cow and herd-level factors in 33 tie-stall farms in the Maritime Provinces of Canada (n= 1,477)

Variable	Category	Cow n (%)	Coefficient	SE	Odds Ratio	95% CI	Overall *P*-value
Manger wall height (cm)	< 10	389 (26)	-0.21	0.24	0.81	0.51-1.30	0.010
	10-19	742 (50)	Referent	-	-	-	
	≥ 20	346 (24)	-0.94	0.31	0.39	0.21-0.72	
Chain length (cm)	< 50	208 (14)	-0.51	0.27	0.60	0.36-1.02	0.026
	50-79	923 (62)	Referent	-	-	-	
	≥ 80	346 (23)	0.36	0.22	1.45	0.95-2.21	
Stall width (cm)	<120	248 (17)	0.65	0.29	1.92	1.10-3.38	0.014
	120-124	437 (30)	-0.12	0.24	0.89	0.55-1.43	
	125-134	288 (19)	Referent	-	-	-	
	≥135	504 (34)	-0.02	0.25	0.98	0.60-1.59	
Flank cleanliness	Clean	1,425 (96)	Referent	-	-	-	0.032
	Dirty	52 (4)	0.73	0.34	2.07	1.07-4.03	
Constant			-1.50	0.27			
Variance herd level			0.70	0.25			

Table 2.5. Final multilevel logistic regression model for neck lesions with cow and herd-level factors in 33 tie-stall farms in the Maritime Provinces of Canada (n= 1,360)

Variable	Category	Cow n (%)	Coefficient	SE	Odds Ratio	95% CI	Overall *P*-value
Manger wall height (cm)	< 10	362 (27)	0.88	0.37	2.41	1.16-4.99	0.026
	10-19	671 (49)	Referent	-	-	-	
	≥ 20	327 (24)	0.72	0.45	2.04	0.84-4.95	
Tie-rail to curb distance (cm)	<180	195 (14)	1.37	0.50	3.93	1.48-10.44	0.003
	180-189	319 (23)	0.45	0.47	1.56	0.62-3.93	
	190-199	514 (38)	Referent	-	-	-	
	200-209	186 (14)	1.48	0.46	4.37	1.77-10.81	
	≥210	146 (11)	0.38	0.52	1.46	0.53-4.03	
Parity	1st	465 (34)	Referent	-	-	-	0.001
	2nd	357 (26)	0.46	0.31	1.58	0.86-2.92	
	3rd	227 (17)	0.85	0.33	2.33	1.22-4.44	
	4th +	311 (23)	1.16	0.31	3.19	1.75-5.82	
Cow height (cm)	<146	284 (21)	0.44	0.37	1.55	0.76-3.18	0.016
	146-149	373 (27)	0.90	0.29	2.45	1.37-4.36	
	150-152	451 (33)	Referent	-	-	-	
	≥153	252 (19)	0.72	0.32	2.05	1.10-3.81	
Constant			-5.17	0.53			
Variance herd level			1.61	0.70			

Table 2.6. Final multilevel logistic regression model for hock lesions with cow- and herd-level factors on 40 free-stall farms in the Maritime Provinces (n=2,662).

Variable	Category	Herd/Cow n (%)	Coefficient	SE	Odds Ratio	95% CI	Overall *P*-value
Stall base	Mattress	23 (57)	Referent	-	-	-	0.137
	Rubber mat	5 (13)	0.45	0.36	1.56	0.80-3.06	
	Soil-based	12 (30)	-0.48	0.42	0.62	0.28-1.37	
Bedding type	Wood by-products	14 (35)	Referent	-	-	-	<0.001
	Recycled construction	6 (15)	0.13	0.27	1.13	0.66-1.93	
	Sand	7 (18)	-1.77	0.47	0.17	0.07-0.43	
	Straw	13 (32)	0.06	0.24	1.06	0.68-1.71	
Bedding dryness	Dry	11 (28)	Referent	-	-	-	
	Wet	29 (72)	1.30	0.50	3.66	1.39-9.65	0.009
Average bed length	<182	9 (22)	Referent	-	-	-	0.001
	182-185	9 (23)	-0.33	0.68	0.72	0.18-3.14	
	186-207	8 (20)	-0.74	0.53	0.48	0.17-1.35	
	≥208	14 (35)	0.99	0.54	2.69	0.93-7.79	
Bedding dryness x average bed length	-	-	-	-	-	-	0.009
DIM x stall base	-	-	-	-	-	-	0.008
DIM	<100	734 (27)	Referent	-	-	-	<0.001
	100-199	790 (30)	0.62	0.13	1.87	1.43-2.43	
	200-299	749 (28)	0.49	0.14	1.64	1.25-2.15	
	≥300	389 (15)	0.72	0.18	2.05	1.44-2.93	
Parity	1st	974 (37)	Referent	-	-	-	0.004
	2nd	765 (29)	-0.34	0.11	0.71	0.57-0.89	
	3rd	435 (16)	-0.42	0.13	0.66	0.50-0.85	
	4th +	488 (18)	-0.20	0.13	0.82	0.63-1.06	
Leg cleanliness	Clean	2,460 (92)	Referent	-	-	-	
	Dirty	202 (8)	-0.38	0.17	0.69	0.49-0.96	0.026
Constant			-0.93	0.50			
Variance herd level			0.21	0.08			

Table 2.7. Final multilevel logistic regression model for knee lesions with cow- and herd-level factors on 40 free-stall farms in the Maritime Provinces (n=2,696).

Variable	Category	Herd/Cow n (%)	Coefficient	SE	Odds Ratio	95% CI	Overall *P*-value
Parlour	Herringbone	20 (50)	Referent	-	-	-	0.014
	Parallel	9 (22)	-0.69	0.35	0.50	0.25-0.98	
	AMS	5 (13)	0.10	0.39	1.10	0.51-2.37	
	Other	6 (15)	0.76	0.39	2.13	1.00-4.55	
Bedding type	Wood by-product	14 (35)	Referent	-	-	-	0.024
	Recycled construction	6 (15)	1.07	0.35	2.92	1.47-5.80	
	Sand	7 (18)	0.68	0.35	1.97	0.98-3.94	
	Straw	13 (32)	0.39	0.32	1.48	0.79-2.80	
Parity	1^{st}	988 (37)	Referent	-	-	-	<0.001
	2^{nd}	771 (29)	-0.17	0.14	0.84	0.64-1.11	
	3^{rd}	442 (16)	-0.20	0.17	0.82	0.58-1.14	
	4^{th} +	495 (18)	0.52	0.15	1.69	1.26-2.27	
Constant			-2.25	0.27			
Variance herd level			0.48	0.15			

Table 2.8. Final multilevel logistic regression model for neck lesions with cow and herd-level factors on 40 free-stall farms in the Maritime Provinces (n=2,715).

Variable	Category	Herd/Cow n (%)	Coefficient	SE	Odds Ratio	95% CI	Overall *P*-value
Feed rail type	Post & rail	23 (58)	Referent				0.007
	Headlocks/ Diagonal bars	17 (42)	-1.71	0.64	0.18	0.05-0.63	
Parity	1st	998 (37)	Referent				<0.001
	2nd	775 (29)	0.67	0.36	1.97	0.97-3.98	
	3rd	445 (16)	1.27	0.37	3.58	1.72-7.44	
	4th +	497 (18)	2.18	0.34	8.85	4.54-17.28	
Constant			-4.88	0.50			
Variance herd level			2.04	0.94			

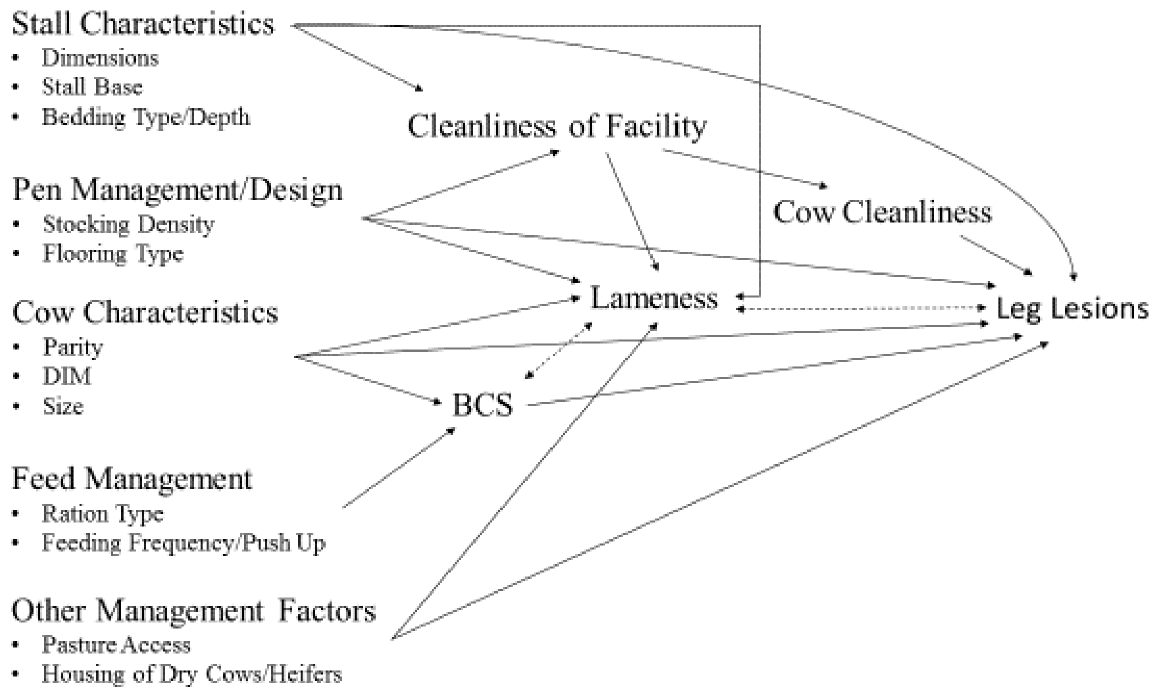

Figure 2.1. Causal diagram depicting the relationships considered between the animal-, environmental-, and management-based measurements and lesions to the hock and knee joints, in tie-stall and free-stall facilities.

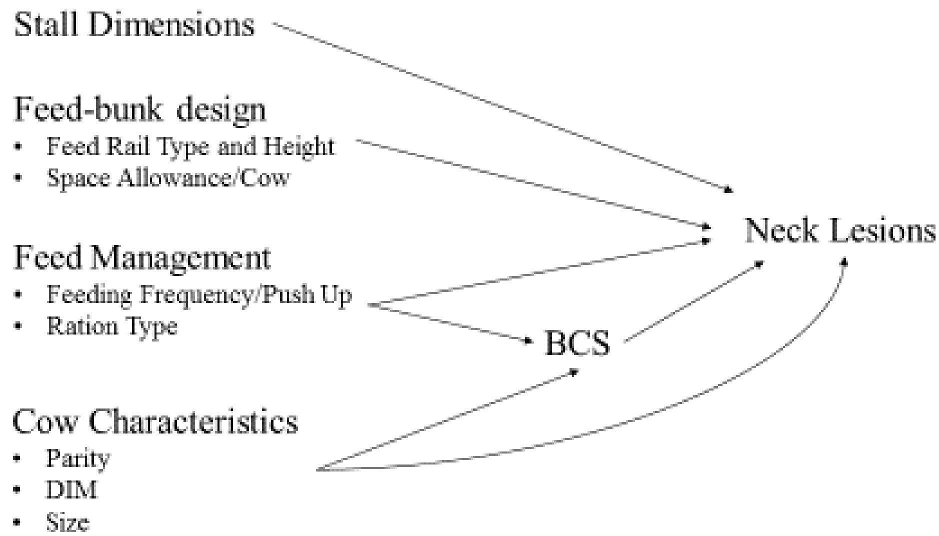

Figure 2.2. Causal diagram depicting the considered relationships between the animal-, environmental-, and management-based measurements and lesions to the neck, in tie-stall and free-stall facilities.

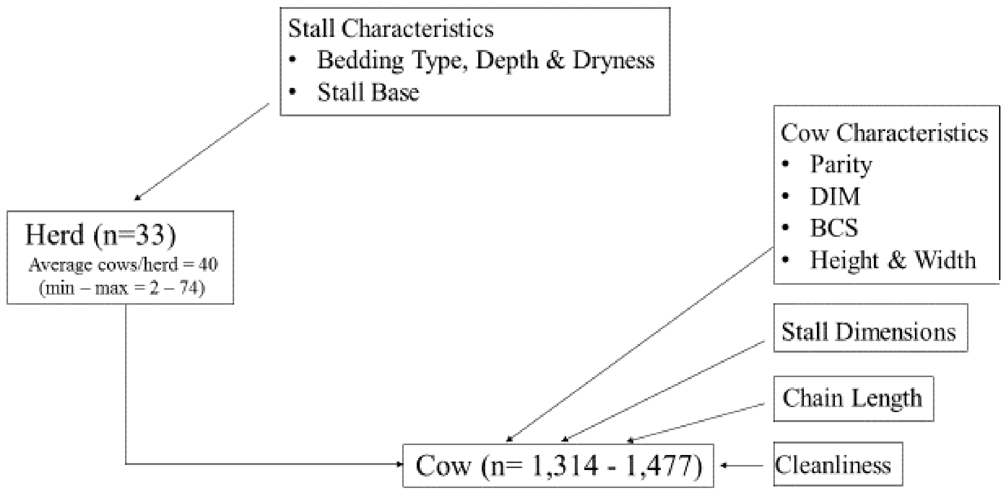

Figure 2.3. Hierarchical structure diagram illustrating the levels within the mixed effect models for tie-stall facilities, as well as the risk factors associated with these levels.

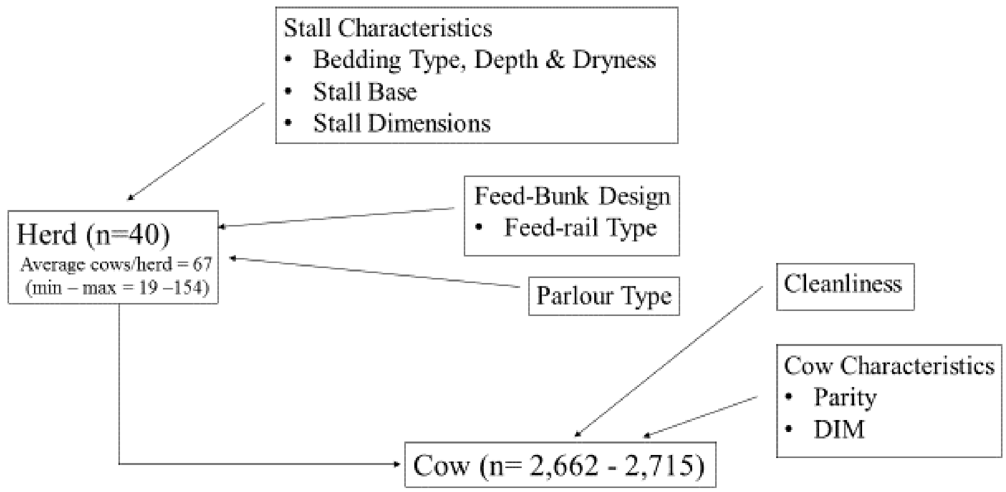

Figure 2.4. Hierarchical structure diagram illustrating the levels within the fixed effects models for free-stall facilities, as well as the risk factors associated with these levels.

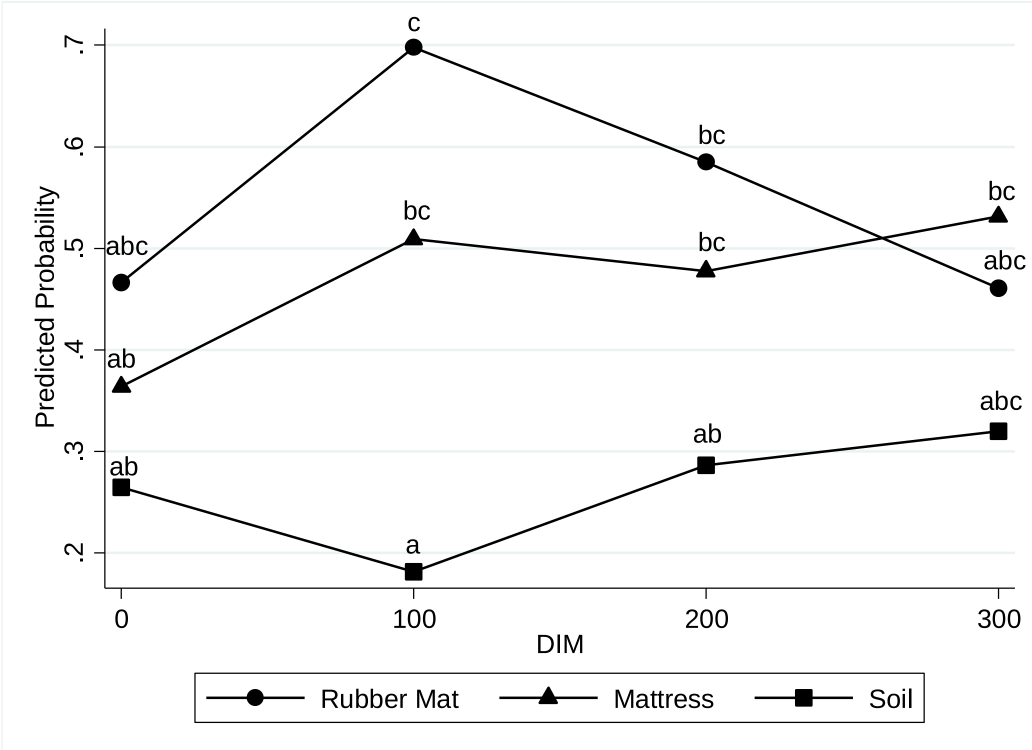

Figure 2.5. Plot of the predicted probability of hock lesions for the interaction between stall base and stage of lactation (DIM) in free-stall facilities, with all other variables being constant.

*Lettering above the points in the graph corresponds to grouping after Bonferroni adjustment for multiple comparisons, where differences in letters correspond to significant differences.

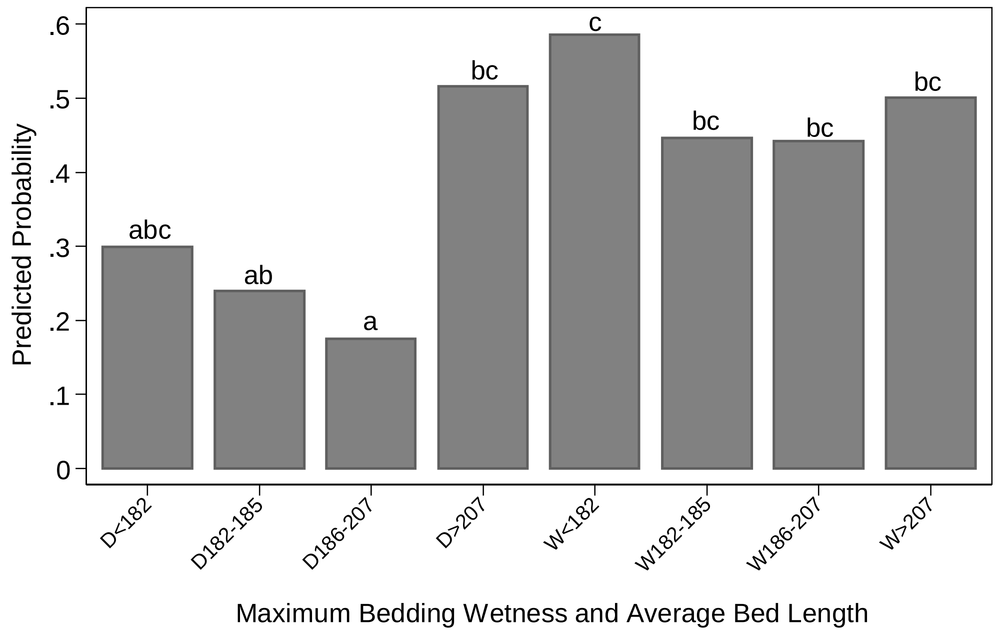

Figure 2.6. Predicted probability of hock lesions for the interaction term between bed length (cm) and bedding wetness (D = dry; W = wet) in free-stall facilities, with all other variables being constant.

*Lettering above the bars corresponds to grouping after Bonferroni adjustment for multiple comparisons, where differences in letters correspond to significant differences

Chapter 3: Prevalence of lameness and associated risk factors on dairy farms in the Maritime Provinces of Canada

Jewell, M. T., M. Cameron, J. Spears, S. L. McKenna, M. S. Cockram, J. Sanchez, and G. P. Keefe. 2019. Prevalence of lameness and associated risk factors on dairy farms in the Maritime Provinces of Canada. J. Dairy Sci. 102(4):3392-3405.

3.1 Abstract

Lameness in dairy cattle is a major issue for the industry due to the effects on the welfare of the animal, the economic impact and consumer perception. The aim of this study was to determine the prevalence of lameness and explore potential risk factors, in the Maritime Provinces of Canada. Cows were scored for lameness and potential risk factors were assessed in 46 free-stall herds and 33 tie-stall herds in NS, NB and PE. In free-stall herds, lameness was assessed using the most common method, locomotion scoring. A cow with a gait score of ≥3 out of 5 was considered to be lame. In tie-stall herds, lameness was assessed using an alternative method known as stall lameness scoring. This assessment consisted of observation of the cow for four behavioural changes: standing on the edge of the stall, shifting weight, resting a limb and uneven weight bearing when moved side to side. A cow displaying ≥ 2 of these behaviours was considered to be lame. At the time of the assessment, other animal-, environmental-, and management-based measurements were collected. These measurements were used in multivariable logistic regression analysis to determine risk factors that were associated with lameness, for both free-stalls and tie-stalls independently. The prevalence of lameness was 21% for free-stall housed cattle and 15% for tie-stall housed cattle. Of the 1,488 tie-stall housed cows that were assessed, 68% showed no behavioural changes, whereas, 15%, 15%, 2% and <1% showed 1-4 changes, respectively. In free-stalls, a higher odds of lameness was seen when cows spent ≥ 3 hours a day in the holding area for milking, compared to those that spent < 3 hours a day. In tie-stall herds, a higher odds of lameness was seen when bedding material was wet compared to when it was dry. For both lactating cow facility types, housing the dry cows and heifers on a deep bedded pack

compared to tie-stalls or free-stalls was associated with a decreased odds of lameness. There were also many cow-level variables associated with lameness which included, parity, daily milk production, stage of production, body condition and width at the tuber coxae (hook bones). If producers become aware of the risk factors associated with lameness they can make informed decisions on where to implement changes to help reduce the level of lameness in their herd.

3.2 Introduction

A common animal-based measurement in dairy welfare assessments is lameness (Whay et al., 2003). This painful condition is commonly seen in commercial dairy herds and in North American studies has been reported to affect 15 to 55% of lactating dairy cows (von Keyerslingk et al., 2012; Westin et al., 2016). The prevalence of lameness can vary depending on the region, facility type and milking system, and criteria used to determine if a cow is lame or not. For example, when assessing cattle using stall lameness scoring (SLS), the prevalence of lameness in the same population of cows could range from 6-74%, depending on the number of observed behavioural changes used to classify a cow as lame (Gibbons et al., 2014). Wide variability in the prevalence of lameness is also seen at the herd-level, for example, the reported herd-level prevalence in Canadian free-stalls ranged from 0-69% (Solano et al., 2015). Lameness is not only an important welfare concern, but has a large financial impact on the dairy industry. One reason for this is due to decreased milk production. In a recent Canadian study, King et al. (2017) found that compared to sound cows, lame cows in AMS herds produced 1.6 kg/d less. Other reasons for financial loss include reduced reproductive performance (Garbarino et al., 2004; Bicalho et al., 2007) and an increased culling risk (Bicalho et al., 2007; Cramer et al., 2009). When considering all of these factors it has been estimated that lameness costs on average 175 USD per case (Cha et al., 2010). To improve the welfare of dairy cattle and the financial outcomes for producers, the number of clinically lame cows needs to be reduced. It is important to know what risk factors are associated with lameness, as some of these risk factors may have a direct or indirect causal role, and this information may provide producers with information on when and how to intervene to decrease the prevalence of lameness in the dairy industry.

Numerous cow- and herd-level risk factors have been reported to be associated with lameness in dairy cattle. A higher risk of lameness has been found for older cows (Vanegas et al., 2006; Randall et al., 2015; Solano et al., 2015), those later in lactation (Onyiro et al., 2008; Solano et al., 2015) and under-conditioned cows (Randall et al., 2015; Solano et al., 2015). A decreased risk of lameness has been found in herds that have deep-bedded sand stalls (Chapinal et al., 2013; Solano et al., 2015; Cook et al., 2016) and rubber flooring throughout the pen (Vanegas et al., 2006). The behavioural time budget of a cow also plays a role in the risk of lameness. When a cow spends more time standing idle, whether it be in a stall (Cook et al., 2004) or in the holding area (Espejo and Endres, 2007), there is a higher likelihood that she will become lame.

There have been a few recently published studies focusing on the prevalence and risk factors of lameness in commercial Canadian dairy herds, however, these studies did not include the three Maritime Provinces (NS, NB, and PE), and focused primarily on free-stall facilities. There is currently little known about the prevalence of lameness in this region of Canada and about risk factors associated with lameness in tie-stall facilities. Therefore, the objectives of this study were 1) estimate the prevalence of lameness in the

Maritime Provinces of Canada, in both free-stall and tie-stall facilities and 2) explore relationships between lameness and various animal-, environmental-, and management-based risk factors measured on these herds.

3.3 Materials and Methods

3.3.1 Herd selection

A total of 80 dairy herds, both tie-stalls and free-stalls, from across NS, NB and PE chose voluntarily to participate in this study. The inclusion criteria for participation in the study was enrollment in the regional milk recording system provided by Valacta Inc. (Sainte-Anne-de-Bellevue, Quebec, Canada) and a milking herd consisting of primarily Holstein cows (>80%). Recruitment of herds for the study occurred through regional veterinarians, advertisements in provincial dairy board newsletters, and cow comfort seminars by Valacta Inc. The primary author (MJ), then contacted each producer by phone to ensure they met the inclusion criteria and confirmed their participation in the study.

3.3.2 Cow selection

The number of cows assessed from each herd or management group within a herd (free-stall facilities) was determined based on a sample size calculation for proportions. This calculation was based on the herd or group size, an estimated prevalence of 10%, a precision of 5% and an accuracy of 95%. Management groups or pens of lactating cows, in free-stalls, were assessed independently if they were not in contact with each other and/or had major differences in design. Factors which were considered as major differences were flooring type, stall base, feed-barrier type, and bedding. When this occurred, the required number of animals to assess was determined based on each individual group size. When management groups were separated only by a gate and were designed similarly, the groups were treated as one. The number of animals required was calculated based on the total size of the groups and animals were selected proportionately from each of the pens within this overall grouping.

In tie-stalls, cows were selected for the assessment using a systematic random sampling scheme. However, in free-stall herds, a random sampling scheme was not as easily achievable, due to the assessment being completed while the cows were freely moving around. In order to compensate for this, the observers took care to select animals from different areas of the pen and animals performing different behaviours, such as lying, feeding, walking, and drinking and not just those in the proximity of the observers. Animals were selected as the observers walked through the herd until the required number of animals had been assessed. Due to the large proportion of the herd being sampled (67%-90%), multiple trips were required around the entire pen in order to achieve this. Cows were uniquely identified to ensure they were not scored multiple times throughout the process. When locking head gates were present at the feed-bunk, or the assessment had to be completed during milking, cows were selected using a systematic random sampling scheme, similar to that used in the tie-stall facilities.

3.3.3 On-farm assessments

During each herd visit numerous animal-, environmental-, and management-based factors were measured. These visits were completed between September 2015 and July 2016 and measurements were collected by two trained observers, one of which was always MJ and the other a student or technical assistant from the Atlantic Veterinary

College (Charlottetown, Prince Edward Island). Observers were trained following previously described methods (Gibbons et al., 2012; Vasseur et al., 2013) and were required to achieve an inter-observer agreement level of a weighted Cohen's *Kappa* >0.6 prior to completing assessments on farm. This level of agreement was achieved and maintained. Tie-stall herds that allowed their herds access to pasture were assessed in the late spring (at the end of their winter housing period) to ensure the observations reflected the housing environment as well as possible. All methods used to collect the data were approved by the Animal Care Committee at the University of Prince Edward Island (Charlottetown, PE, Canada; protocol #15-015).

3.3.4 Animal-based measurements

The cows selected to be in the study were assessed for the outcome of interest, lameness, by the primary observer (MJ) using live scoring. The type of lameness assessment performed differed between the two facility types. In free-stall herds, lameness was assessed using locomotion scoring with a numerical ranking, as previously described (Flower and Weary, 2006; Solano et al., 2015), where cows with a score of ≥3/5 were considered lame. The gait of the cow was observed when the animal was walking at a normal pace and travelling in a straight path, throughout the pen.

In tie-stall herds, cows were evaluated using SLS as previously described (Leach et al., 2009; Gibbons et al., 2014; Palacio et al., 2017). With this method, the animals were evaluated in their stall for four behavioural changes: standing on the edge of the stall, resting one hind limb, shifting weight between hind limbs and uneven weight bearing when moving side to side. The cows were required to stand for at least 3 minutes (Leach et al., 2009; Gibbons et al., 2014) prior to beginning the assessment. Following the protocol of Gibbons et al. (2014), the cow was observed undisturbed from behind for 30 seconds and evaluated from different angles for behavioural changes. Then the cow was encouraged to step side to side, 2 to 4 times, to assess weight bearing in the hind-limbs. The cow was observed after movement for another 30 seconds for behavioural changes. A cow with two or more behavioural changes was considered to be lame.

Other animal-based measurements assessed on-farm were BCS, cleanliness, width and height of the cow. The BCS of the cow was assessed using the scoring chart described by Vasseur et al. (2013). Cows were scored on a scale of 1 (emaciated) to 5 (obese), with increasing increments of 0.25. The cleanliness of the leg, flank and udder were scored on a 4-point scale based on the amount and freshness of fecal contamination present, as shown in Table 1 and described previously (Vasseur et al., 2015; Solano et al., 2015). The area of the leg that was assessed was between the coronary band and lower half of the tarsal joint on the lateral aspect of the right limb. The flank region was defined as the area between the upper half of the tarsal joint and the level of the hooks and pins. Again, this was assessed on the right side of the animal. Given that the accumulation of contamination is primarily though manure splashed on the lower limb while walking, it is reasonable that there would be a balanced distribution for lower leg cleanliness. Cows appear to have no preference for which side they lie down on (Forsberg et al., 2008). Therefore, it would be expected that the distribution of manure contamination would be equally distributed on the right and left side. For consistency between cows and to reduce the amount of time spent on animal-based measurements, evaluation of the right side only was chosen. In tie-stalls, each animal was measured for the width between the tuber coxae (hook bones) and their height at the level of the rump (Nash et al., 2016).

3.3.5 Environmental- and management-based measurements

During the assessment of the herd, quantitative and qualitative measurements were taken from the environment, including stall dimensions, both bedding quality and quantity, and stocking density. The stall dimensions were measured on the stalls at either end of each row and averaged to determine the herd's stall size (Zaffino Heyerhoff et al., 2014; Solano et al., 2015). The stall dimensions included nine stall aspects (e.g. stall width and rear curb height) in free-stalls and four stall aspects (e.g. tie-rail height and manger wall height) in tie-stalls. Cows in tie-stalls had designated stalls, therefore, the stall width and length of each individual cow was determined (Nash et al., 2016). The bedding quantity and quality were measured on the two middle stalls of each row. The quantity of bedding was determined by visual assessment of the entire stall. For organic bedding materials (straw, shavings) the presence of >2cm of bedding was considered deep and ≤ 2cm was considered sparse. When stalls were bedded with non-organic materials (sand) the quantity of bedding was determined by the level of the rear curb, with presence at or above the level considered deep and below this level considered sparse (Zaffino et al., 2014; Solano et al., 2015; Nash et al., 2016). At the herd level, the overall depth of bedding, regardless of the type, was considered deep if >50% of the measured stalls were deep bedded. The quality of the bedding was then assessed on these same two stalls in each row. This was done by measuring the dryness of the bedding from two areas of each stall. A piece of paper towel folded into four was placed under the knee of the observer, who applied pressure to the bedding for three seconds. The quality of the bedding was determined as dry or wet based on the number of layers and size of area on the paper towel that absorbed moisture, with the highest score being assigned to each stall

(Vasseur et al., 2015). The stocking density was calculated as the number of cows in the herd or group divided by the number of useable stalls.

A questionnaire, developed and utilized by Vasseur et al. (2015), was administered by interview to each producer or farm manager. A total of 61 and 54 questions, for free-stalls and tie-stalls, respectively were asked during this interview. Multiple choice questions and open end questions captured information about the management that may not have been measurable during the visit, such as, frequency of hoof trimming, length of time needed to complete milking, and type of facilities the dry cows and heifers were reared in. The questionnaire also contained ranking questions that captured the thoughts and opinions of the producers on what causes lameness in cattle, along with what factors prevent them from treating lameness promptly, such as lack of time, expense of treatment and ease of getting a hoof trimmer.

3.3.6 Statistical analysis

All data were analyzed using Stata14 (StataCorp, College Station, TX). The experimental unit was the cow, with the outcome of interest being whether the cow was classified as lame, according to the scoring scheme. The prevalence of lameness in both facility types was determined at the cow- and herd-level. The prevalence and 95% CI at the cow-level was determined from the inverse logit of a null model, in order to account for the clustering effect within farms. Descriptive statistics (mean, standard deviation, minimum and maximum) were used to review the characteristics of the outcome variable, as well as cow- and herd-level explanatory variables presented in the causal diagram in Figure 3.1. Any intervening variables identified in the causal diagram were not included in the model building process. Using a random effect logistic regression model, with herd as the random effect, the unconditional associations of the explanatory variables and the outcome were tested for each facility type. Continuous variables were assessed for linearity graphically on a logit scale and by fractional polynomials (Dohoo et al., 2009). If the relationship was determined to be non-linear, the variable was categorized based on quartiles or industry recommendations, and then tested for associations with the outcome. Variables that were unconditionally associated ($p \leq 0.2$) with the outcome were carried forward to a multivariable logistic regression model. Prior to beginning the multivariable analysis, the explanatory variables were assessed for collinearity. If variables were highly correlated (correlation coefficient > 0.7), the variable that had the strongest statistical association was considered for multivariable analysis.

Through a manual backwards step-wise process, the final multivariable mixed effects models were generated. This method started with all variables of interest in the model and continued by elimination of the most non-significant ($p > 0.05$) variable one at a time, with addition of previously removed variables. If (a) the removal of a variable resulted in a greater than 30% change in the coefficient of a remaining variable, (b) it preceded and was associated with the outcome and (c) was not an intervening variable in the causal diagram, the variable was considered to be a confounder and left in the model. Once the final variables were decided, biologically plausible interactions between them were tested and kept in the model if significant ($p \leq 0.05$). The fit of the model was assessed by checking the herd-level residuals for normality, both visually and statistically with a Shapiro-Wilk test. If outliers were identified, the effect of this herd on the model was determined by removing them from the analysis. If there was a significant difference in the results, they would be considered for permanent removal.

The results presented in this study are presented as CS estimates. These estimates are appropriate for making comparisons of two animals within the same herd for cow-level factors, such as DIM and BCS. Since herd-level factors are unlikely to vary within the same herd, we wanted to make comparisons between two cows from two different herds. To make this comparison accurately, it was more appropriate to use PA estimates. To accomplish this, the variance components were calculated using latent variables and cluster-specific estimates were converted to population-averaged estimates, when deemed appropriate, using the following equation: $\beta_k/sqrt(1+0.346*\sigma^2_{herd})$, where – β_k is the regression coefficient from predictor "k" from the random effects model (i.e. cluster specific) and σ^2_{herd}, is the herd level variance (Dohoo et al., 2009). The hierarchical structure of the data, as well as which factors are considered herd-level and cow-level predictors, is depicted in Figures 3.2 & 3.3.

3.4 Results

3.4.1 Description of study population

A total of 80 commercial dairy herds were assessed, of which 34 (43%) and 46 (57%) were tie-stalls and free-stalls, respectively. These herds were distributed throughout the Maritime Provinces, with 18 in NB, 32 in NS and 30 in PE. Due to major differences in housing design, it was decided to exclude one tie-stall herd from the analysis; this herd was the only one housing the lactating cows in stanchions. Similarly, two free-stall herds were excluded from the analysis because of differences in housing design and management; one herd was the only barn with concrete stalls and the other was the only herd not providing bedding material. Another four herds were excluded from the analysis due to inconsistencies in the availability of their production records.

The 33 tie-stall herds that were included in the analysis had a median herd size (interquartile range) of 60 cows (46-82) and ranged in size from 26 to 148 lactating cows. The average production (mean (SD)) of these herds was 9,538 (993) kg/cow/year. Of the 1,347 cows in this group with production records, the average daily individual production was 33.6 (9.32) kg, based on the test date data closest to the visit date. This group of cows were on average 186 (114) DIM. Of the 1,498 cows in this group that were measured for width between hook bones, the average width was 63.9 (4.7) cm. An explanatory variable of interest was where the dry cows and heifers were housed prior to calving. There were 13 tie-stall herds (39%) that housed the cows in a pack bedded housing facility, or straw yard. The other 20 herds (61%) had either tie-stall or free-stall housing for dry cows and heifers. The remaining herd- and cow-level explanatory variables in this study are described in Tables 3.2 & 3.3, respectively, along with the results from the univariable analysis for tie-stalls.

The 40 free-stalls included in the analysis had a median herd size (interquartile range) of 90 cows (50-121) and ranged in size from 22 to 255 lactating cows. These herds were producing on average 10,112 (1,214) kg/cow/year. Of the 2,719 cows in this group with production records from the test date closest to the visit, the average daily individual production for these cows was 33.7 (10) kg. These animals were on average 182 (116) DIM. The measurement of the stall dimensions in these herds showed that the average height of the brisket board was 9.8 (7.1) cm. There were three main types of stall bases used in these herds with the most common being mattresses (58%). Soil-based stalls, which were defined as either a sand or clay base, were the next most common (30%) type of stall base and the least common were rubber mats (12%). The distribution of the other herd- and cow-level variables of interest in this study can be found in Tables 3.4 & 3.5, respectively, along with the results from the univariable analysis for free-stalls.

3.4.2 Prevalence of lameness

The prevalence of hind limb lameness for tie-stall housed cows was 15.3% (95% CI: 12.5-18.6). The prevalence of lameness at the herd-level for tie-stalls ranged from 0-30.6%. Of the 1,488 cows evaluated using SLS, 1,012 (68%) had no behavioural changes, while 230 (15%), 216 (15%), 28 (2%) and 2 (<1%) had 1 to 4 behavioural changes, respectively. Of all cows evaluated, 22% were bearing weight unevenly, 14% were resting one foot, 9% were repeatedly shifting weight and 6% were standing on the edge of the stall.

The prevalence of lameness for free-stall housed cows was 20.7% (95% CI: 17.7-24.1). At the herd-level, the prevalence of lameness in free-stalls ranged from 0-52.3%. Lameness scores were recorded dichotomously as <3/5 or ≥3/5, so no comments can be made on the distribution of severity in lameness.

3.4.3 Risk factors associated with lameness

As there were no variables found to be highly correlated (0.7), for either facility type, all of the variables that were significant after univariable analysis were used for the multivariable analysis. The results indicate that, in tie-stall facilities, when the bedding was wet there were 2.66 times higher odds of lameness than when the bedding was dry. The remaining results and risk factors significantly associated with lameness for tie-stall facilities in this study are presented in Table 3.6. The variability between herds that was unexplained by the final model was 9%.

Results from the analysis for free-stall facilities indicate that cows with a holding time ≥ 3 hours a day and cows in AMS herds had 2.11 and 1.67 higher odds of being lame, respectively, when compared to cows that were in the holding area for < 3 hours a day. The results from the final multivariable model for free-stalls and the risk factors significantly associated with lameness are presented in Table 3.7. The variability between herds that was unexplained by this model was 3%.

3.5 Discussion

Eighty herds (13.6%), of a possible 588 farms available for participation from the region, were chosen voluntarily for this study. Within the Maritime Provinces, there are approximately 50% tie-stall and 50% free-stall, of which 5% are AMS herds, as reported by The Canadian Dairy Information Centre (CDIC) (2016). The average herd size for tie-stall herds in this region is 60 cows and the average herd size for free-stalls is 120 cows, with an average yearly production of 10,187 kg/cow/year (CDIC, 2016). The study population consisted of a similar demographic, with 43% tie-stall and 57% free-stalls of similar average size and production levels, and therefore, a good representation of the farm demographics in the Maritime region.

In this study, we found that the prevalence of lameness in free-stall herds was 21%, which is similar to levels reported in a recent Canadian study of free-stall herds in Ontario, Alberta and Quebec (Solano et al., 2015). In this study, the prevalence of lameness in tie-stalls was lower than that of free-stalls, at 15%, and also lower than the most recent Canadian reports of 25% (Nash et al., 2016; Bouffard et al., 2017). The majority of tie-stall herds that were included in the current study had access to pasture during the summer months, whereas, the previous study included herds that did not graze their animals. Grazing has been found to decrease the risk of lameness (Onyiro et al., 2008), therefore, the lower prevalence in this study could be because cows were not kept housed year-round. Lameness was determined using two different methods in this study, therefore, making it difficult to compare the prevalence of lameness in free-stall and tie-stall herds. It is possible that the prevalence of lameness in tie-stall herds is underestimated as the method of assessment evaluated the hind limbs only, whereas, locomotion scoring in free-stalls captured both hind- and fore-limb lameness. It is also possible that SLS was unable to classify all lame cows correctly, as it was found that when comparing SLS to locomotion scoring, 24% false negatives were identified (Gibbons et al., 2014). That study concluded that this method is useful to estimate the prevalence of lameness in a herd, but is not as accurate at determining individual cow lameness. For these reasons, we should not make comparisons in the prevalence between tie-stalls and free-stalls in this study.

Due to cows in free-stall facilities being assessed anywhere throughout the pen, the surface in which cows were walking on could differ between herds and within herds. Gait scores have been found to improve when cows are walking on higher friction surfaces, such as rubber flooring, when compared to concrete (Telezhenko & Bergsten, 2005; Flower et al., 2007). In the current study, the majority of herds were assessed on concrete flooring (93%) and the type of flooring was not associated with lameness. For these reasons, there should be limited concern that all herds were not assessed on similar surfaces.

Due to the enrollment in the study being voluntary a potential for selection bias exists, as those with higher levels of lameness and poor management are more likely to decline participation. Even though the study population was not randomly selected from the target population, we still found a wide variation between herds for the prevalence of lameness. It is possible that the prevalence of lameness reported in this study could be under- or overestimated, compared to if a random selection of herds was completed.

Although the methods of assessment were different and management differs between facility types, there were similar risk factors associated with lameness in tie-stalls and free-stalls. In both facility types, we found that the majority of the variation explained by the logistic regression models was at the cow-level, as demonstrated in Figures 3.2 & 3.3, which is in agreement with previous studies (Solano et al., 2015). Although the majority of the risk factors were at the cow-level, there were a few herd-level factors which may have a direct or indirect causal role in lameness. Implementing changes in these areas could help producers reduce the prevalence of lameness in their herds. In free-stall facilities, the amount of time that cows spend away from the pen, specifically during milking impacts the time budget of the animal and their hoof health (Cook et al., 2004; Espejo & Endres, 2007). We found that when cows spent ≥ 3 h away from their pen, they were 2.11 times more likely to be lame than those who spent less than 3 h away from the pen. Although cows in AMS do not spend much time away from their pen, we found that they were 1.67 times more likely to be lame than those in traditional parlour systems with a waiting time of less than 3 h. These results could be a reflection of facility design and management factors which were not found to be significantly associated with lameness in our study, but have been previously associated with lameness, specifically in AMS herds. These factors include the frequency of alleys being scraped, stocking density, stall dimensions and width of the feed alleys (King et al., 2016; Westin et al., 2016). As there were only five AMS herds in the current study, it would have been beneficial to have more herds to compare them with traditional parlour systems.

Another herd-level risk factor in free-stalls was the type of stall surface that was used. In agreement with other studies, we found that cows housed on soil-based stalls were less likely to be lame than those on mattresses (Chapinal et al., 2013; Solano et al., 2015; Cook et al., 2016). This finding could be a reflection of how much bedding was provided, as previous studies have found that providing deep bedding was associated with a lower risk of lameness (Chapinal et al., 2013; Solano et al., 2015). Although the depth of bedding was not significantly associated with lameness in the current study, all 11 herds with soil-based stalls had deep bedding, whereas, only 10 of the 24 herds (42%) with mattresses had deep bedding. Although lying behaviour was not measured in our study, the difference found between soil-based stalls and mattresses in the current study could also be a reflection of this behaviour. Cook & Nordlund (2009) reported that when lame cows were housed on sand-based stalls the softer, deeper bedding, allowed for traction and ease to rise and lower in the stall. For this reason, lame cows spent more time lying in the stalls providing them more time to recover, compared to lame cows on mattresses who spent more time standing idle in the stall.

In tie-stall facilities, we found that cows housed on wet bedding had 2.5 times higher odds of showing behavioural changes of lameness, than those housed on dry bedded stalls. Experimental studies have shown that exposure of bovine hooves to urine and fecal contamination causes the hoof to swell and soften (Gregory, 2004; Gregory et al., 2006). Although the relationship between claw hardness and hoof lesions is not easily defined, there is some evidence to support that cows with softer claws are at an increased risk of developing more severe hoof lesions (Borderas et al., 2004), which may result in increased gait scores (Flower and Weary, 2006). It is important to keep the environment that cattle are housed in clean and dry in order to reduce the prevalence of lameness in dairy cattle.

Another aspect to consider is where the dry cow and heifers are housed prior to entering the lactating herd. In this study, we found that when cows were housed in deep-bedded straw packs during this stage of their lactation cycles, there was a lower odds of lameness compared to when they were housed in tie-stalls or free-stalls during the dry period, regardless of the lactating cow facility type. Placing cattle on straw packs has been shown to help heal hoof lesions, such as sole ulcers and white line disease (Livesey et al., 1998), therefore, housing animals in this type of facility during the dry period could aid in treating lame cows. Housing cattle on straw packs has two main benefits for hoof health; first, it decreases the mechanical stress placed on the sole and second, cattle lie down for longer when compared to free-stall housed cattle (Webster, 2002). Providing pack bedding during the dry period, or even during the lactation, would likely be beneficial for the older animals in the herd by improving their hoof health and ultimately the longevity of the herd. In free-stall facilities, an interaction with dry cow housing and leg cleanliness was also identified, as shown in Figure 3.4. These results show that, when cows are housed in tie-stalls or free-stalls during the dry period, the cleanliness of the leg does not significantly change the odds of being lame. When cows are housed in pack bedded facilities, the odds of becoming lame are significantly lower when the hind-limb of the cow was considered dirty. Studies on cleanliness in different housing systems have shown that cows housed on straw-bedded packs are dirtier than those in cubicle housing (Fregonesi & Leaver, 2001). Perhaps the dry cows that had dirty hind limbs spent more time lying down, decreasing their risk of being lame in their next lactation. Further information would be required on the lying time and cleanliness during the dry period in order to make further conclusions.

The majority of factors found to be associated with lameness in this study were cow-level factors, such as BCS, DIM, parity and production. We found that cows with lower BCS (≤2.5) were at a higher risk of lameness than those that were in better condition (Randall et al., 2015; Solano et al., 2015). The digital cushion that is located in the bovine hoof, to help absorb the forces applied to the foot during locomotion, is composed of adipose tissue. As we would expect, when the cow is under conditioned, the thickness of the digital cushion decreases, therefore, not providing as much support to the hoof and increasing the risk of lameness (Bicalho et al., 2009). It has been reported that cows are at a higher risk of developing a non-infectious hoof lesion (e.g. sole ulcer or white line disease) if they were previously classified as under conditioned (BCS <2.5) (Green et al., 2014). It is also possible that cows with a low BCS have a higher odds of lameness due to a change in their feeding behaviour. Norring et al. (2014) reported that lame cows consumed less silage and spent less time at the feed-bunk. In free-stall facilities, we found that the risk of lameness increased with increasing parity (Vanegas et al., 2006; Randall et al., 2015; Solano et al., 2015) and decreasing BCS. The relationship with lameness for these two variables was found to be dependent on one another, as shown in Figure 3.5. From this graph we see, that first lactation animals that were well conditioned (BCS ≥3.25) had significantly lower odds of lameness when compared to first lactation animals with less condition (BCS ≤3). When we look at animals in their third lactation, we see that the odds of lameness does not differ significantly based on BCS. Cows in their 4th or greater lactation, which were under conditioned (BCS ≤2.5) had the highest odds of lameness when compared to all other groups. Cows that have been lame previously are at a higher risk of becoming lame again (Green et al., 2014), therefore, the older animals in this study could have been lame previously and were unable to regain body condition, increasing their risk of lameness further. Lame cows may spend more time lying down during the day (Solano et al., 2016) as it may be too painful to stand or remain standing (Chapinal et al., 2009; Ito et al., 2010). If this is the case, it may be too painful for lame cows to stand at the feed-bunk and eat as long as the other cows in the herd, making them more likely to lose body condition. The results show that it is important for producers to correct low body condition, but especially for older cows, in order to help reduce the prevalence of lameness.

In free-stall facilities, the risk of lameness increased with increasing DIM (Onyiro et al., 2008; Solano et al., 2015). This could be related to the thickness of the digital cushion, as it is thickest at the beginning of the lactation and gradually decreases to the thinnest at 4 months post-calving, before beginning to increase in thickness again (Bicalho et al., 2009). It could also be that they were previously lame in the lactation and were at a higher risk of becoming lame again (Green et al., 2014). We found that as daily milk production increased there was a decreased risk of lameness, in agreement with other studies (Onyiro et al., 2008; Green et al., 2014; Solano et al., 2015). It is believed that higher producing cows are at a higher risk of lameness (Green et al., 2002; Onyiro et al., 2008), but that their production levels decrease prior to signs of lameness becoming evident (Reader et al., 2011; Green et al., 2014). Since we only measured lameness and milk production at one point in time, it is possible that our results could be a reflection of this. The cows that were lame in our study could have had higher production earlier in their lactation, which decreased prior to and during the time they were considered to be lame. Without follow-up, it is unknown whether those higher producing cows in our study became lame later in their lactation. If producers are aware of this potential relationship, they could monitor their higher producing cows and use any reduction in production as an early indicator of lameness.

3.6 Conclusion

This study found that the prevalence of lameness within herds can be high in the Maritime dairy industry but overall is comparable with those in other areas of Canada. There were herds within the study that were able to achieve low levels of lameness, showing that this is an achievable goal for the regional dairy industry. Although the majority of risk factors found in this study were at the cow-level, there were still some areas of management and facility design that were identified where producers could implement changes and lower the risk of lameness. This could be achieved by ensuring cattle are provided with dry bedding and making sure that the time away from the pen is below 3 hours a day. Dry cows and heifers could be housed in pack bedded systems to improve hoof health prior to entering the lactating herd. A higher risk of lameness was identified for older animals, those in a later stage of lactation, those who are under conditioned, and those with lower milk production. Making producers aware of these risk factors could help them manage their herds better and reduce the prevalence of lameness.

3.7 References

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Table 3.1. Description of scoring system used to assess cleanliness of the leg, flank and udder based on Vasseur et al., 2015.

	Clean		Dirty	
Score	0	1	2	3
Description	Fresh manure splashes <50%[1] of area	Fresh manure splashes ≥50% of area	Dried on manure ≥50% of area	Dried manure on entire area

1- 50% of the area for the flank region was equivalent to standard letter sized paper for one single area of contamination.

Table 3.2. Distribution of herd-level variables that were unconditionally associated ($P \leq 0.2$) with lameness after univariable analysis from 33 tie-stall herds in the Maritime Provinces of Canada.

Variable	Units/Categories	Herds, n[1] (%)	*P*-value
Bedding type	Straw/Hay	19 (58)	0.006
	Wood by-product	7 (21)	
	Combination	7 (21)	
Bedding depth	Sparse/None	7 (21)	0.128
	Deep	26 (79)	
Maximum bedding wetness	Dry	9 (27)	0.146
	Wet	24 (73)	
Dry cow housing	Pack-bedded	13 (39)	0.022
	Other	20 (61)	
Footbath use	No	29 (88)	0.187
	Yes	4 (12)	
Total Mixed Ration	No	16 (48)	0.031
	Yes	17 (52)	
Difficulty getting trimmer	No	20 (63)	0.133
	Yes	12 (38)	
Difficulty identifying lameness	No	22 (67)	0.085
	Yes	11 (33)	

1 – Does not always equal 33, due to missing data.

Table 3.3. Distribution of cow-level variables measured that were unconditionally associated with lameness ($P \leq 0.2$) on 1,503 cows from 33 tie-stall farms in Maritime Provinces of Canada.

Variable	Units/ Categories	Cows, n[1] (%)	*P*-value
Lactation	1	465 (34)	<0.001
	2	358 (26)	
	3	227 (17)	
	4+	312 (23)	
BCS	≤ 2.5	302 (20)	<0.001
	2.75	581 (39)	
	3	350 (23)	
	≥ 3.25	267 (18)	
Leg cleanliness	Clean	1,457 (97)	0.075
	Dirty	43 (3)	
Stall length (cm)	<165	190 (13)	0.107
	165-174	614 (41)	
	175-184	497 (33)	
	≥185	198 (13)	
Stall width (cm)	<120	250 (17)	0.055
	120-124	444 (30)	
	125-134	289 (19)	
	≥135	515 (34)	
Tie-rail to rear curb distance (cm)	<180	199 (13)	0.047
	180-189	340 (23)	
	190-199	543 (36)	
	200-209	250 (17)	
	≥210	171 (11)	
Daily milk production	kg/cow	1,347	0.001
Cow width	Cm	1,498	<0.001

[1]Does not always equal 1,503 because of missing data

Table 3.4. Distribution of herd-level variables that were unconditionally associated with lameness ($P \leq 0.2$) from 40 free-stall herds in the Maritime Provinces of Canada.

Variable	Units/Categories	Herds/Pens, n[1] (%)	*P*-value
Stall base	Mattress	23 (57)	0.020
	Rubber Mat	5 (13)	
	Soil	12 (30)	
Dry cow housing	Pack-Bedding	18 (45)	0.023
	Other	22 (55)	
Time away from pen daily	AMS	5 (12)	<0.001
	< 3 hours	13 (33)	
	≥3 hours	22 (55)	
Holding area floor	Concrete	31 (78)	0.020
	Rubber	9 (22)	
Treatment time for lame cows	Immediately	28 (70)	0.125
	Delayed	12 (30)	
Expense prevents immediate treatment	Yes	10 (26)	0.032
	No	29 (74)	
Lack of time prevents immediate treatment	Yes	19 (47)	0.001
	No	21 (53)	
Adequate lunge space	Yes	24 (60)	0.128
	No	16 (40)	
Herd size	<50	15 (37)	0.036
	50-74	13 (33)	
	75-94	5 (12)	
	≥95	7 (18)	
Neck rail to curb distance (cm)	<165	13 (32)	0.200
	165-174	16 (40)	
	≥175	11 (28)	
Stocking density	<1 cow/stall	26 (65)	0.134
	≥1 cow/stall	14 (35)	
Average brisket board height	per 1 cm	40	0.158

1 – Does not always equal 40, due to missing data.

Table 3.5. Distribution of cow-level variables that were unconditionally associated with lameness ($P \leq 0.2$) measured on 2,758 cows from 40 free-stall herds in the Maritime Provinces of Canada.

Variable	Units/Categories	Cows, n[1] (%)	*P*-value
Parity	1	1,011 (37)	<0.001
	2	791 (29)	
	3	453 (16)	
	4+	502 (18)	
BCS	≤ 2.5	517 (19)	<0.001
	2.75	859 (31)	
	3	805 (29)	
	≥ 3.25	571 (21)	
Leg cleanliness	Clean	2,512 (91)	0.061
	Dirty	242 (9)	
DIM	days	2,758	<0.001
Daily milk production	kg/day	2,719	0.011

1- Does not always equal 2,758 due to missing data

Table 3.6. Cow- and herd-level factors significantly associated with lameness after final logistic regression model on 33 tie-stall herds in the Maritime Provinces (n=1,346 cows).

Variable	Units/Categories	Coefficient	SE	OR[1]	95%CI OR	Overall *P*-value
Bedding dryness	Dry	Referent				
	Wet	0.98	0.31	2.66	1.43-4.92	0.002
Dry cow/heifer housing system	Other	Referent				
	Pack Bedding	-0.69	0.28	0.50	0.29-0.87	0.013
Parity	1	Referent				<0.001
	2	0.58	0.28	1.79	1.03-3.11	
	3	0.97	0.31	2.63	1.44-4.79	
	4+	2.03	0.27	7.58	4.32-13.31	
BCS	≤2.5	Referent				<0.001
	2.75	-0.46	0.22	0.63	0.41-0.97	
	3	-1.01	0.27	0.36	0.21-0.62	
	≥3.25	-1.32	0.32	0.27	0.14-0.50	
Cow width	cm	0.09	0.03	1.10	1.04-1.15	0.001
Milk production	10 kg/cow/day	-0.21	0.11	0.81	0.66-0.99	0.045
Constant		-8.77	1.74			
Herd-level variance		0.32	0.16			

1 – All results presented as cluster specific estimates.

Table 3.7. Cow- and herd-level factors significantly associated with lameness on 39 free-stall herds (n=2,670 cows)

Variable	Units/Categories	Coefficient	SE	OR[1]	95% CI OR	Overall *P*-value
Stall base	Mattress	Referent				0.007
	Rubber Mat	0.52	0.20	1.68	1.13-2.50	
	Soil	-0.21	0.17	0.81	0.58-1.14	
Time away from pen daily	AMS	0.51	0.26	1.67	1.01-2.76	<0.001
	<3 hours	Referent				
	≥3 hours	0.74	0.18	2.11	1.48-3.00	
Dry cow/heifer housing system	Other	Referent				
	Pack Bedding	-0.28	0.16	0.76	0.55-1.04	0.082
Leg cleanliness	Clean	Referent				
	Dirty	0.05	0.25	1.05	0.65-1.71	0.845
Parity	1	Referent				<0.001
	2	0.79	0.32	2.20	1.18-4.11	
	3	0.69	0.35	2.00	1.00-4.01	
	4+	1.96	0.33	7.10	3.75-13.46	
BCS	≤2.5	Referent				<0.001
	2.75	-0.53	0.32	0.59	0.31-1.10	
	3	-0.67	0.31	0.51	0.28-0.94	
	≥3.25	-2.09	0.43	0.12	0.05-0.29	
DIM	days	0.02	0.01	1.02	1.01-1.03	0.002
Daily milk production	kg/cow/day	-0.26	0.07	0.77	0.67-0.88	<0.001
Dry cow/heifer housing X leg cleanliness[2]						0.002
Parity X BCS[3]						0.003
Constant		-1.23	0.42			
Herd-level variance		0.10	0.05			

1 – All results presented as cluster specific estimates

2 – Results presented in Figure 4

3 – Results presented in Figure 5

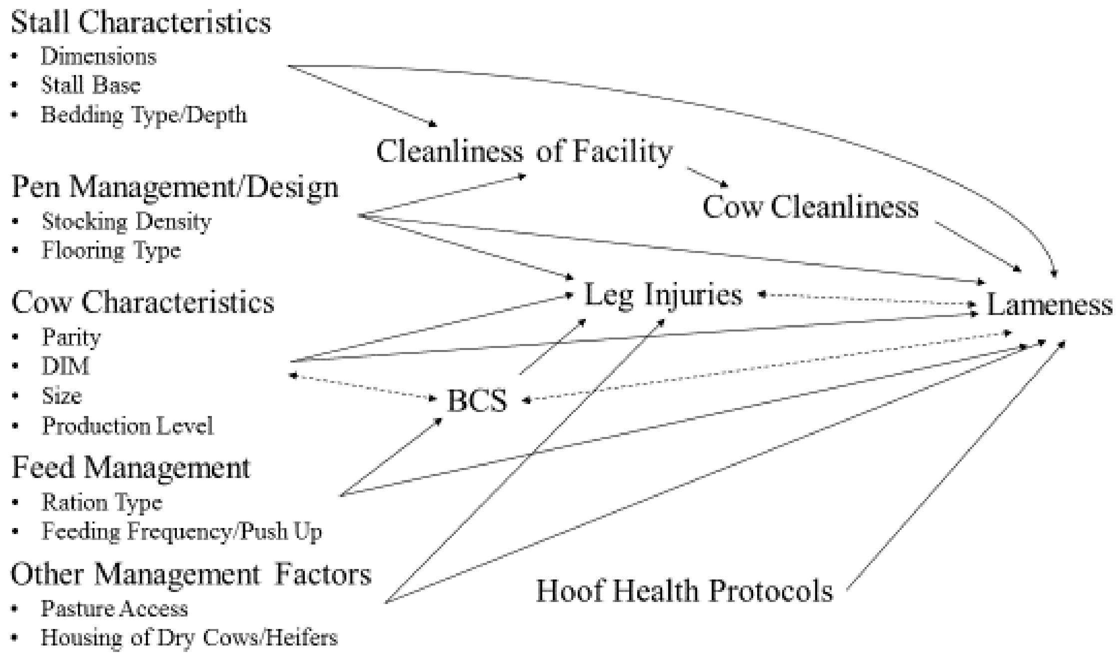

Figure 3.1. Causal diagram depicting the potential relationships between animal-, environmental-, and management-based measurements and lameness in dairy cattle.

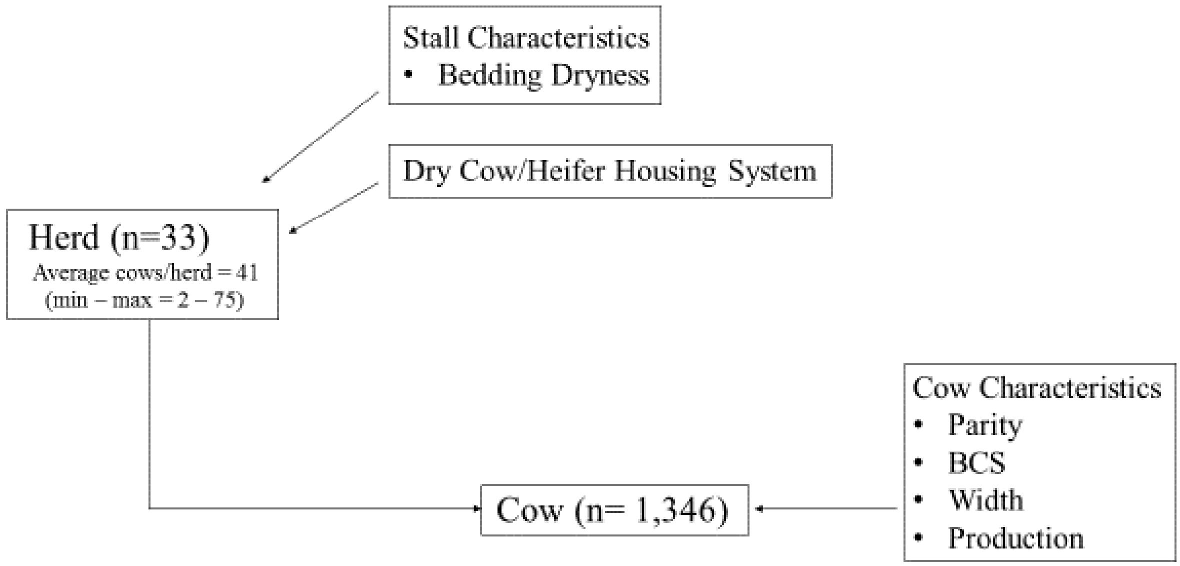

Figure 3.2. Hierarchical structure diagram illustrating the levels within the mixed effect models for tie-stall facilities, as well as the risk factors associated with these levels.

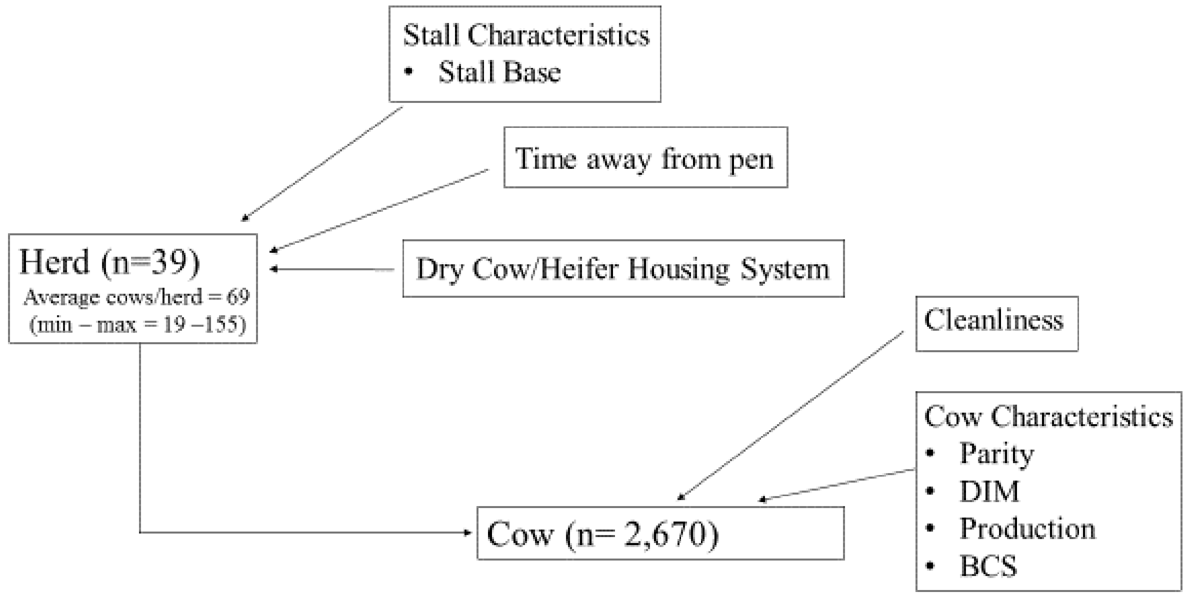

Figure 3.3. Hierarchical structure diagram illustrating the levels within the mixed effect models for free-stall facilities, as well as the risk factors associated with these levels.

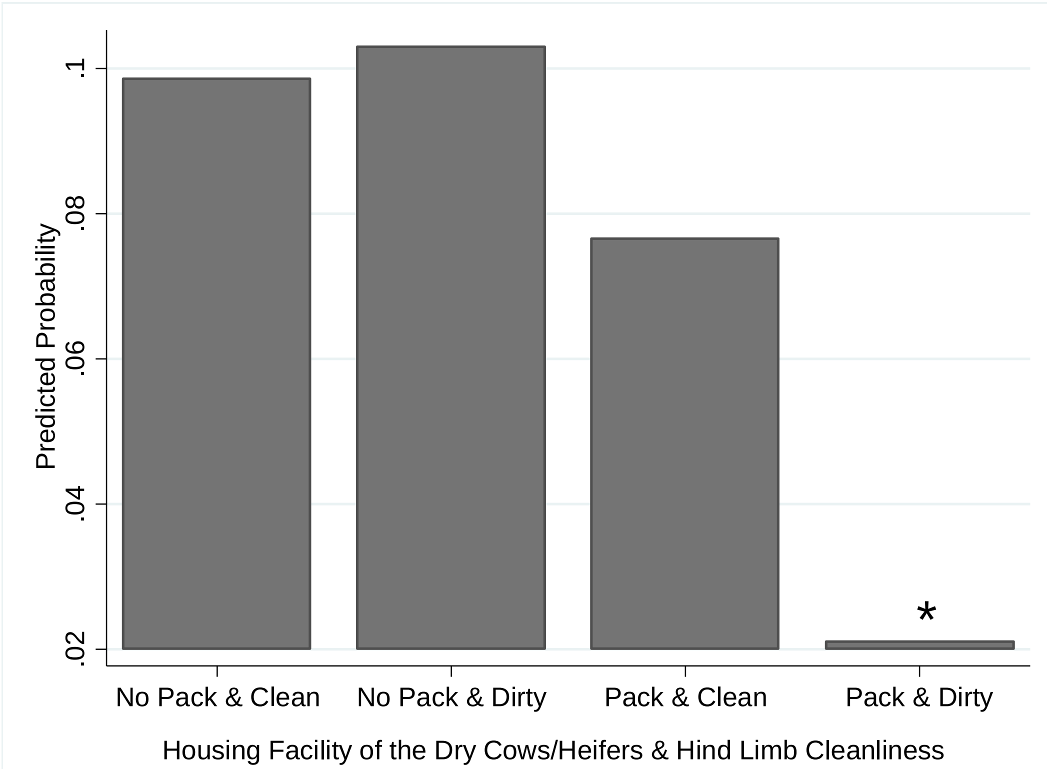

Figure 3.4. Plot of the predicted probability of lameness in free-stall herds for the interaction between dry cow/heifer housing system and hind limb cleanliness, with all other variables being constant.

*Significantly different from the other groups

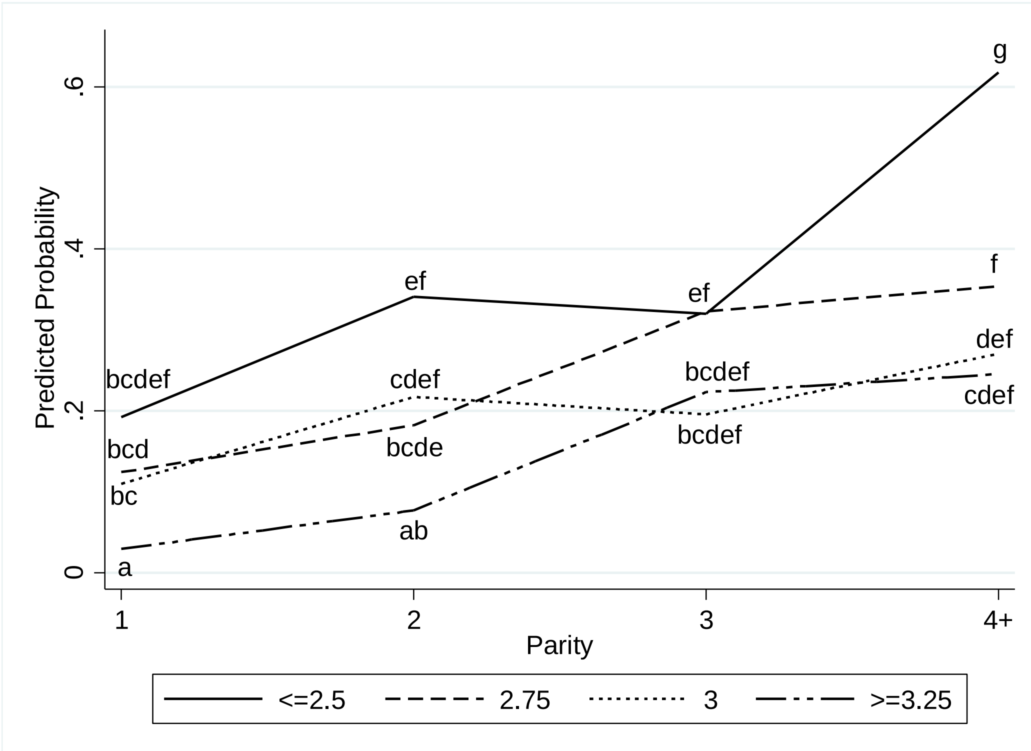

Figure 3.5. Plot of the predicted probability of lameness in free-stall herds for the interaction between parity and BCS, with all other variables being constant.

*Lettering above or below the closest point on the graph corresponds to grouping after Bonferroni adjustments, where differences in letters are indicative of significant differences between groups.

Chapter 4: Relationships between type of hoof lesion and behavioural signs of lameness in Holstein cows housed in Canadian tie-stall facilities

Jewell, M. T., M. Cameron, S. L. McKenna, M. S. Cockram, J. Sanchez, and G. P. Keefe. 2021. Relationships between type of hoof lesion and behavioural signs of lameness in Holstein cows housed in Canadian tiestall facilities. J. Dairy Sci. 104(1): 937-46.

4.1 Abstract

Although foot pain can affect gait, the presence of a hoof lesion may or may not influence the cow to show visible changes in their gait. This can be dependent on the type and severity of the lesion; for example, the presence of a sole ulcer (SU) has been associated with increased gait scores, whereas digital dermatitis (DD) and sole hemorrhage (SH) have not. In tie-stall facilities gait scoring can be difficult to perform. An alternative method, known as stall lameness scoring (SLS), allows observers to assess cattle for lameness while they remain in their stall. Lameness is determined based on behavioural changes in weight bearing and foot positioning, which include: shifting weight, resting a foot, standing on the edge of the stall and uneven weight bearing when stepping side to side. The aim of this study was to examine relationships between hoof lesions and these behavioural indicators. A total of 557 observations of SLS and corresponding hoof trimming records, collected during routine trimming events on seven tie-stall herds, were obtained. Trimming was performed by two trained hoof trimmers, with excellent agreement on lesion identification, based on quizzes taken at the beginning and mid-way through the study. To ensure trimming had no effect on the behavioural indicators observed, SLS was always performed prior to trimming by a trained observer. Behavioural indicators focused on the hind limbs only; therefore, the analysis was confined to hind limb lesions using logistic regression to detect the presence of hoof lesion based on observations made during SLS. Seventy-five percent of observed cows had no SLS behavioural indicators, whereas, 11%, 12% and 1% had 1, 2 and 3 behavioural indicators, respectively. At least one hind limb lesion was noted during trimming in 19% of cows, with the most common lesions being DD (7%), SU (6%) and

SH (4%). A cow that was observed resting one foot and bearing weight unevenly when moving side to side had a higher odds of having a hind limb hoof lesion than a cow without a lesion. When looking at specific hoof lesions, a cow observed resting one limb and bearing weight unevenly had a higher odds of having a SU, compared to those not displaying these behaviours. A cow observed shifting their weight from one foot to another had a higher odds of having SH and a cow observed bearing weight unevenly had a higher odds of DD. Behavioural indicators in weight bearing and foot positioning can help identify cows in tie-stalls with hind limb hoof lesions. Producers could routinely observe their cattle for these indicators to assist in the identification of cows which may require treatment. This could help reduce the duration of clinical lameness through earlier intervention.

4.2 Introduction

Lameness has an impact on the welfare of dairy cattle, as it has an effect on all five freedoms. Producers have the ability to minimize the impact on the welfare of their herd through early detection of lame cows and treating them quickly (Whay and Shearer, 2017). A common cause of lameness in dairy cattle (Murray et al., 1996), as well as beef cattle (Newcomer & Chamorro, 2006), swine (Wang et al., 2018) and equids (Bras & Redden, 2018) is a lesion in the hoof. If dairy producers were able to better identify cows with lesions they could be detected and treated quicker, therefore, improving the welfare of their herd.

Previous studies have found that the presence of a hoof lesion in dairy cattle was associated with increased locomotion scores (Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010; Thomsen et al., 2012), and changes in lying behaviour

(Chapinal et al., 2009; Ito et al., 2010; Thomsen et al., 2012). In cattle these lesions can be categorized by their etiology as non-infectious (e.g. sole ulcer) and infectious (e.g. digital dermatitis) (Cramer et al., 2009; Potterton et al., 2012; Solano et al., 2016). In two Canadian studies reporting the prevalence of hoof lesions during routine hoof trimming of dairy herds, 26-46% of cattle had at least one hoof lesion, with differences noted between regions, facility types (i.e. free-stalls vs tie-stalls) and herds (Cramer et al., 2008; Solano et al., 2016). Although hoof lesions are the most common cause of lameness, the type and severity of the lesion can influence whether a change in gait score will be evident. Not every cow with a hoof lesion will be classified as lame (Manske et al., 2002; Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010).

Gait scoring is commonly used to identify lameness in dairy herds. However, this approach is not as simple to complete when cows are confined in tie-stall facilities (Leach et al., 2009; Gibbons et al., 2014; Palacio et al., 2017). For this reason, Leach et al. (2009) developed an alternative method of lameness assessment specifically for tie-stall housing, known as stall lameness scoring (SLS). Using this methodology cows are observed for behavioural indicators of limb pain, based on foot positioning and weight bearing. This methodology was later adapted by Gibbons et al. (2014) by removing the behavioural indicator of “foot rotation” and providing further precision to the definition of each indicator. When this adapted methodology was compared to the reference standard, gait scoring, cows with a limp were classified as lame with 64-68% sensitivity and 77-96% specificity (Leach et al., 2009; Gibbons et al., 2014).

Several studies have investigated associations between gait scores and the occurrence of hoof lesions (e.g. Flower and Weary, 2006). However, there is no information about the relationships between the behavioural indicators assessed during SLS and the presence of hoof lesions (Gibbons et al., 2014). For this reason, the aim of the current study was to explore the relationship between behavioural indicators observed using SLS and records of hoof lesions collected during routine hoof trimming events. Additionally, very few studies have reported the prevalence of hoof lesions during routine hoof trimming in tie-stalls, therefore, the secondary aim of the study was to determine the prevalence of hoof lesions detected during routine trimming in tie-stall facilities in the Maritime Provinces of Canada.

4.3 Materials and Methods

4.3.1 Study design

Seven hoof trimmers (HT) working in the Maritime region were invited to participate in this study, of which two agreed to participate. Following similar methods as Cramer et al. (2008), a classroom-based training session on lesion identification was held in April, 2016 for the participating HTs. To assess the knowledge of the HT and the inter-observer agreement, a hoof lesion identification quiz was administered at the end of the training session. This quiz consisted of 16 photos of various hoof lesions presented during the training session. To ensure that the level of agreement between trimmers remained consistent, another identification quiz was administered in August, 2016. This quiz consisted of 13 photos of various hoof lesions, some of which were new and some being included in the first quiz. Participating trimmers were asked to record any lesions that were observed during routine trimming, as well as the location within the hoof where the lesion was identified. To incentivise trimmers to continue with their participation, they were offered $5 CDN per record.

The target population for this study was tie-stall herds in the Maritime Provinces of Canada. A subset of herds were selected from 34 herds that voluntarily participated in a larger cross-sectional study on lameness and were milking primarily Holstein cattle (Jewell et al., 2019). This subset was selected because they were regular clients of the participating HTs and performed routine hoof trimming at least twice annually. Trimmers visited the farms between two and four times per year, trimming a substantial portion of the herd at each trimming session. When visits coincided with the visits for the larger study, cows were selected for assessment using a systematic random method (Jewell et al., 2019). During the other visits either the whole herd or a portion of the herd, selected by the producers, were evaluated. Between April 2016 and April 2017, cows within each herd were assessed for lameness using the Gibbons et al. (2014) adaptation of the stall lameness scoring (SLS) method as previously described (Leach et al., 2009; Gibbons et al., 2014; Palacio et al., 2017). Using this method cows were assessed for behavioural indicators of foot positioning and weight bearing, while standing in their stall; these behaviours included: standing with the heels of the hind limbs over the edge of the stall, continuously shifting weight between hind limbs, resting the weight of one hind limb, and bearing weight unevenly when encouraged to move side to side. The number of behavioural indicators observed was used to classify cows as lame or not (i.e. ≥ 2 behavioural indicators = lame) (Leach et al., 2009; Gibbons et al., 2014). All lameness assessments were performed live by the primary author (MJ), who had received similar training as Palacio et al. (2017) for SLS. The cows were observed undisturbed, from behind, for 30 seconds looking for the behavioural indicators described above. The cow was then encouraged to step side to side in their stall, at least twice each way, to assess their ability to bear weight evenly between their hind limbs. These assessments were always completed prior to a routine hoof trimming event, to avoid any behavioural indicators being associated with trimming. To ensure a high level of repeatability was achieved for this observer (kappa ≥0.6), cows from some herds were video recorded. Intra-observer agreement was measured by comparing the scores determined live to those given while watching the video recordings, one week later. The intra-observer agreement was excellent, with kappa >0.87 for all behavioural indicators, based on 35 observations. Scores between two trained observers, MJ and co-author MC, were also compared for inter-observer agreement on one farm. For all behavioural indicators the inter-observer agreement was excellent, with kappa >0.89.

During routine hoof trimming, cows were examined for the presence of hoof lesions. Each HT was required to identify the type of lesion, in accordance with International Lameness Committee (2008) definitions, and the location of this lesion on a hoof zone map (Zinpro Corporation©, 2018). One HT (ED), kept these records using Hoof Supervisor® (KS Dairy Consulting Inc., Dresser, WI) software, while the other kept paper records. Since the method of assessing lameness focuses on indicators of limb pain in the hind limbs only, the focus of the hoof trimming records obtained from the HT was only on the hind limbs.

4.3.2 Statistical analysis

All data were analyzed using Stata14 (StataCorp, College Station, TX). To calculate the inter-observer repeatability between the two HTs, the agreement between their answers for both lesion identification quizzes were compared using Cohen's kappa coefficient. In order to participate in the study, they were required to have a kappa ≥0.6.

For the remainder of the analysis, the experimental unit of interest was the cow, and the outcome the presence of a hoof lesion or specific hoof lesion on one or both hind limbs. The main predictors of interest were the four behavioural indicators observed during SLS. Other predictors which could influence the outcome, such as the trimmer, season and year, were also included in the analysis. Descriptive statistics were completed on the outcome, as well as the potential predictors. The prevalence of the behavioural indicators and the presence of any lesion, as well as specific lesions, were determined by the number of cows with a behavioural indicator or hoof lesion/number of observed cows. Using univariable random effects logistic regression the relationships between the presence of a hind limb hoof lesion and the potential predictors were explored for each specific outcome of interest. Herd was used as the random effect to account for potential clustering of lesions within herds. Predictors that were unconditionally associated ($P \leq 0.2$) with the lesion of interest were used in a multivariable random effects logistic regression analysis. All variables that were considered for this analysis were assessed for associations with the other variables, using chi square or univariable logistic regression. If two variables were associated ($P \leq 0.05$), the variable that was most significantly associated with the outcome or the one that was most biologically plausible (e.g. behaviour > time between assessment) was added to the model. The final model for each outcome of interest was completed in a manual backward stepwise approach, removing the least significant variable ($P > 0.05$) at a time and reintroducing them back into the model until all remaining predictors were significant ($P \leq 0.05$). The models were tested for interacting variables, for example between the year and season of observation and the behavioural indicators. To determine the significance of these interactions in the model a post-hoc adjustment was made based on the number of interactions tested. Due to the low prevalence of SH in the population, with some herds having none reported, a generalized estimation equation model was used instead of the random effects model. The same methods for selecting predictors were used for the univariable and multivariable analysis for this outcome.

After the final models were completed, the fit and predictability of the models were assessed. The fit of the model was assessed through graphical and statistical evaluations of the residuals for normality. The predictive ability of the model was assessed by computing the sensitivity (Se), specificity (Sp), and area under the curve (AUC) as suggested by Dohoo et al. (2009). The apparent prevalence of the outcome in the study population was used as the threshold for computing the predictions used to determine Se, Sp and AUC for each model. The predictive ability of the models were also determined based on models with only the significant behavioural indicators and compared to those with all predictors.

4.4 Results

4.4.1 Hoof trimmers agreement

After in class training on lesion identification, one HT was able to correctly identify all lesions, when examined at the beginning and mid-point of the study period, while the other HT incorrectly identified one lesion on each assessment. Agreement was acceptable at the beginning of the study period (Kappa 0.93 (95%CI: 0.85-1.00)) and remained acceptable at the mid-point assessment (Kappa 0.91 (95%CI: 0.84-1.00)). With these results, both HTs were accepted to participate in the study.

4.4.2 Description of study population

A total of seven tie-stall herds, of which three were located in New Brunswick (NB) and four in PE, were included in this study. Routine hoof trimming was completed by trimmer A for the NB herds and by trimmer B for the PE herds. Cows in each herd were assessed using SLS prior to a hoof trimming event, between one and four times throughout the study period, resulting in a total of 557 observations of behavioural indicators and corresponding hoof trimming records. There were 224 cows with single observations, 135 cows with two observations and 21 cows with three observations, with an average of 1.4 observations per cow. As there was a limited number of cows with repeated observations, this was not accounted for in the random effects model. Table 4.1 outlines the distribution of when and where these observations occurred, for example, 69% percent of observations occurred in PE herds and 67% of hoof trimming assessments occurred within one week of SLS assessments. When hoof trimming and assessments occurred between March and August, they were considered to be spring/summer observations, while those that occurred between September and February were considered fall/winter. Seasons were grouped into these two categories because there were very few observations made during the summer and winter months. Herds were visited more frequently just prior to pasturing (April-May) and just after being removed from pastures (Oct-Dec). Sixty-one percent of the observations in this study occurred during the spring/summer months.

4.4.3 Prevalence of behavioural indicators observed during SLS and prevalence of hoof lesions

Throughout the study period, 75% of the observed cattle had no behavioural indicators. The remaining 11%, 13%, and 2% displayed one to three different behaviours, respectively. The most common behavioural indicator was uneven weight bearing when being moved from side to side, with 15% of cows presenting with this behavioural indicator. The next most common behavioural indicator was resting one hind limb, with 13% showing this behavioural indicator. Eight percent of the cows were observed shifting their weight continuously between their hind limbs and 5% were observed standing on the edge of their stall.

The cow- and herd-level prevalence of hind limb hoof lesions observed during routine hoof trimming are shown in Table 4.2. In this table, we see that 18.7% (95%CI: 15.5-22.2) of observed cows had a hoof lesion present on at least one hind limb and 7.7% (95%CI: 5.6-10.3) had lesions on both hind limbs. Looking at specific lesions, the most commonly noted was digital dermatitis (DD), with 6.8% of cows identified with this lesion. The next most common lesions were sole ulcers (SU) and sole hemorrhage (SH), with 6.3% and 3.9% of cows identified with these lesions, respectively. Of the cows with lesions present during routine hoof trimming, 38% had infectious lesions, 57% had non-infectious lesions and 5% had a combination of both non-infectious and infectious lesions. Variability of the number and type of hoof lesions were observed between herds, with the within-herd prevalence of any hoof lesion on the hind limb ranging from 11-54%.

4.4.4 Factors associated with the presence of a hoof lesion

The unconditional associations of the behavioural indicators observed during SLS, as well as other factors which could influence the presence of a hoof lesion, are presented in Table 4.3. No variables were highly correlated, therefore, all variables that met the inclusion criteria ($P \leq 0.20$) were considered for the final multivariable analysis of each outcome of interest.

The predictors that were statistically significant in the final multivariable analysis for any lesion, SU, DD and SH are presented in Tables 4.4 to 4.7, respectively. There were eight interactions tested per model, with none being significant in the final models. The results from each of these models show that at least one type of behavioural indicator was significantly associated with the presence of a hind limb hoof lesion. For example, in Table 4.5 we see that there was an association between a cow resting one hind limb and the presence of a SU in at least one hind limb. The presence of a SU was also associated with uneven weight bearing when encouraged to step side to side. Along with behavioural indicators, we found that other factors such as year, season and trimmer, were associated with the presence of hoof lesions in the hind limbs.

The predictive ability of these models is presented in Table 4.8 and Table 4.9, as the Sensitivity (Se), Specificity (Sp) and area under the curve (AUC). The models created in this study, in general had better Sp (range 77-87%) than Se (37-86%), giving them the ability to better identify cows without lesions. The overall accuracy of the models (i.e. AUC) of correctly classifying cows with and without lesions, and each specific lesion of interest, ranged from 62 to 83%.

4.5 Discussion

4.5.1 Prevalence of hind limb hoof lesions

The percentage of observed cows with a hoof lesion present on at least one hind limb during routine hoof trimming were comparable to a larger study in Ontario, where 24% of tie-stall cattle had a hoof lesion on the hind limb (Cramer et al., 2008). The percentage of cows observed with multiple lesions was similar to the 5% previously reported by Cramer et al. (2008) and Solano et al. (2016). When looking at the type of hoof lesions based on their etiology (i.e. infectious vs non-infectious) we found that non-infectious types of lesions were the most common, with 57% of observed lesions being classified as non-infectious. This is different than the findings of previous studies, where infectious lesions, primarily DD and HE, were most commonly observed (Manske et al., 2002; Cramer et al., 2008; Solano et al., 2016).

In this study not all cows were trimmed at each trimming session, particularly in herds with more frequent trimming. Producers could have selected a proportion of animals for trimming at each session based on specific criteria, such as, stage of lactation or because of a previous observation of lameness. If producers were selecting cows based on their stage of production, which has been associated with the presence of hoof lesions (Somers et al., 2005; Solano et al., 2016), or due to observation of lameness this could lead to an overestimation of hoof lesions reported during this study. Five herds trimmed twice per year including all cows, whereas two herds trimmed a portion of herd at more frequent time periods. The specific selection criteria for the cows selected for trimming was not recorded. Additionally, the herds within the current study were not randomly selected from the target population and they were chosen based on voluntary participation in the study, as well as, their relationship with the participating trimmers.

4.5.2 Associations between behavioural indicators of limb pain and hoof lesions

In the current study we hypothesized that the behavioural indicators observed during SLS were associated with the presence of a hind limb lesion. The focus was specifically on hind limb lesions because the behaviours observed during SLS focus on the hind limbs (Leach et al., 2009). Cows have limited ability to redistribute weight from their fore limbs to their hind limbs (Neveux et al., 2006) and therefore any forelimb lesions would be unlikely to cause behavioural indicators in the hind limbs.

During our study, 11% (48/417) of observations with no recorded behavioural indicators during SLS assessment had at least one hind limb lesion. Being a prey species, cattle can be quite stoic when experiencing pain, and may show no overt signs of pain until it is severe (Anil et al., 2005; Nechanitzky et al., 2016). It is possible that the lesions these cows had were at an early stage and not severe enough to cause sufficient pain to show overt signs to the observers. Perhaps behavioural indicators without visible lesions indicates limb pain, prior to an observable lesion or that these cows were exhibiting behavioural indicators of limb pain due to another reason, such as, joint pain or poor confirmation.

When cows did show behavioural indicators, we found that those resting a hind limb and bearing weight unevenly were more likely to have a hoof lesion on their hind limb than those not displaying these behaviours, as shown in Table 4.3. When using two or more behavioural indicators of limb pain, Palacio et al. (2017) found that 90 and 97%

of cows classified as lame were resting a hind limb and bearing weight unevenly, respectively. For this reason, it is not unexpected that these two behaviours would be more likely to be observed when a lesion was present, as hoof lesions are the principal reason for cows to appear lame (Murray et al., 1996; Newcomer & Chamorro, 2016).

When looking at specific hoof lesions, cows that were resting a hind limb and bearing weight unevenly were also more likely to have a SU than those not displaying these behaviours. Previous studies focusing on locomotion scoring in association with hoof lesions have found that SU was associated with an increase in gait score, indicative of a greater severity of lameness (Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010). Since we know resting a limb and uneven weight bearing are the most common behaviours exhibited by lame cows (Palacio et al., 2017), these results are not unexpected. The presence of a SU can be painful for the animal, resulting in longer lying bouts and total lying times, as these animals are more reluctant to stand (Chapinal et al., 2009). The pain associated with this type of lesion could explain why they are more reluctant to bear weight evenly and fully on the effected limb.

We found that cows that bear weight unevenly were more likely to have DD on at least one hind limb. In previous studies, no significant associations between DD and increased gait scores have been found (Chapinal et al., 2009; Tadich et al., 2010). Herds with a high prevalence of DD, also have a higher prevalence of lameness at the herd level, however at the individual cow level, not all cows with DD appear lame (Berry, 2001). The lesions of DD can be differentiated based on their macroscopic appearance, which aids in defining the infection as active, chronic, chronic active or healing (International Lameness Committee, 2008; Berry et al., 2012). When these lesions are in their active stages, applied pressure to the lesion can result in a pain response (Cutler et al., 2013). Although the stage of the lesion was not recorded in our study, perhaps those that were bearing weight unevenly in our study had lesions in an active or chronic active stage, which could be more likely to elicit a pain response. In future studies, it would be recommended to distinguish the stage of the lesion to determine whether the behavioural indicators observed can help determine the stage and better identify those cows that require treatment.

In our study we found that cows that were shifting their weight were more likely to have SH on at least one hind limb, than those not shifting their weight. In previous literature in dairy cattle, an association between gait scores and the presence of SH has not been identified (Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010), perhaps because this lesion is variable in the amount of pain it causes compared to other non-infectious lesions, such as SU. Since SH can be considered as a subclinical lesion of other non-infectious lesions (Shearer and van Amstel, 2017), it is possible that observation of cows shifting their weight could be used to identify cows with these lesions. This would allow earlier intervention for these cows, hopefully reducing the likelihood of these cows developing more severe lesions and becoming clinically lame. With a low prevalence of SH in our study population, the probability of correctly classifying cows having SH with our model may be affected. For this reason, would be ideal to repeat the study on a larger scale to confirm these results.

4.5.3 Other factors associated with hoof lesions

Along with the behavioural indicators noted above, other factors were found to be associated with the presence of hoof lesions. One of these factors was the trimmer, where one of the two trimmers was significantly more likely to report SH. Other studies have reported high variability between HT when reporting SH (Holzhauer et al., 2006; Cramer et al., 2009; Kujala et al., 2010). In our study the trimmers used different recording techniques (electronic versus paper) and it is possible that the trimmer with the higher reporting rate was more likely to report the mild lesions, because of ease in the electronic records system.

When focusing on SU, we also found that cows observed during the fall and winter months were less likely to have this type of lesion present, in agreement with previous studies (Sanders et al., 2009). The majority of the spring/summer trimming events occurred just prior to the cows going to pasture for the summer, therefore, the seasonal effect could be a reflection of the environment during winter housing. Cook and Nordlund (2009), noted that there are many aspects of facility design that have been associated with hoof lesions. Although some management and environmental factors were measured for the larger study (Jewell et al., 2019), many of these measurements were on dynamic variables which could potentially vary throughout our study period. As these measurements were only obtained once throughout the study period, they were not used in the current study, however, it is possible that the results in the current study are a reflection of these factors. In the future, measurement of different environmental and management factors could be taken at each visit in order to determine their relationship with the presence of hoof lesions and behavioural indicators of limb pain.

The length of time between the SLS assessment and hoof trimming was only significant for the SH model. A cow trimmed within one week of SLS was 1.89 times the odds to be identified with SH as compared to a cow trimmed three weeks or more after

SLS. When the observations of SLS and trimming are close together, we are more likely to see the most accurate representation of what is going on in the hoof at that time. A cow identified with SH within one week of SLS observations could be showing the contusion type injuries to the sole, which can then progress to other non-infectious lesions, such as SU and WLD, within 8-12 weeks (Shearer and van Amstel, 2017). Perhaps when there is a longer period of time between SLS and trimming, some lesions were still in development and were not visible at this time. It has also been shown that mild to moderate lesions can heal in 21-30 days (Shearer and van Amstel, 2017). Perhaps when a cow was trimmed 3 or more weeks after SLS the lesion was healed and therefore nothing was identified. These findings could explain why 84 cows (15%) had at least one behavioural indicator but no hoof lesion was identified. It would have been beneficial to have multiple observations over time to determine if these cows presented with lesions at a later date.

4.5.4 Predictive ability of final multivariable analysis

In order to determine the usefulness of the models to identify cows with specific hoof lesions, the predictive ability of the models with all predictors considered was examined, as seen in Table 8. When looking at the overall accuracy of the models, the models correctly identified cows with and without a lesion 62-83% of the time, depending on the lesion type. The models had a good ability to identify cows without lesions, with specificities ranging from 77-87%. When looking at the ability of the models to identify cows with lesions, we found that the sensitivities of the models varied from 37-86%.

The predictive ability of the models were also examined for the models considering only the significant behavioural indicators, as shown in Table 9. As the only significant predictor for DD was uneven weight bearing, the predictive ability of this model was unchanged. When looking at the models for any lesion and SU, the Se, Sp and AUC varied slightly, but overall Sp remained high for these models. On the other hand, for the model for SH only considering the predictor of shifting weight, the Se is greatly decreased, suggesting that this particular lesion will depend on other factors, such as, the trimmer's lesion identification, year (surrogate of the prevalence of SH) and the time between SLS and trimming when classifying a cow with SH. Finally, none of the predictors assessed were significant for the DD model, therefore, the predictive ability remains the same in Table 8 and 9. The low predictability for DD could be because the stage and severity of this lesion were not assessed. Overall the models with only behavioural indicators have a lower predictive ability, with lower AUC, suggesting that other herd-level or cow-level factors should be considered to help correctly classify cows as having a lesion or not. The behavioural indicators themselves are significantly associated with the presence of hind limb lesions, therefore, may be of value in conjunction with other decision methods to identify which cows would require treatment.

4.5.5 Study limitations

This study presented with a few limitations, one of which was the size of the study population. This small sample size is mostly due to a low response for participation from the local HTs, with only 2 taking part in the study. Even though the response rate for participation was low, we do not believe there would be a response bias within our study, as the main predictors of interest (i.e. behavioural indicators of limb pain) are not associated with the HT. The small sample size and low prevalence of some lesions within the study population could also impact the predictive ability of these models. For these reasons, it is recommended that this study be repeated within a larger population.

Another major limitation with the study was that more information about the cows and environment were not available for every visit. As the main objective of this project was to provide insight on the ability to detect lesions based on behavioural indicators of limb pain, information about DIM, parity and environment were not collected routinely. It is possible that this type of data could help improve the predictive ability of the models and would be recommended to use in future studies.

4.6 Conclusion

In the current study, we found that behavioural indicators of limb pain, such as resting a limb, shifting weight between limbs and bearing weight unevenly, are associated with the presence of a hind limb hoof lesions. Using this method of detecting lameness in dairy cattle may be beneficial for producers, veterinarians and hoof trimmers, to aid in identifying which cows may require treatment. Prospective longitudinal studies would also be valuable to determine temporal relationships between these behavioural indicators and the presence of a hoof lesion.

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Table 4.1. Distribution [n (%)] of non-behavioural factors considered as predictors of hind limb hoof lesions of non-randomly selected observations, on 7 Maritime tie-stall housed cows (n=557).

Variable	Category	Observations
Trimmer	A	170 (31)
	B	387 (69)
Season	Spring/Summer	340 (61)
	Fall/Winter	217 (39)
Year	2016	301 (54)
	2017	256 (46)
Time between SLS and hoof trimming	≤ 7 days	371 (67)
	8-14 days	88 (16)
	≥ 15 days	98 (17)

Table 4.2. Prevalence of hind limb lesions observed during routine hoof trimming of 557 observations, on 7 tie-stall herds in PE and NB, Canada.

Lesion Type	Cow-level prevalence	Within herd prevalence[1]
None	81.3	77.5 (46.3-89.1)
Any lesion	18.7	22.5 (10.9-53.7)
Bilateral lesion	7.7	9.5 (2.2-17.1)
Infectious	8.1	8.7 (1.9-18)
Digital dermatitis	6.8	7.6 (1.9-18.0)
Heel erosion	1.1	0.9 (0-2.4)
Non-infectious	11.5	14.9 (3.3-41.5)
Sole ulcer	6.3	8.0 (2.9-19.5)
Sole hemorrhage	3.9	5.0 (0-14.6)
White line disease	1.3	1.8 (0-9.8)
Other	0.9	1.3 (0-2.4)

1 – Mean (minimum and maximum)

Table 4.3. Univariable analysis to identify significant predictors for any lesion, sole ulcer, digital dermatitis and sole hemorrhage, on 557 observations from 401 cows.

	Any Lesion		Sole Ulcer		Digital Dermatitis		Sole Hemorrhage	
Variable	OR	*P*-value	OR	*P*-value	OR	*P*-value	OR	*P*-value
Behavioural Indicator								
Edge[2]	2.61	0.026	**1.57**	**0.492**	2.46	0.128	1.46	0.095
Shift[3]	2.62	0.005	**0.88**	**0.834**	3.14	0.015	4.38	<0.001
Rest[4]	6.70	<0.001	12.01	<0.001	3.05	0.005	**1.46**	**0.453**
Uneven[5]	5.61	<0.001	9.17	<0.001	3.65	0.001	**1.74**	**0.464**
Season								
Spring/Summer	Referent	-	Referent	-	Referent	-	Referent	-
Fall/Winter	0.52	0.058	0.23	0.006	1.87	0.123	-[1]	-
Year								
2016	Referent	-	Referent	-	**Referent**	**-**	Referent	-
2017	0.39	0.001	0.21	0.001	**1.47**	**0.345**	0.34	0.042
Time between SLS and HT observations								
≤ 7 days	Referent	0.043	**Referent**	**0.581**	**Referent**	**0.683**	Referent	<0.001
8-14 days	2.51	-	**1.18**	**-**	**1.45**	**-**	2.25	-
≥ 15 days	1.19	-	**1.76**	**-**	**0.78**	**-**	0.33	-
Trimmer								
A	Referent	-	Referent	-	**Referent**	**-**	Referent	-
B	0.30	<0.001	0.37	0.017	**1.22**	**0.752**	0.04	<0.001

1 – No variation in season when SH was observed
2 - Intentionally standing with the heel of one or both hind limbs over the rear edge of the stall
3 – Continuously shifting weight between hind limbs
4 – Uneven weight distribution of hind limbs when standing in place
5 – Uneven weight distribution between hind limbs when stepping side to side
* Bold lettering is used to indicate those variables which did not meet the inclusion criteria for the multivariate analysis.

Table 4.4. Factors significantly associated with the presence of any lesion on 557 observations from 401 cows in the final multivariable random effects logistic regression analysis.

Variable	Category	Coefficient	SE	OR	95% CI	*P*-value
Rest[1]	No	Referent	-	-	-	-
	Yes	1.54	0.35	4.66	2.35-9.24	<0.001
Uneven[2]	No	Referent	-	-	-	-
	Yes	0.91	0.33	2.49	1.31-4.73	0.005
Trimmer	A	Referent	-	-	-	-
	B	-1.06	0.45	0.35	0.14-0.83	0.018
Year	2016	Referent	-	-	-	-
	2017	-0.92	0.31	0.40	0.22-0.73	0.003
Constant		-0.90	0.37			
Herd Level Variance		0.23	0.21			

1 – Uneven weight distribution of hind limbs when standing in place

2 - Uneven weight distribution between hind limbs when stepping side to side

Table 4.5. Factors significantly associated with the presence of sole ulcers, in the final multivariable random effects logistic regression model using 557 observations from 401 cows.

Variable	Category	Coefficient	SE	OR	95% CI	*P*-value
Rest[1]	No	Referent	-	-	-	-
	Yes	2.17	0.50	8.72	3.29-23.14	<0.001
Uneven[2]	No	Referent	-	-	-	-
	Yes	1.01	0.48	2.77	1.08-7.07	0.033
Season	Spring/Summer	Referent	-	-	-	-
	Fall/Winter	-1.22	0.53	0.29	0.11-0.82	0.020
Year	2016	Referent	-	-	-	-
	2017	-1.70	0.48	0.18	0.07-0.47	<0.001
Constant		-2.78	0.32			
Herd Level Variance[3]		0.02	0.17			

1 – Uneven weight distribution of hind limbs when standing in place

2 - Uneven weight distribution between hind limbs when stepping side to side

3 – Between herd variance was not statistically significant

Table 4.6. Factors significantly associated with digital dermatitis in the final multivariable random effects logistic regression analysis of 557 observations from 401 cows.

Variable	Category	Coefficient	SE	OR	95% CI	*P*-value
Uneven[1]	No	Referent	-	-	-	-
	Yes	1.29	0.38	3.65	1.75-7.62	0.001
Constant		-3.03	0.33			
Herd Level Variance		0.35	0.34			

1 – Uneven weight distribution between hind limbs when stepping side to side

Table 4.7. Factors significantly associated with sole hemorrhage in the multivariable generalized estimation equation using 557 observations from 401 cows.

Variable	Category	Coefficient	SE	OR	95% CI	*P*-value
Shift[1]	No	Referent	-	-	-	-
	Yes	1.45	0.29	4.28	2.43-7.55	<0.001
Trimmer	A	Referent	-	-	-	-
	B	-3.25	0.70	0.04	0.01-0.15	<0.001
Year	2016	Referent	-	-	-	-
	2017	-0.90	0.34	0.41	0.21-0.79	0.008
Time Between SLS and HT Observations	≤ 7 days	Referent	-	-	-	0.001
	8-14 days	0.01	0.40	1.01	0.46-2.19	
	≥ 15 days	-0.63	0.23	0.53	0.34-0.83	
Constant		-1.83	0.30			

1 – Continuously shifting weight between hind limbs

Table 4.8. Predictive ability of models to identify cows with hind limb hoof lesions

Outcome	Threshold (%)[1]	Sensitivity (%)	Specificity (%)	Area Under Curve (AUC)	SE
Lesion	19	62	82	0.72	0.03
SU	6	63	87	0.75	0.04
DD	7	37	86	0.62	0.04
SH	4	86	77	0.83	0.04

1 – Threshold determined based on the apparent prevalence of the specific outcome of interest within the study population

Table 4.9. Predictive ability of models to identify cows with hind limb hoof lesions with SLS behaviours only.

Outcome	Significant Behavioural Indicators	Threshold (%)[1]	Sensitivity (%)	Specificity (%)	Area Under Curve (AUC)	SE
Lesion	Rest & Uneven	19	48	87	0.67	0.03
SU	Rest & Uneven	6	63	83	0.73	0.04
DD	Uneven	7	37	86	0.62	0.04
SH	Shift	4	32	92	0.62	0.05

1 – Threshold determined based on the apparent prevalence of the specific outcome of interest within the study population

Chapter 5: Benchmarking herd-level prevalence of skin lesions and lameness to motivate Canadian dairy producers to improve welfare

5.1 Abstract

The data collected from on-farm welfare assessments of dairy herds can be used for benchmarking and motivation for producers to improve animal welfare and health. On-farm assessments were completed on 75 dairy herds in the Maritime Provinces of Canada and results were provided to the producers as both a paper-based report, as well as through an online benchmarking tool. Animal-based measurements, such as lameness and skin lesions on the hock, knee and neck, were re-assessed on these farms approximately one year after the initial evaluations. During these evaluations producers were also questioned on what changes they had made to management or the environment since their initial evaluations. We found that the average herd level prevalence of hock lesions was reduced from 42% to 37% (P = 0.001) and lameness from 19% to 16% (P = 0.008) between assessments. Specific changes that were found to be associated with these reductions included: the addition of partitions at the feedbunk, change in type of milking parlour used, changing the frequency in which cows are fed, and changing the protocol for treatment of lame cows. While there was an overall reduction, there were some changes that were made that were found to be associated with an increase in the herd-level prevalence of skin lesions and lameness, which included: increasing the time spent observing lameness in the herd, viewing the benchmarking website and changing the type of bedding being used in the stalls. Making producers aware of their herd-level prevalence of these animal-based measurements and what changes may be beneficial in their reduction, could help producers lower the prevalence in their herds and improve animal welfare.

5.2 Introduction

Providing producers with data and giving them the opportunity to compare results with their peers by benchmarking can influence them to make improvements in their management (Sumner et al., 2018), leading to improved animal welfare (Main et al., 2012; Chapinal et al., 2014; Atkinson et al., 2017) and health (Tremetsberger et al., 2015). Many producers underestimate the prevalence of lameness within their herds (Higginson Cutler et al., 2017). By underestimating the problem in their herds, lameness may not be perceived as major issues needing to be addressed. Other barriers which could hold them back from making changes and improvements could be a lack of time or labour and prioritizing the management of other health concerns in their herds (Leach et al., 2010). Even if the producers are aware of the problem, there can be a discrepancy between this knowledge and actual application of changes to correct the problem. When advisory approaches are taken to try and improve animal welfare such as lameness, the results are not always as expected (Whay et al., 2012). The manner in which the advisors communicate with the producers has been found to influence how producers adopt and apply recommended changes (Main et al., 2012; Whay et al., 2012; Ritter et al., 2019). Ensuring that the producer is a part of the decision making and that communication is centered on them is one method by which positive change can be achieved (DeGroot et al., 2021).

Lameness and skin lesions, which are common animal welfare concerns for dairy cattle, can be prevalent within dairy herds. In recent Canadian studies, the prevalence of lameness has been reported to be between 15-26% (Solano et al., 2015; King et al., 2016; Westin et al., 2016; Jewell et al., 2019a) and the prevalence of skin lesions on the hock has been reported to be between 39-56% (Zaffino Heyerhoff et al., 2014; Nash et al., 2016; Jewell et al., 2019b). Skin lesions on the limbs can develop into hygromas or arthritis, restricting the range of motion in the associated joint (Kester et al., 2014) and have been associated with other negative health effects, such as poor udder health (Fulwider et al., 2007). In addition to the welfare concerns arising from the pain associated with lameness in affected cows (Chapinal et al., 2009), lame cows may produce less milk (King et al., 2017) and have impaired reproduction (Garbarino et al., 2004; Bicalho et al., 2007) when compared to sound cows. For these reasons cows affected by lameness or skin lesions can be at a higher risk for early culling (Bicalho et al., 2007; Fulwider et al., 2007; Cramer et al., 2009a), which can have a substantive economic impact on the herd. Even though these animal-level issues can lead to financial loss and decreased animal welfare, the reported prevalence of these outcomes has changed very little over the last couple of decades.

The main objective of the current study was to benchmark the prevalence of lameness and skin lesions on dairy farms in the Maritime Provinces of Canada, and determine the impact of benchmarking on subsequent prevalence measures. By increasing awareness through benchmarking, it was anticipated that dairy producers would have increased motivation to make management changes to reduce the prevalence of skin lesions and lameness in their herds.

5.3 Materials and Methods

5.3.1 Study Design

Within NB, NS and PE 80 herds (13.6%), of a possible 588 dairy farms (CDIC, 2016), were selected voluntarily to participate; recruitment occurred through advertisements in provincial dairy board newsletters, dairy herd improvement (DHI) seminars on cow comfort, and through recruitment by regional veterinarians. The aim was to have approximately 50% tie-stall and 50% free-stall herds to reflect the dynamics of housing within this region (CDIC, 2016). To participate in the study these herds were required to be enrolled in the regional milk recording service provided by Valacta Inc. (Sainte-Anne-de-Bellevue, Quebec, Canada) and have a herd that was primarily Holstein (>80%).

Herds were visited twice during the study period. The first visit occurred as part of a larger study previously described, between October 2015 and July 2016 (Jewell et al. 2019a; Jewell et al., 2019b) and the second visit occurred approximately one year later (range 10-20 months), between April and July 2017. At each visit, the number of cows selected for assessment was determined using a sample size calculation for proportions based on herd/group size, estimated prevalence of the animal-based measurements of 10%, 5% precision and 95% accuracy. When free-stall producers had distinct management groups, based on parity or stage of production, each group was assessed individually and a sample size was calculated for each group. If management groups had no distinct differences, they were treated as one large group and cows were chosen proportionately from each group (Jewell et al., 2019a; Jewell et al., 2019b). Selected animals were assessed for 8 different animal-based outcomes: skin lesions of the hock, knee, and neck, lameness, BCS, and cleanliness of the leg, flank and udder. Assessments were completed following previously described methodology (Jewell et al. 2019a; Jewell et al., 2019b), with scores being assigned on a point-based scale for each outcome. Cows in tie-stall herds were selected for assessment using a systematic random sampling scheme. Assessments in free-stall herds occurred while cows moved freely throughout the pen, as a result, random selection was more difficult to achieve. For these herds, cows were selected as the observers moved throughout the pen (Jewell et al. 2019a; Jewell et al., 2019b). When locking head gates were present in free-stalls, cows were locked up and chosen for assessment using a systematic random sampling scheme.

Assessments were completed on each farm between October 2015 and July 2017 by two trained observers. One observer was always the primary author (MJ) and the other a research assistant from the Atlantic Veterinary College (Charlottetown, PE, Canada). Both MJ and the research assistants received training and were required to achieve and maintain an inter-observer agreement of a weighted Cohen's *Kappa* >0.6 prior to completing assessments (Jewell et al., 2019a; Jewell et al., 2019b). In tie-stall herds, stall lameness scoring (Jewell et al., 2019a; Jewell et al., 2021) was always completed by MJ. All methods used to collect the data were approved by the Animal Care Committee at the University of Prince Edward Island (Charlottetown, PE, Canada; protocol #15-015).

5.3.2 Presentation of results to producers

As part of the larger study, producers were provided with the scores for their farm assessment, similarly to Vasseur et al. (2015). For each score, the producer was provided with the score that was achieved by the top 25% of dairy herds in Ontario, Quebec and Alberta (Vassuer et al., unreported) as one method of benchmarking. The results for Ontario, Quebec and Alberta were used as these reports were given to producers shortly after their assessments and not all data was available for regional comparison. The report was further supplemented with bar graphs outlining the breakdown of the number of cows scored and what scores they received for each animal-based measurement during the initial visit. These reports were sent via mail or e-mail to producers, shortly after their herd visit, and they were encouraged to reach out the researchers if they had any questions.

To allow the herds within the study population to compare their results to others within the study, a benchmarking website (www.benchmarkcowcomfort.com) was created and launched in November, 2016. Each participating herd was provided with a unique username and password to view their results and compare them with other study herds of similar size and facility type. Prior to launching the website to all participants, three of the producers were shown the website, allowed to explore their results and provide their feedback. The website was also made available to non-participating herds to perform their own self-assessments, input their results to compare to the study population. A how-to video was created to explain how the website worked and how to read the results. With approval from the Research Ethics board at University of Prince Edward Island (protocol # 6006874), producer logins were tracked by the website.

5.3.3 Measurement of changes in management

Specific recommendations were not provided to producers to guide them on what changes to make, however, they were provided with potential risk factors for lesions and lameness through the benchmarking website, if they chose to read them. In order to determine what, if any, changes in management or facility design had been made at each herd between visits, a questionnaire was administered by MJ during the second herd visit. This questionnaire consisted of 20 multiple choice questions to determine areas of specific changes and approximately when those changes were applied. For example, producers were asked "Have you made any changes in recording lameness within the last year and if so what season and year (2016 or 2017) did this occur?" and "Did you make any changes to the frequency routine hoof trimming was performed and if so what season and year (2016 or 2017) did this occur?" For each question where a producer answered that a change was made, they were asked open ended question to specify what that change was. There were also 5 numerical ranking questions to determine how influential the website or assessments themselves were in motivating the producers to make changes and what specific factors motivated them to make the changes (e.g., improving the quality of life of the cows, increasing farm profitability and/or making farm desirable for successors).

5.3.4 Statistical analysis

All data were analyzed using Stata14 (StataCorp, College Station, TX). After each herd visit, the prevalence of the animal-based measurements was calculated as the proportion of cows assessed in each specific herd which was affected by the outcome of interest. After the second visit, the difference in the prevalence between the two visits was calculated as the prevalence from the second visit – the prevalence from the first visit, for each animal-based outcome. The primary outcome variables of interest were skin lesions and lameness and therefore statistical analysis was limited to these outcomes. To determine whether the change in the prevalence between visits was significant, a paired t-test was performed for each outcome of interest. Descriptive statistics were completed on all outcomes.

For the analysis, the experimental unit of interest was the farm, and the outcome was the difference in the prevalence between the two assessments for the skin lesions and lameness. The main predictors of interest were the management changes the producers applied between visits, as determined through the producer questionnaire, and the use of the benchmarking website. Another predictor of interest, which could potentially influence the motivation of producers to make changes, was the prevalence of the outcome of interest at the first visit. Herds were categorized as low ($<25^{th}$ percentile), medium (25^{th}-75^{th} percentile) and high ($>75^{th}$ percentile) prevalence herds for each outcome of interest, based on the distribution of the results from the first herd visits. Descriptive statistics were completed on potential predictors. Using univariable linear regression, the relationships between the difference in prevalence and the potential predictors were explored for each animal-based measurement of interest. Predictors that were found to be unconditionally associated ($P \leq 0.2$) with the outcome of interest were used in the multivariable linear regression analysis. To check for confounders related to viewing the benchmarking website, this variable was checked for associations with other variables such as, initial herd-level prevalence, herd size and facility type using chi-square. No significant associations were found. A linear regression model was created using backward elimination, starting with all predictors of interest and removing predictors with the largest *P*-values one at a time until all predictors left in the model were statistically significant ($P \leq 0.05$). A limited number of biologically plausible interactions, for which there was sufficient variability in the data, were tested, with no significant interactions being found. The fit of the model was assessed through residual analysis and potential outliers were removed from the analysis to determine their influence on the model (Dohoo et al., 2009).

For the difference in the prevalence of neck skin lesions, the outcome was not normally distributed and a linear regression model could not be fitted to the data. The outcome was dichotomized based on whether the farm saw improvement in the prevalence and/or remained the same (1) or if prevalence worsened (0) between assessments. Predictors for the multivariable logistic regression were chosen and a final model created following the same methodology as described above for the linear regression.

5.4 Results

A total of 80 herds from NS, NB and PE were voluntarily selected to participate in the project. There were 46 free-stall herds (58%) and 34 tie-stall herds (42%), milking primarily Holstein cows. Three free-stall farms were unavailable for re-assessment (2 had sold and one did not wish to participate). Of the 77 remaining herds one free-stall and one tie-stall, had management questionnaires that were incomplete. After these exclusions, a total of 75 herds were included in the analysis. The average length of time between the two animal assessments was 14.7 ± 2.8 months for free-stall herds, and 12 ± 1.2 for tie stall herds. The slightly shorter duration for tie-stall herds was due to prioritization of reassessments on these herds prior to cows going out to pasture.

Herd-level prevalence for the individual animal-based measurements of interest, for all herds in each time period, can be found in Table 5.1 and Figures 5.1-5.8. There was a significant decrease in the average herd-level prevalence of lameness (P=0.001) and hock lesions (*P*=0.008) from the initial assessment to the subsequent assessment. The average herd-level prevalence of knee lesions remained consistent for the subsequent assessment compared to the initial assessment (*P*=0.277), however, the maximum herd-level prevalence dropped from 78% in the first year to 48% in the second year. A significant increase in the average herd-level prevalence of neck lesions (*P*=0.028) was found when comparing the two assessments, however, the prevalence still remained low at 8% on the subsequent assessment. Figures 5.1-5.8 illustrates that, while there may be trends in the data for improvements or deterioration relative to the average of each parameter, at the individual farm level there was a high degree of variability.

Table 5.2 shows the difference in prevalence for skin lesions and lameness broken down by herd housing type. When comparing the change in the average herd-level prevalence of lameness, a larger decrease was seen in free-stall herds (*P*=0.016), whereas, tie-stall herds had no change (*P*=0.952). Figures 5.1 and 5.2 depict changes in lameness prevalence between assessments for free-stalls and tie-stalls, respectively. The change in herd-level prevalence of hock lesions was very similar between the two housing types, however, the change was significant for tie-stall herds (*P*=0.023) but not free-stall herds (*P*=0.11). Figures 5.3 and 5.4 depict changes in hock lesions prevalence between assessments for free-stalls and tie-stalls, respectively. Although a significant increase in neck lesions was found overall, when the housing types were analyzed individually there was no significant difference in the average herd-level prevalence in free-stalls (*P*=0.801) and a significant increase in tie-stall herds (*P*=0.019). A graphical depiction of the prevalence of neck lesions at each visit in free-stall and tie-stall herds is shown in Figures 5.7 and 5.8, respectively.

Figures 5.9 and 5.10 show a frequency distribution of the number of changes made in tie-stall and free-stall herds, respectively. From the responses to the management changes questionnaire, 63 (84%) producers reported making at least one change in management between the two assessments. The number of changes made to the environment or management of the herd ranged from 1 to 12, including two herds that built completely new barns. The most common changes that were reported to the environment included the stall base (n=14), bedding type (n=9), amount of bedding added (n=15), and stall dimensions (n=10). The most common management changes that were reported included increasing the frequency of hoof trimming (n=15), frequency with which cows were observed for lameness (n=12), lameness treatment protocols (n=16) and footbath protocols (n=10). For parameters which were significant ($P < 0.2$) for one or more lesion type, the distribution of the specific changes applied on free-stall and tie-stall farms, as well as their unconditional associations with the outcomes of interest can be found in Tables 5.3 & 5.4, respectively. For producers that did not make changes the reason of highest importance for why they did not change was cost (mean = 3.2/5). When asked specifically why they did not make changes common responses from producers were that there was no point spending money on a tie-stall facility, not feasible at their stage of life and uncertainty of where to apply change.

When asked on a scale of 1 (not important) to 5 (very important) the reason for applying changes to their herds the highest importance reasons were to improve the quality of life of the animals (mean = 4.5/5) and increase the profitability of the farm (mean = 4.25/5). Others of lesser importance were succession planning (mean = 3.44/5), and to be competitive with other herds (mean = 3.59/5). Some reasons specified by the producers were to increase their herd longevity and to meet criteria for proAction® (DFC, 2019) assessments. Producers were also asked on a scale of 1 (not helpful) to 5 (very helpful), how helpful the herd assessment was at identifying problem areas in the herd. Of the 75 producers, those ranking the assessment on a helpfulness scale recorded 5/5, 4/5 and 3/5, 8%, 49% and 42%, respectively. Tracking the login for the benchmarking website revealed that 39 (52%) of the study participants had viewed their results on the website.

The average herd-level prevalence of lameness in tie-stall herds did not change significantly between assessments and no factors were found to be significantly associated with a change in prevalence of lameness in this group. For free-stall herds, adding partitions at the feed-bunk was associated with a reduction in the average prevalence of lameness by 8.2% (*P*=0.011), but increasing the frequency cows were observed for lameness was associated with an increase in average prevalence by 6.9% (*P*=0.012), as shown in Table 5.5.

Factors found to be significantly associated with the change in average herd-level prevalence of hock lesions in free-stalls and tie-stalls are found in Table 5.6 and 5.7, respectively. Of interest, we found that free-stall producers that viewed the website on average had an increase in hock lesions of 12.6%, ((*P*=0.003) Table 5.5). Changing the frequency in which cows were fed and the parlour in free-stalls and changing the lameness treatment protocol in tie-stalls were associated with a reduction of the average herd-level prevalence of hock lesions.

Factors found to be significantly associated with the change in the average herd-level prevalence of knee lesions can be found in Tables 5.8 & 5.9, for free-stalls and tie-stalls respectively. Interestingly, when changes were made to the bedding type or the stall dimensions in free-stalls, this was associated with an increase in the herd-level prevalence of knee lesions. In tie-stalls, changing the time of day (i.e. switched to feeding during afternoon milking) cows were fed was associated with a decreased prevalence of knee lesions in tie-stall herds.

When the change in prevalence of neck lesions between visits was evaluated using multivariable logistic regression, the only factor found to be significantly associated with the outcome was the initial prevalence of lesions in free-stall herds (P=0.003). Although a significant difference was noted in tie-stall herds, no significant predictors were found to be associated with this.

5.5 Discussion

In a period of 10-20 months, herds within our study population saw changes in the prevalence of skin lesions and lameness. On average, the herd-level prevalence of lameness and hock lesions decreased by 5% and 3%, respectively, however, an increase of 2% was seen in the average herd-level prevalence of neck lesions. The difference in prevalence between assessments was much lower than the reduction of 17% in lameness and 38% in hock lesions reported by Chapinal et al. (2014). This may be because their study included only herds that had made changes and requested a second assessment. In agreement with Chapinal et al. (2014) we found that when farmers are motivated to make changes, large improvements in the prevalence of skin lesions and lameness are possible. Producers within our study population were able to achieve substantial reductions in the prevalence within their herds, with the greatest improvements being a reduction of 54% in knee lesions and 49% in hock lesions. As expected, due to the multifactorial nature of the cause of these animal-based measures, there were also herds that saw substantial increases in prevalence, with the most severe being an increase of 50% in hock lesions and 32% in neck lesions. Part of the variation where conditions deteriorated could be from producers applying a solution in one area, which worsened conditions for another lesion type. For example, changing to sand-bedded stalls which were found to be associated with a lower odds of hock lesions but a higher odds of knee lesions (Jewell et al., 2019b). In free-stalls, some of the herd assessments would have occurred in different seasons, perhaps the change in prevalence is related to seasonal variations. For example, it has been found that there is a seasonal relationship in the prevalence of hoof lesions in tie-stalls (Cramer et al., 2009b).

Differences in the amount of change that was seen between assessments also varied between free-stall and tie-stall herds. On average there was a 6% reduction in the prevalence of lameness in free-stall herds, however, no difference was seen in tie-stalls. This could be due to the prevalence of lameness already being lower in tie-stalls than in free-stalls, at 15% compared to 21% (Jewell et al., 2019a). There was no significant change in the prevalence of hock lesions in free-stalls herds, however, a 5% reduction was seen for tie-stall herds. When compared to free-stall herds, tie-stall herds on average had a larger drop in knee lesions and higher rise in neck lesions. During the first assessment, we found that knee lesions were seen more in cows housed in tie-stalls compared to free-stalls, with cow-level prevalence of 16.6% and 13.6%, respectively (Jewell et al., 2019b). The greatest improvement in the maximum prevalence between assessments was the decrease from 78% to 49% of knee lesions, as seen in Table 1, which occurred in a tie-stall herd. The prevalence of neck lesions increased more in tie-stall herds than free-stall herds, as seen in Table 2. The prevalence of neck lesions was already very low in the free-stall herds in our study population, at 1% (ranging from 0-21%) (Jewell et al., 2019b). For this reason, it is expected that very little change would be seen for this measurement. Risk factors for each outcome, as well as the management of the herd, vary between facility types (Zaffino Heyerhoff et al., 2014: Nash et al., 2016; Jewell et al., 2019a; Jewell et al., 2019b). This could help explain why differences were observed between the two facility types in this study.

In contrast to Chapinal et al. (2014), we found that the improvement in the second assessment was greatest for those herds that initially had the highest prevalence of hock lesions, but did not see this for lameness. This was true for both free-stall and tie-stall herds. Herds that had a prevalence in the >75th percentile in the initial assessments saw a greater reduction in the prevalence of hock and knee lesions, than herds that were in the ≤ 25th percentile, as shown in Figures 5.1-5.4. It might be expected that those with the highest prevalence initially would be more motivated to make improvements in their herd. It is also possible that some of the improvements we saw in this group are due to a regression towards the mean, which can be seen with repeated measurements (Barnett et al., 2005). However, it would be expected that the values at the extreme (i.e. the very low prevalence and very high prevalence herds) would have little variance, consequently being a more precise measurement in these herds because of the binomial distribution of the data. This trend toward greater improvement in high prevalence herds was not seen for lameness.

When headlocks or partitions were added at the feed-bunk in 6 of the free-stall herds, the prevalence of lameness was decreased. It has been reported that providing adequate bunk space, in conjunction with partitions, minimizes competition for feed. This allows for more consistent intakes and healthier feeding patterns within and between animals in the herd (DeVries, 2019). Changes in feeding patterns and more consistent intake may have had a beneficial effect on overall health including metabolic diseases and standing and laying patterns. Interestingly, when herds reported an increase in the frequency of observations for lameness in the herd, there was an increase in the observed prevalence of lameness. An increased intensity of observation, without concurrent changes in hoof health management would not result in improved lameness prevalence. Producers may also have made changes to their hoof health management that had negative consequences, for example, other studies have found that providing year-round exercise in tie-stalls or increasing the frequency of alley scraping in free-stalls resulted in increased lameness (Cramer et al., 2009b).

An interesting result was the association between feeding frequency and hock lesions. When free-stall producers increased the feeding frequency, the prevalence of hock lesions decreased on average by 16%. Delivery of fresh feed encourages cows to visit the feed-bunk area, which can lead to longer periods of inactive standing and cows being away from their stalls (De Vries et al., 2006; Huzzey et al., 2006). When increasing the frequency in which cows are being fed, cows could potentially be spending less time lying in their stalls. Since many of the risk factors associated with hock lesions are focused around the stall, such as the type of stall base (Weary and Taszkun, 2000; Zaffino Heyerhoff., 2014; Nash et al., 2016), the amount and type of bedding (Fulwider et al., 2007; Rutherford et al., 2008; Zaffino Heyerhoff., 2014), stall dimensions (Weary and Taszkun, 2000; Keil et al., 2006; Nash et al., 2016) and lying time (Nash et al., 2016), this could explain why an improvement in hock lesions were seen in these herds. Another area, where change was associated with an improvement in hock lesions in free-stalls, was the milking area/system. Although only two herds made changes, one replacing their parlour with AMS and one building a rotary parlour, an average of 25% reduction in hock lesions was seen in these herds. Ekman et al. (2018) found an association between the type of parlour and hock lesions; specifically, a higher odds of hock lesions was seen in herringbone parlours compared to tandem parlours. Possible reasoning for this could be cow flow through the milking parlour, where tandem parlours allow cows to enter and exit individually, rather than pushing a group of cows through the parlour together. By changing to a rotary and AMS system, cows in these herds would be entering and exiting the milking area individually, therefore, reducing the likelihood of developing lesions on their hocks.

In tie-stall herds, when producers changed their lameness treatment protocol the herd-level prevalence of hock lesions was reduced. When these 6 producers were asked to specify what changes were made to their protocols, all had reported treating lame cows more quickly. This change could lead to a reduction in the duration of lameness; because lameness has been associated with hock lesions (Rutherford et al., 2008; Zaffino Heyerhoff et al., 2014; Solano et al., 2015; Nash et al., 2016), a shorter duration of lameness could also result in a decreased likelihood of developing hock lesions. These results are in agreement with Chapinal et al. (2014), where a change in the prevalence of lameness was found to be correlated with a change in the prevalence of hock lesions. While there was an association with treatment protocol changes, we did not find a strong correlation between a change in hock lesions and observed prevalence of lameness (ρ =

0.18) at the time of assessment. Because hock and hoof lesions require time to heal, the results of this study would be reflective of what was happening in the weeks and months prior to the second assessment.

Fifty two percent of producers in the study chose to benchmark their results with the other participating farms. Viewing the website was associated with an increase in the prevalence of hock lesions in the second assessment on free-stall farms. There is no clear explanation for this observation and since only generic information was provided on the website it is difficult to speculate.

When the bedding type was changed in free-stall herds between assessments the prevalence of knee lesions increased on average by 8.6%. When asked what changes producers made specifically to their bedding, of the 6 herds which made changes, two herds (33%) switched to recycled construction waste and one (17%) switched to sand. During the initial assessments when compared to herds using shavings/sawdust bedding, the odds of knee lesions was 2.92 and 1.97 times higher when recycled construction waste or sand were used, respectively (Jewell et al. 2019b). As these bedding types are known risk factors for knee lesions, this could explain the association between changing bedding type and an increased prevalence of knee lesions. An increase in the prevalence of knee lesions was also found when herds made changes to their neck rail position in their stalls, with all four herds which made this change an increase in the prevalence of knee lesions. Cows housed in free-stalls without restrictive neck rails can have more frequent lying bouts compared to those with restrictive neck rails (Bernardi et al., 2009). Although lying durations and lying bouts were not measured in our study, if the number of times a cow chose to lie down in a stall had increased this would also increase the number of times her knees would come into contact with the stall and increase the risk for lesions. When the stalls are less restrictive they could also potentially lie down further forward in the stall and could increase the likelihood of the cow’s knees coming into contact with the brisket locator.

When tie-stall producers changed the time of day that feed was delivered to the cows, a decrease in the average herd-level prevalence of knee lesions was seen. Of the three herds that made this change, two changed to feeding during the PM milking and one herd changed to feeding three times/day. To our knowledge the time of day that cows are fed has not been associated with skin lesions previously. When cows are reaching for feed they will often lower down on their knees, if the feed-bunk is fullest overnight the cows would be able to reach it during a time when it is less likely to be manually pushed up to them.

With a small number of herds making changes in each of the specific areas of interest in this study, some of these herds were found to be influential in the model building process. For the free-stall herds, one herd built a new facility between the assessments and was one of the two herds which made changes to their milking system and one of four that changed stall dimensions. As this herd made 12 changes in total between assessments, and were found to have substantial changes in the prevalence of hock and knee lesions during that time, this herd was influential on the significance of these variables in the final model. One of the three free-stalls herds that changed the frequency in which their herd was fed, was found to be influential in the hock lesion model. This herd had made a total of 5 changes between assessments and saw a substantial decrease in lesions. For the tie-stall herds, one herd was found to be a potential outlier in the knee lesion model, with the largest decrease in knee lesions of 58% between assessments. This herd was also one of the three herds which made changes to the time of day that the herd was fed making it influential on this predictor as well. With little variability in some of the predictors in these models it would be advisable to perform this on a larger scale to determine the repeatability of these results. Given that the information provided to producers in this study was generic and not tailored to their specific lameness or lesion issue, and numerous changes could be applied to the environment/management of the herd between assessments, it would be interesting to observe changes following specific recommendations in future research.

5.6 Conclusion

Although the range in prevalence for skin lesions and lameness between herds remained similar during re-evaluation of these Maritime dairy herds, this study found that many herds were able to considerably reduce the herd-level prevalence of these animal measurements. Making small changes to management and/or the environment, such as, changing the time of day the herd is fed and how often feed is delivered, adding partitions, or treating lame cows sooner could lead to improved animal welfare. Increasing producers' awareness of the prevalence of these animal measurements could help motivate them to make improvements as well. It is important that producers make informed decisions about the changes that they make, as some changes may be associated with an increased prevalence of skin lesions and lameness.

5.7 References

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Table 5.1. Comparison of descriptive statistics of prevalence of lameness and skin lesions on 75 dairy herds within the Maritime Provinces of Canada between the first and second assessment.

Animal-based measurement	Mean ± SD (%)		Median (%)		Min (%)		Max (%)	
	1st	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Lameness[1]	19.4 ± 10.3	16.0 ± 10.5	19.4	14.3	0	0	52.3	52.6
Skin Lesions								
Hock[1]	41.7 ± 21.3	37.1 ± 19.7	45.9	37.7	0	0	83.3	79.0
Knee	17.7 ± 13.4	16.1 ± 10.4	14.2	15.2	0	0	78.3	48.5
Neck	5.8 ± 8.0	7.6 ± 10.1	2.3	4.5	0	0	31.4	44.4

1 – The mean between first and second assessments was significantly different ($P \leq 0.05$).

Table 5.2. Difference in the prevalence of lameness and skin lesions (mean ± SD (%)) between the first and second animal-based assessments performed on 75 dairy herds within the Maritime Provinces of Canada.

Animal-based measurement	All herds (n=75)	Tie-Stall (n=33)	Free-Stall (n=42)
Lameness	**-3.42 ± 8.22**	-0.14 ± 7.45	**-6.00 ± 7.95**
Skin Lesions			
Hock	**-4.58 ± 14.42**	**-5.38 ± 12.91**	-3.95 ± 15.63
Knee	-1.60 ± 12.62	-3.75 ± 14.46	0.09 ± 10.85
Neck	1.87 ± 6.96	**3.89 ± 9.07**	0.27 ± 4.14

*Bold lettering used to indicate the difference between the first and second assessments was significantly different ($P \leq 0.05$).

Table 5.3. Distribution of predictors and their unconditional association with the change in the prevalence of skin lesions and lameness in free-stalls in the Maritime Provinces of Canada (n= 42).

		Observations	Hock Lesion	Knee Lesion	Neck Lesion	Lameness
Variable	Category	n (%)	*P*-value	*P*-value	*P*-value	*P*-value
Initial prevalence hock lesions	Low	13 (31)	**0.05**	-	-	-
	Medium	15 (36)	-	-	-	-
	High	14 (33)	-	-	-	-
Initial prevalence knee lesions	Low	16 (38)	-	**0.003**	-	-
	Medium	18 (43)	-	-	-	-
	High	8 (19)	-	-	-	-
Initial prevalence neck lesions	Low	25 (60)	-	-	**0.003**	-
	Medium	9 (21)	-	-	-	-
	High	8 (19)	-	-	-	-
Initial prevalence lameness	Low	9 (21)	-	-	-	**0.045**
	Medium	21 (50)	-	-	-	-
	High	12 (29)	-	-	-	-
Viewed website	No	18 (43)	**0.03**	0.93	0.336	**0.191**
	Yes	24 (57)	-	-	-	-
Changed feeding frequency	No	39 (93)	**0.145**	0.948	0.926	**0.055**
	Yes	3 (7)	-	-	-	-
Changed feed-bunk rail type	No	36 (86)	**0.012**	0.633	0.287	**0.012**
	Yes	6 (14)	-	-	-	-
Changed height of the feed-bunk barrier	No	35 (83)	0.876	**0.015**	0.881	0.229
	Yes	7 (17)				
Changed time of day fed	No	39 (93)	**0.039**	**0.178**	0.926	0.239
	Yes	3 (7)	-	-	-	-
Changed frequency of footbath	No	33 (79)	0.385	**0.046**	0.526	0.534
	Yes	9 (21)	-	-	-	-
Changed frequency observed for lameness	No	33 (79)	0.910	0.906	**0.175**	**0.014**

	Yes	9 (21)	-	**-**	-	**-**
Changed hoof trimming frequency	No	38 (90)	0.881	**0.104**	0.787	0.756
	Yes	4 (10)	-	**-**	-	**-**
Started keeping records of hoof trimming	No	39 (93)	**0.137**	0.712	0.926	0.209
	Yes	3 (7)	-	**-**	-	**-**
Changed parlour	No	40 (95)	**0.008**	**0.128**	0.561	**0.162**
	Yes	2 (5)	-	**-**	-	**-**
Changed stall dimensions	No	38 (90)	**0.061**	**0.007**	0.787	0.298
	Yes	4 (10)	-	**-**	-	**-**
Changed stall base	No	33 (79)	**0.061**	0.976	0.862	**0.032**
	Yes	9 (21)	-	**-**	-	**-**
Changed bedding type	No	35 (83)	0.952	**0.025**	0.316	0.292
	Yes	7 (17)	-	**-**	-	**-**
Changed amount of bedding used	No	33 (79)	0.503	**0.165**	0.526	0.825
	Yes	9 (21)	-	**-**	-	**-**

*****Bold lettering used to indicate that the predictor was used in the multivariable analysis.

Table 5.4. Distribution of predictors and their unconditional association with the change in the prevalence of skin lesions and lameness in tie-stalls in the Maritime Provinces of Canada (n= 33).

		Observations	**Hock Lesion**	**Knee Lesion**	**Neck Lesion**	**Lameness**
Variable	Category	n (%)	*P*-value	*P*-value	*P*-value	*P*-value
Initial prevalence hock lesions	Low	8 (24)	**<0.001**	-	-	-
	Medium	21 (64)	-	-	-	-
	High	4 (12)	-	-	-	-
Initial prevalence knee lesions	Low	8 (24)	-	**<0.001**	-	-
	Medium	15 (45)	-	-	-	-
	High	10 (30)	-	-	-	-
Initial prevalence lameness	Low	11 (33)	-	-	-	**0.145**
	Medium	14 (43)	-	-	-	-
	High	8 (24)	-	-	-	-
Viewed website	No	18 (55)	0.778	**0.012**	0.336	0.599
	Yes	15 (45)	-	-	-	-
Changed time of day fed	No	30 (91)	0.852	**0.020**	0.805	0.222
	Yes	3 (9)	-	-	-	-
Changed lameness treatment protocol	No	27 (82)	**0.064**	0.276	0.713	**0.064**
	Yes	6 (18)	-	-	-	-
Started keeping records of hoof trimming	No	27 (84)	0.835	**0.193**	0.525	0.575
	Yes	5 (16)	-	-	-	-
Changed stall dimensions	No	27 (82)	0.336	**0.062**	**0.182**	0.236
	Yes	6 (18)	-	-	-	-
Changed stall base	No	28 (85)	0.441	**0.136**	0.493	0.467
	Yes	5 (15)	-	-	-	-

*****Bold lettering used to indicate this predicator was used in the multivariable analysis.

Table 5.5. Final multivariable linear regression for factors associated with change in the prevalence of lameness between the first and second assessment on 42 free-stall herds in the Maritime Provinces of Canada.

Variable	Category	Herd n (%)	Coefficient	SE	95% CI	*P*-value
Added partitions to feedbunk	No	36 (86)	Referent	-		0.011
	Yes	6 (14)	-8.22	3.06		
Changed frequency of lameness observations	No	33 (79)	Referent	-		0.012
	Yes	9 (21)	6.90	2.61		
Constant			-6.30	1.29		

Table 5.6. Final multivariable linear regression for factors associated with change in the prevalence of hock lesions between the first and second assessment on 42 free-stall herds in the Maritime Provinces of Canada.

Variable	Category	Herd n (%)	Coefficient	SE	95% CI	*P*-value
Previous hock prevalence	Low	13 (31)	Referent	-		0.012
	Medium	15 (36)	-8.44	4.79		
	High	14 (33)	-14.98	4.72		
Viewed website	No	18 (43)	Referent	-		0.003
	Yes	24 (57)	12.58	3.91		
Changed Feeding Frequency	No	39 (93)	Referent	-		0.027
	Yes	3 (7)	-16.54	7.20		
Changed Parlour	No	40 (95)	Referent	-		0.006
	Yes	2 (5)	-25.57	8.81		
Constant			-0.73	3.68		

Table 5.7. Final multivariable linear regression for factors associated with change in the prevalence of hock lesions between the first and second assessment on 33 tie-stall herds in the Maritime Provinces of Canada.

Variable	Category	Herd n (%)	Coefficient	SE	95% CI	*P*-value
Previous hock prevalence	Low	8 (24)	Referent	-		<0.001
	Medium	21 (64)	-6.71	3.44		
	High	4 (12)	-31.75	5.09		
Changed lameness treatment protocol	No	27 (82)	Referent	-		0.027
	Yes	6 (18)	-8.72	3.75		
Constant			4.33	2.96		

Table 5.8. Final multivariable linear regression for factors associated with change in the prevalence of knee lesions between the first and second assessment on 42 free-stall herds in the Maritime Provinces of Canada.

Variable	Category	Herd n (%)	Coefficient	SE	95% CI	*P*-value
Previous knee lesion prevalence	Low	16 (38)	Referent	-		0.004
	Medium	18 (43)	-1.08	2.88		
	High	8 (19)	-12.63	3.68		
Changed bedding type	No	35 (83)	Referent	-		0.019
	Yes	7 (17)	8.58	3.49		
Changed stall dimensions	No	38 (90)	Referent	-		0.014
	Yes	4 (10)	11.06	4.47		
Constant			0.43	2.26		

Table 5.9. Final multivariable linear regression for factors associated with change in the prevalence of knee lesions between the first and second assessment on 33 tie-stall herds in the Maritime Provinces of Canada.

Variable	Category	Herd n (%)	Coefficient	SE	95% CI	*P*-value
Previous knee lesion prevalence	Low	8 (24)	Referent	-		<0.001
	Medium	15 (45)	-10.85	4.04		
	High	10 (30)	-26.53	4.34		
Changed feeding time	No	30 (91)	Referent	-		0.006
	Yes	3 (9)	-16.54	5.59		
Constant			10.72	3.21		

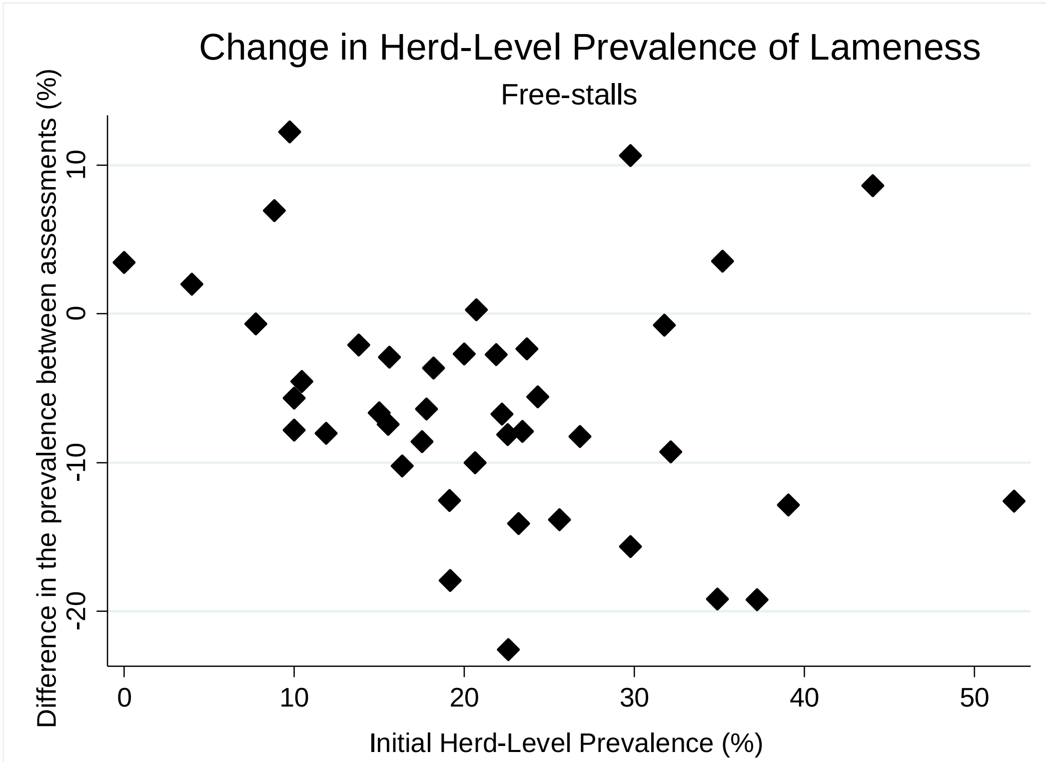

Figure 5.1. The change in herd-level prevalence of lameness between two on-farm assessments of free-stalls in the Maritime Provinces of Canada (n=42).

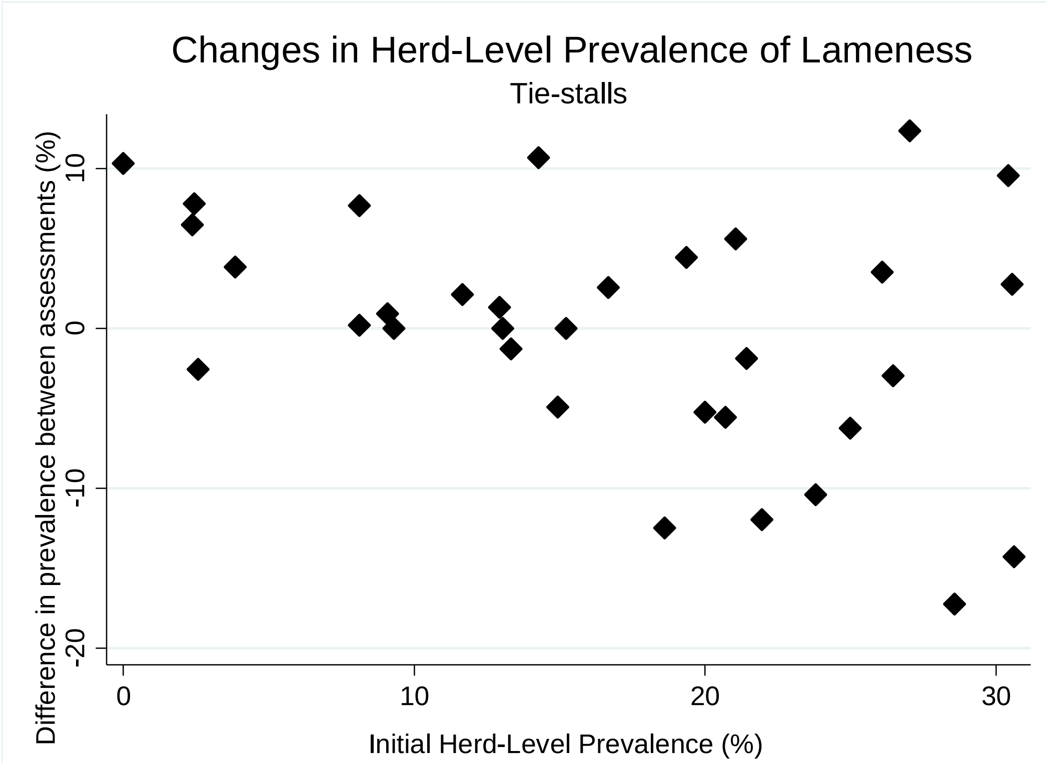

Figure 5.2. The change in herd-level prevalence of lameness between two on-farm assessments of tie-stalls in the Maritime Provinces of Canada (n=33).

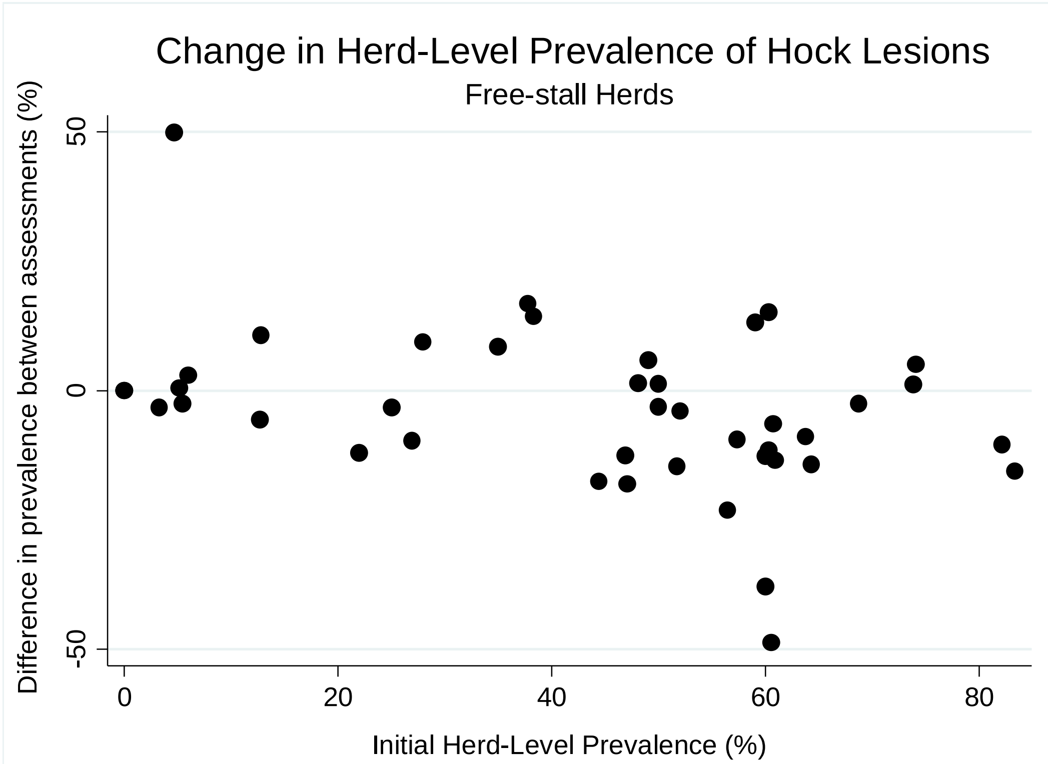

Figure 5.3. The change in herd-level prevalence of hock lesions between two on-farm assessments of free-stalls in the Maritime Provinces of Canada (n=42).

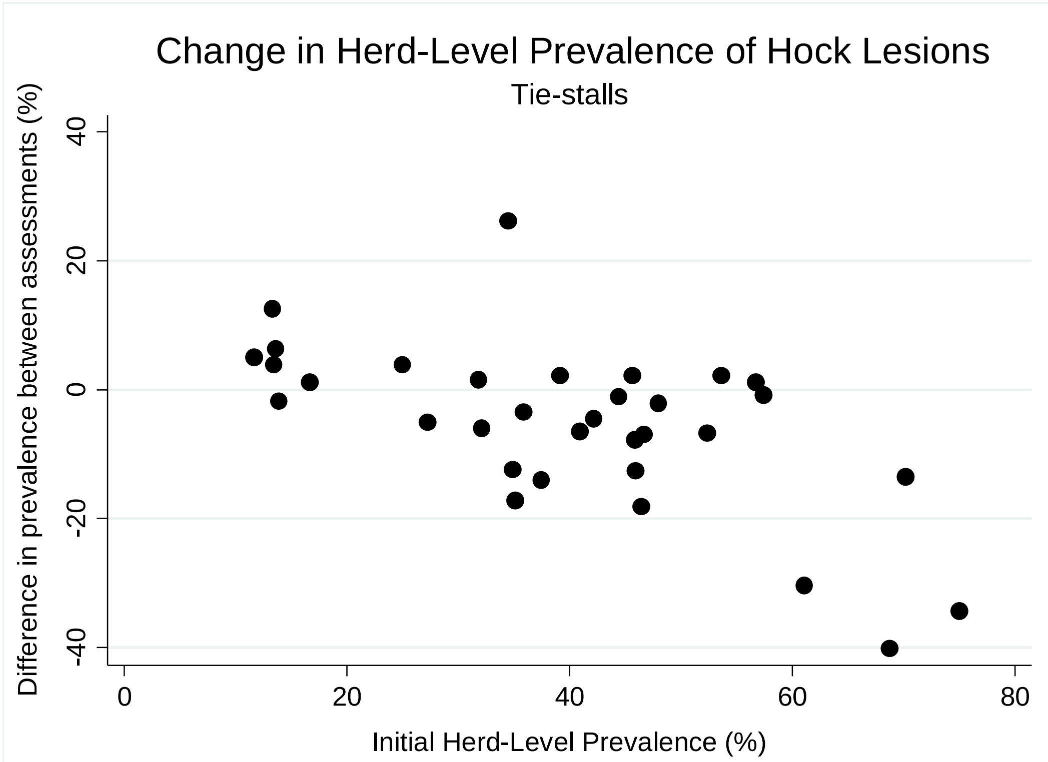

Figure 5.4. The change in herd-level prevalence of hock lesions between two on-farm assessments of tie-stalls in the Maritime Provinces of Canada (n=33).

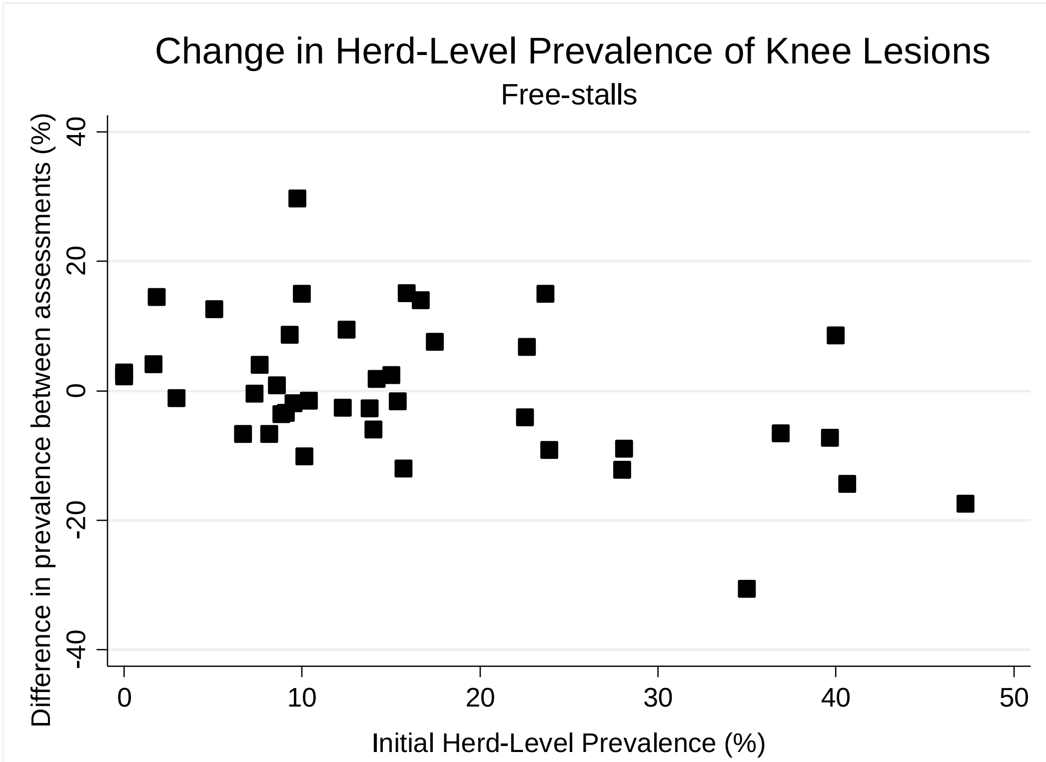

Figure 5.5. The change in herd-level prevalence of knee lesions between two on-farm assessments of free-stalls in the Maritime Provinces of Canada (n=42).

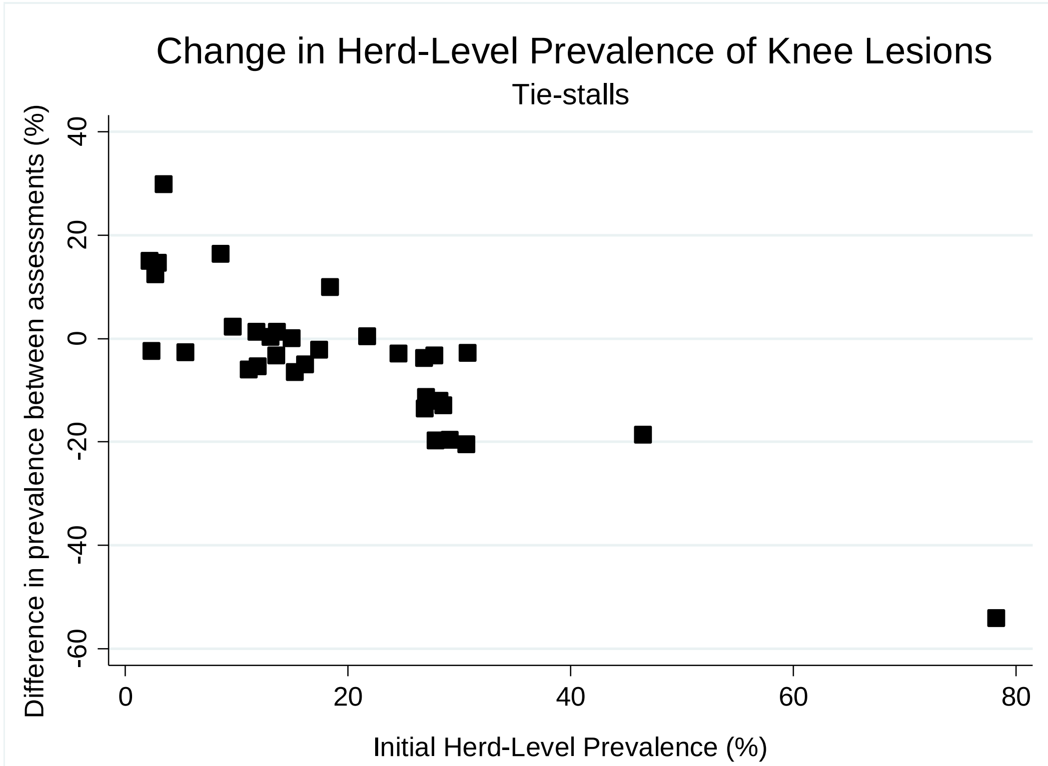

Figure 5.6. The change in herd-level prevalence of knee lesions between two on-farm assessments of tie-stalls in the Maritime Provinces of Canada (n=33).

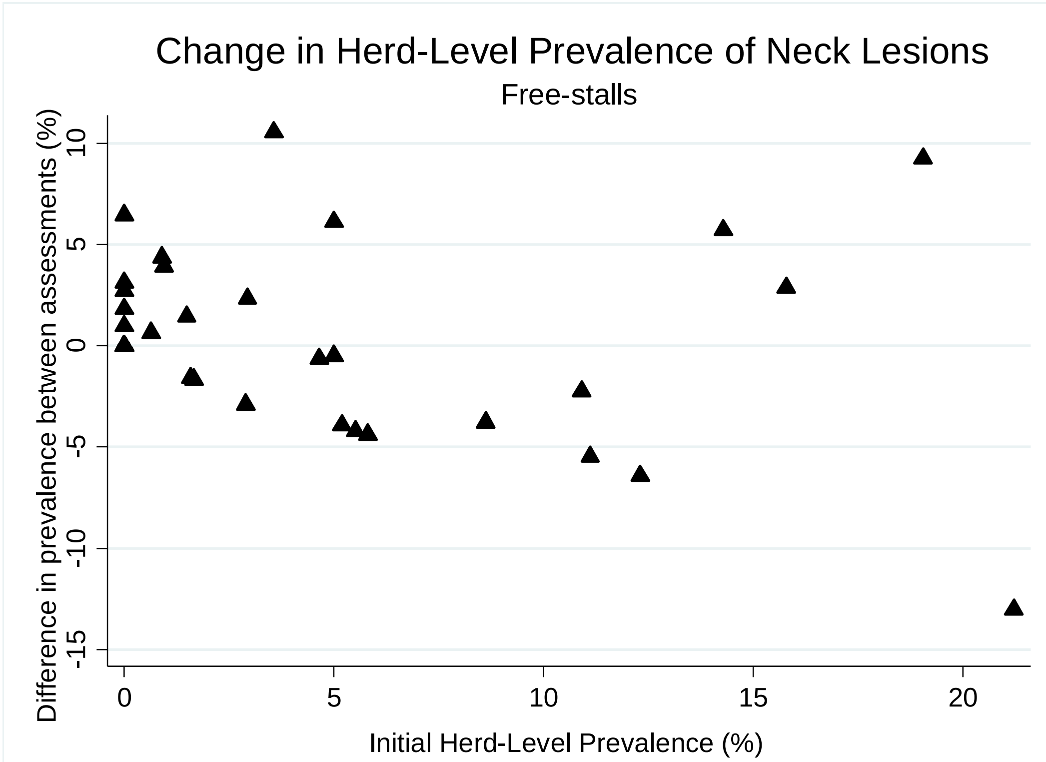

Figure 5.7. The change in herd-level prevalence of neck lesions between two on-farm assessments of free-stalls in the Maritime Provinces of Canada (n==42).

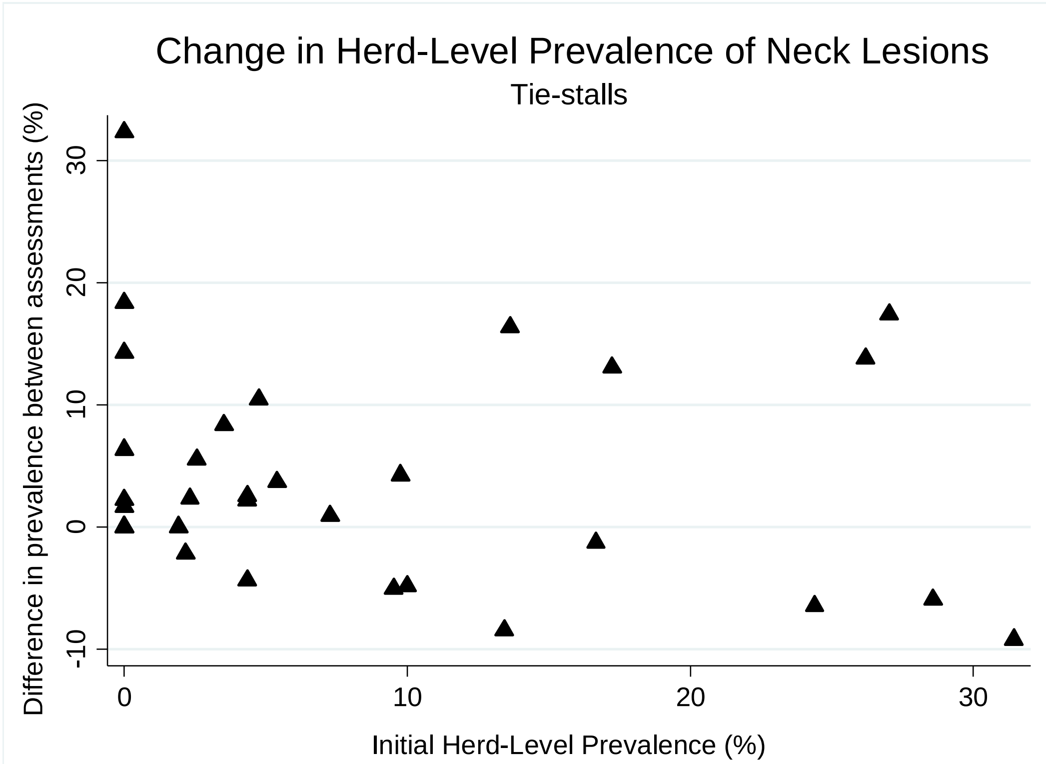

Figure 5.8. The change in herd-level prevalence of neck lesions between two on-farm assessments of tie-stalls in the Maritime Provinces of Canada (n=33).

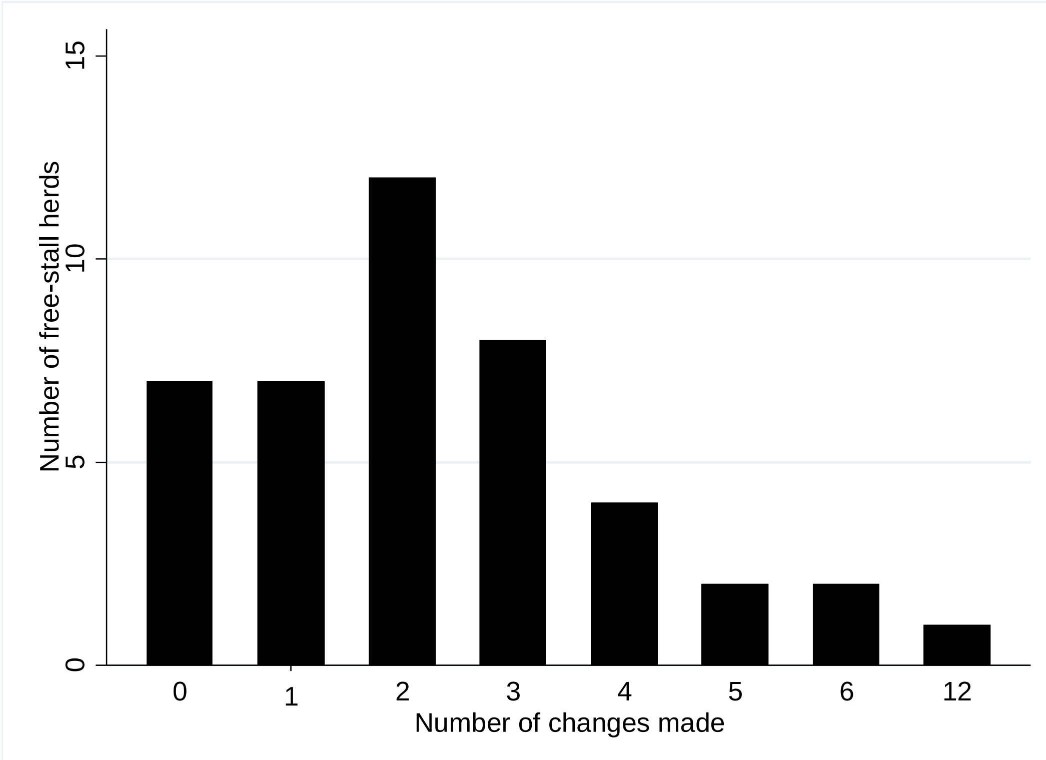

Figure 5.9. Number of changes producers made to the environment or herd management of free-stall herds between two animal-based assessments.

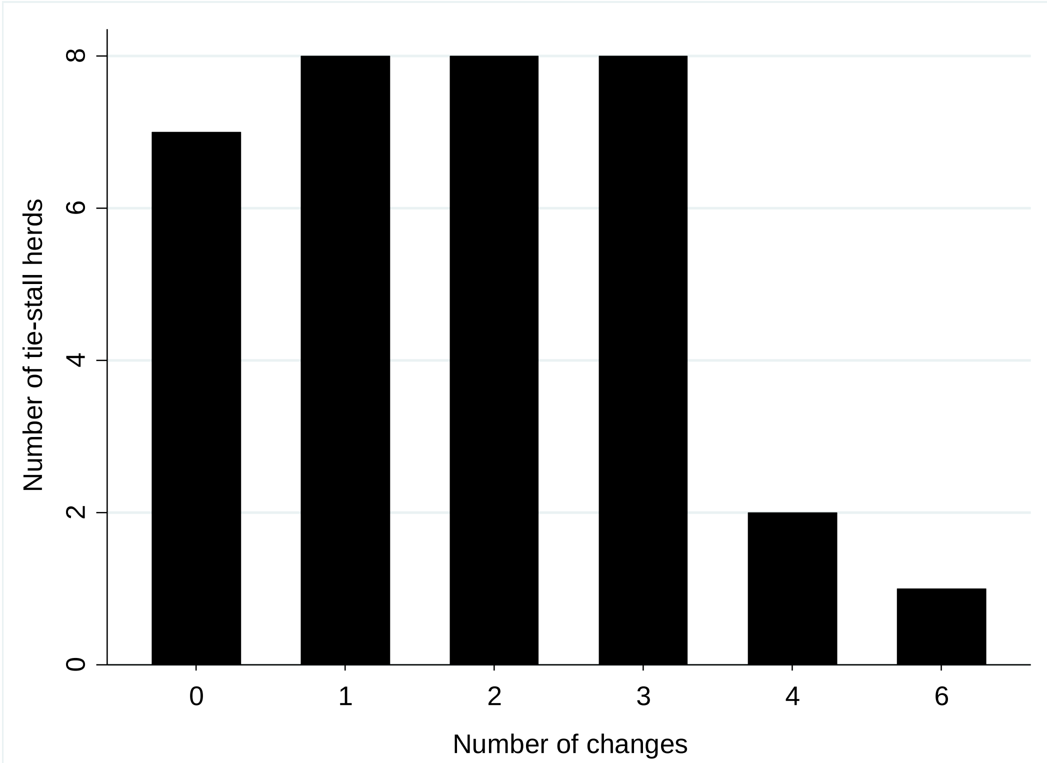

Figure 5.10. Number of changes producers made to the environment or herd management of tie-stall herds between two animal-based assessments.

Chapter 6: Overall Conclusions

6.1 Introduction

Previous Canadian studies have reported the prevalence and risk factors of skin lesions and lameness in dairy herds in Alberta, Ontario and Quebec (Zaffino Heyerhoff et al., 2014; Solano et al., 2015; Nash et al., 2016), however, little is known or reported on for the Maritime Provinces of Canada. The focus of this thesis was to determine the prevalence of hock, knee and neck lesions and lameness in this region, with the hypothesis that the prevalence would be comparable to other regions of Canada. As previous studies have done, we wanted to also determine the risk factors that were associated with skin lesions and lameness. These studies focused on tie-stall and free-stall facilities separately, therefore, for this thesis a comparison of the risk factors of the two facilities types was also completed. Using a modified version of the on-farm dairy cattle assessment described by Vasseur et al. (2015), animal-, environmental-, and management-based measurements were collected on dairies in the Maritime Provinces. The data was used to determine the prevalence of skin lesions and lameness and their associated risk factors, as outlined in Chapter 2 & 3.

When assessing cows for lameness in this study, two methodologies were used, locomotion scoring in free-stall facilities and SLS in tie-stall facilities. Looking at the associations between locomotion scores and the presence of hoof lesions has been examined previously (Flower and Weary, 2006; Chapinal et al., 2009; Tadich et al., 2010; Thomsen et al., 2012), however, there is little to no information looking at the association between SLS and the presence of hoof lesions in tie-stall housed dairy cattle. Using the SLS scores in addition to routine hoof trimming information from a subset of tie-stall herds, associations between hoof lesions and SLS were explored and described in detail in Chapter 4.

The on-farm assessment described by Vasseur et al. (2015) was used as the basis for data collection for this thesis, as well as the animal care assessments for proAction® (DFC, 2019). During discussions about this program with Canadian producers, they stated that these assessments were identifying problems on each farm, tailored to that farm and informed producers of issues that may have gone unnoticed or overlooked (Ritter et al., 2020). Providing the results from an on-farm assessment to the current study participants allowed for increased awareness of the prevalence of animal-based measurements in their herds. For this thesis an online benchmarking website was also created to provide them the opportunity to benchmark their results with their peers, with the hypothesis that this would motivate them to reduce the herd-level prevalence of skin lesions and lameness. Animal-based measurements were re-evaluated after providing benchmarking to determine the differences in herd-level prevalence between the two assessments. Changes to environment or management were also noted during the second assessment to explore relationships with changes in the herd-level prevalence of skin lesions and lameness, as described in Chapter 5.

6.2 Prevalence and associated risk factors of hock, knee and neck skin lesions

In agreement with previous Canadian studies (Zaffino Heyerhoff et al., 2014; Nash et al., 2016), we found that both the cow- and herd-level prevalence of skin lesions was high in some Maritime dairy herds. Although the herd-level prevalence of skin lesions were as high as 83% in our study herds, there were several herds within our study that had little to no cows with skin lesions. This demonstrates that reducing the prevalence of these lesions with prevention strategies is an achievable goal for the industry. One possible way to encourage this was investigated using benchmarking and networking with peers. After providing herd-level prevalence and the opportunity to benchmark with their peers, many herds reduced the prevalence of skin lesions and the overall prevalence of hock lesions was significantly reduced. Benchmarking could be used as a tool to motivate those with higher prevalence of lesions to make improvements.

In the Maritime dairy herds, several risk factors associated with herd management were identified, along with housing design. Risk factors we found which were specific to each facility type were, the height of the manger wall, stall width, length from tie-rail to the curb, and chain length in tie-stalls and type of parlour, and bedding dryness in free-stalls. There were also some risk factors which were identified for both tie-stall and free-stall facilities, for example stall base, type of bedding used and stall length were associated with hock lesions for both housing types. However, since the design and management can differ between the two housing systems the interpretation of these shared risk factors were not exactly the same. For example, when mattresses were used as the stall base in tie-stalls the odds of hock lesions were higher than those with mats, however, the opposite results were found for free-stall cows. Having risk factors identified for each housing system allows for more specific guidance for producers to make decisions on where to implement changes to lower the prevalence of lesions in their herd. Since numerous stall measurements were found to be associated with skin lesions, we can conclude that if cows fit within their stalls, allowing them to rise and lower themselves with ease and minimizing contact with the stall, the risk of lesions to the hock, knee and neck would be lowered. In tie-stall facilities straw bedding had a lower odds of hock lesions, well in free-stall facilities sand bedding had a lower odds of hock lesions when compared to other bedding types and dry bedding compared to wet had a lower odds of hock lesions in free-stalls. From our findings we can conclude that maintaining stalls with soft, dry and comfortable bedding, the odds of skin lesions on the limbs can be reduced. The lowest odds of neck lesions in tie-stalls were found when the tie-rail to rear curb measurement was between 190-199cm and when a barrier was present at the feed-bunk in free-stalls compared to post and rail. These results suggest that with appropriate placement of tie-rails in tie-stalls and feed-bunk railings in free-stalls, the prevalence of neck lesions can be reduced due to a decrease risk of contact between the neck and these barriers. In free-stall herds, it is suggested that adding partitions or headlocks would reduce the number of displacements at the feed-bunk and thereby reduce the prevalence of neck lesions. Providing producers with information on the risk factors that were associated with skin lesions could help guide them on where to apply changes to reduce their herd-level prevalence.

Numerous animal-based factors, such as parity, stage of lactation, cow width, leg cleanliness and BCS, were found to be associated with skin lesions in Maritime dairy herds. Some of these animal-based factors are difficult for the producer to control, however, BCS and leg cleanliness are two in which producers can influence through management. Making sure that cattle are in adequate body condition and providing clean and dry stalls, can help reduce the risk of skin lesions on the limbs and improve the overall health and welfare of the herd. Genetics were not a focus of this thesis, but perhaps placing a focus on breeding for smaller stature, would allow cows to fit more comfortably in the environment resulting in fewer skin lesions in the future. We found the likelihood of older cows having skin lesions was higher than younger cows, in particular neck lesions and knee lesions in free-stalls. As the industry works on improving the longevity of cows, a higher percentage of older cows will remain in the herd, therefore, a potential increase in prevalence of lesions may be seen. It is important that producers simultaneously focus on providing these cows with appropriately designed and maintained environments to reduce this from occurring.

6.3 Prevalence and risk factors associated with lameness

Similar to the prevalence of integumentary lesions, we found that the within herd prevalence of lameness was high in some Maritime dairy herds, with up to 52% of cows assessed in the herd being lame. When looking at the cow-level prevalence, the 15%-21% we found in our study was similar to those reported in other regions of Canada (Solano et al., 2015; Nash et al., 2016; Westin et al., 2016). As with skin lesions, there were herds within our study that had little to no lame cows noted during their on-farm assessments; showing that lowering the prevalence of lameness is an attainable industry goal. Differing risk factors were identified for both tie-stalls and free-stalls, giving more specific direction to producers and industry liaisons on how lameness could be reduced. We found that in tie-stall facilities ensuring a dry lying surface is maintained and in free-stall facilities trying to keep time away from the pen to below 3 hours a day, are areas of management which producers could focus on. Regardless of the housing system for the lactating cows, providing pack bedding to the dry cows and heifers was found to reduce the odds of lameness in the lactating herds. It would be of interest to further investigate the impacts this environmental-based measurement has on improving hoof health.

A higher risk of lameness was identified for older animals, those in a later stage of lactation, those who are under conditioned, and those with lower milk production. If producers were made aware of these findings it could help them manage their herds better and reduce the prevalence of lameness. If producers, veterinarians or hoof trimmers are more aware of these risk factors, targeting preventative practices, such as hoof trimming, and further attention towards cows in these categories could help reduce or prevent the incidence of lameness. Producers could also focus on improving the BCS within their herd, in an attempt to reduce the odds of lameness while simultaneously improving overall health and profitability of their herd.

6.4 Prevalence of hoof lesions and associations with behavioural indicators of limb pain

Associations between the behavioural indicators of limb pain used for SLS and hoof lesions had not been previously reported. While assessing tie-stall cows to explore these relationships, we found that 25% of all cows observed showed at least one behavioural indicator of limb pain and 19% had at least one hind limb hoof lesion identified by a hoof trimmer during routine trimming. The most common lesions identified were DD, SU and SH. In agreement with what we found in Chapter 3, the herd-level prevalence of hoof lesions and behavioural indicators varied greatly, with some herds having little to no affected cows. When looking at the associations between behavioural indicators of limb pain and hind limb hoof lesions, we found that the odds of having any type of hind limb hoof lesions was higher when cows were noted to be resting a limb and/or bearing weight unevenly when moving side to side. We also explored the relationship between the behavioural indicators of limb pain and the presence of the most common hoof lesions observed in our herds. We found that when cows were resting a hind limb there was a higher odds of a SU being observed during routine hoof trimming. When cows were bearing weight unevenly when moved side to side, there were higher odds of either a SU or DD being present. Cows noted to be shifting their weight between their hind limbs repeatedly had a higher odds of having SH present during routine hoof trimming. Our findings show that SLS could be used as an additional tool for producers, veterinarians and hoof trimmers to recognize cows which may be in need of treatment. Having this additional tool could help identify cows sooner, allowing for earlier diagnosis and treatment, leading to reduced duration of lameness and improved animal welfare.

We also found that year of observation, trimmer and season of observation were associated with the presence of hind limb hoof lesions. Exploration of cow-level factors, such as production, BCS, parity, and DIM would be of interest in future studies. As the prevalence of behavioural indicators and hoof lesions was relatively low in this study population, it would be of interest to repeat this study on a larger scale.

6.5 Benchmarking to motivate change and improve animal welfare

After completion of an initial on-farm welfare assessment of Maritime dairy herds and providing producers with the opportunity to benchmark their results, a significant decrease in the herd-level prevalence of hock lesions and lameness was achieved before a second assessment was completed. Increasing the awareness of potential issues in their herd could help motivate producers to reduce the prevalence of animal-based measurements, which can be used as welfare indicators. Benchmarking is another way that social networking could be setup for producers to discuss their results and see how some achieve low prevalence.

We found that producers who applied small changes in their management and/or environment, such as, feeding at a different time of the day, increasing the feeding frequency, adding partitions at the feed-bunk, or treating lame cows sooner had lower herd-level prevalence of animal-based measurements on the subsequent assessments. If producers are concerned about the investment and labour costs which can be associated with making environmental-, or management-based changes, our findings show that many of the changes that were associated with a reduction in herd-level prevalence of skin lesions and lameness are easily applicable, time efficient and low cost. It is important that producers know the risk factors associated with integumentary lesions and lameness so they can apply effective changes. Some changes in management and/or the environment could lead to an increase in the prevalence of animal-based measurements, for example, changing the type of bedding or stall dimensions.

6.6 Main limitations and future directions

One of the limitations of this study, and many other epidemiological studies focused on skin lesions and lameness, is that causal relationships cannot be determined. In order to better understand how skin lesions and lameness progress and how cows recover from these prospective, longitudinal studies would be advantageous where production measures and animal-based measurements could be continuously assessed. If the particular cause of these problems was known it would be easier to help the dairy industry reduce the prevalence and prevent future cases. Another limitation of this study was small sample sizes. In Chapter 4, there were 7 herds participating and 2 hoof trimmers and therefore only a small number of observations with particular hoof lesions and/or behavioural indicators of limb pain. This makes it difficult to make inferences for the target population, tie-stall housed cattle. It would be of interest to repeat this study on a larger scale in order to improve confidence in the outcomes and generalizability of these inferences. In Chapter 5 there were only a small number of herds that had applied specific changes, for example new milking systems and changes in feed management. It would be of interest to repeat these on a larger scale as well to better understand their relationship with the prevalence of animal-based measurements.

In this study producers were not given specific recommendations on where to apply changes to reduce their herd-level prevalence of animal-based measurements. With the knowledge of the specific risk factors associated with skin lesions and lameness in these herds, specific recommendations could have been provided to those with higher prevalence. Giving direct guidance to the producers, using results based on their fellow study participants, could have helped in further reduction of animal-based measurements. More guidance could make the process less overwhelming for the producers and made producers more likely to apply changes.

As we found in Chapter 3, lameness is associated with numerous environmental, management and animal-based risk factors. It would be of interest to explore the relationship of those risk factors, (i.e. parity, DIM, BCS and production) in addition to the associations between behavioural indicators of limb pain and hoof lesions found in Chapter 4. Exploration of these relationships could potentially help explain why cows had behavioural indicators of limb pain noted during SLS but hoof lesions were not observed during routine trimming. It would also be of interest to follow-up on these cows to determine whether hoof lesions developed at a later date and the initial examination of the hoof was too early to detect visible lesions. The follow-up could also be used to see if these behavioural indicators changed after preventative or therapeutic hoof trimming. In this study behavioural indicators of hind limb pain were only scored in tie-stall housed cows, however, these would not be unique to cows in this type of housing system. It is possible that these behavioural indicators could be used for observation in the milking parlour of free-stall systems. As this is a place where the animals are routinely observed, it could be another tool to determine which cows may have hoof lesions and initiate earlier treatment.

When studying risk factors of animal-based measurements, such as skin lesions and lameness of farm animals, we often focus on the individual risk factors within the environment, for example the type of milking system, the stall base or the bedding type. This is helpful to place focus on what environmental changes could be applied in order to try and reduce the prevalence of animal-based measurements, however, the application of these changes alone may not guarantee results. For example, two herds with the same stall dimensions and bedding type could have very different herd-level prevalence of hock lesions. This variation could be mostly be accounted for by one important and highly variable factor, the management of these herds (Sandoe et al., 2013). Additionally, how producers manage their employees as well as their cows, can impact the level of care animals are provided. This shows that health of the animals and the well-being of their caretakers can be linked. Producers need to keep this in mind when trying to make improvements within their farm (Ritter et al., 2020). In the future, more emphasis needs to be placed on exploring the relationship between animal and employee management and animal-based measurements.

Since the assessment protocol for this project was used as the basis for proAction® assessments, it would have been of interest to compare the results of the proAction® assessments with the results from the assessments completed for the study. This would allow another method to evaluate whether an increased awareness of the prevalence of skin lesions and lameness could aid in the reduction in the average herd-level prevalence of these outcomes. The benchmarking website created for this study also allows any producer to input their own data and benchmark their results with the study population. If the website was updated to include the risk factors found to be associated with skin lesions and lameness in the Maritime Provinces, it would allow producers to determine how they compare with their peers and provide some guidance as to where to make changes to see improvements.

In this thesis we were able to determine the prevalence of skin lesions and lameness in Maritime dairy herds. As expected, these findings were similar to those in other regions of Canada. Additionally, we were able to identify risk factors for these animal-based measurements which were unique to tie-stall and free-stall housing systems, as well as some which were shared between the two. New associations between behavioural indicators of limb pain used in SLS and hind limb lesions were identified.

Finally, providing producers with information on the prevalence of animal-based measurements in their herd and allowing them to benchmark with their peers, resulted in a reduction in the overall prevalence of hock lesions and lameness in our study population. As the Canadian dairy industry continues to focus on quality assurance, through methods such as proAction® animal care assessments, will a further reduction in the overall prevalence of these animal-based measurements be achieved?

6.7 References

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APPENDICES

Appendix A: Questionnaire for on-farm assessment (free-stalls)

Farm ID: *(province-DHI 5 digit e.g. ON10020)*

Date: *(yyyy-mm-dd)*

Observer: *(first name, last name)*

Sign letter for permission *

SECTION 1 – ACCOMODATION AND HOUSING
1.3 STALL MANAGEMENT
A) STALL BASE

Q1. If mat or mattresses are used in the stalls *(Fill only if answer B or C at **Q110** in the checklist)*, please ask:

A. Brand (main type): ………………………………………..
B. Year of installation (main type): …………………………………….. (yyyy)

B) *STALL MANAGEMENT*
Q2. How often do you rake out stalls and remove cow patties?
A. Once a day
B. More than once a week
C. Once a week
D. Less than once a week
E. More than once a day

Q3. How often new bedding is added (organic bedding and/or sand)?
A. Once a day
B. More than once a week
C. Once a week
D. Less than once a week
E. More than once a day

1.4. *PEN MANAGEMENT (STANDING AREAS)*
Q4 –How often do you flush/scrape standing areas in pens?

A. Automatic system: ………………… nb times/day
B. 2-3 times a day using a manual system
C. 1 time a day using a manual system
D. Less than 1 time per day using a manual system Specify: ………………….. nb times/week

Q5 –How often do you scrape by hand standing areas in the pen that cannot be scraped automatically (e.g. cross-over alleys, in front of waterers, etc.)?
A. 2-3 times a day
B. 1 time a day
C. Less than 1 time per day specify: ………………….. nb times/week

1.5. MILKING PARLOR, HOLDING PENS AND TRANSFER ALLEYS

Q6. How often do you milk per day?

A. twice
B. three times

Q7 – How often do you flush/scrape the transfer alleys to the milking parlor (not holding pens)?

A. automatic system: ………………… nb times/day
B. 2-3 times a day using a manual system
C. 1 time a day using a manual system
D. Less than 1 time per day using a manual system Specify: ………………….. nb times/week

Q120 – What is the type of milking parlor? (Choose 1 answer)

A. side opening (tandem)
B. herringbone (fishbone)
C. parallel (side by side)
D. rotary (carousel)
E. no milking parlor (Automatic Milking System/robot)
F. no milking parlor (tie-stall)
G. other Specify: ……………………

Q121 – Number of milking units/robots: ………………………………… units/robots

Q122-123. Estimated amount of time to milk all cows in the herd. ………………………..

Q124 – What is the type of flooring in the parlor/robot where the animals stand? (Choose 1 answer, if more than 1 chose **I.** other)

A. smooth concrete
B. textured concrete
C. grooved concrete
D. slatted-concrete
E. smooth rubber
F. textured rubber
G. grooved rubber
H. slatted-rubber
I. other Specify:…………

Q125 – What is the type of flooring in the holding pens? (Choose 1 answer, if more than 1 chose **I.** other)

A. smooth concrete
B. textured concrete
C. grooved concrete
D. slatted-concrete
E. smooth rubber
F. textured rubber
G. grooved rubber
H. slatted-rubber
I. other Specify:…………

Q126 – What is the type of flooring in the transfer alleys to the milking parlor? (Choose 1 answer, if more than 1 chose **I.** other)

A. smooth concrete
B. textured concrete
C. grooved concrete
D. slatted-concrete
E. smooth rubber
F. Textured rubber
G. grooved rubber
H. slatted-rubber
I. other Specify…………………

SECTION 2 – FEED AND WATER

Q8. Do you feed TMR (Total Mixed Ration)?

A. Yes *fill **Q9**, **Q10** and **Q11**, skip **Q12***
B. No *go to **Q12***

Q9. How often do you deliver feed to cows? (does not need to be a fresh mix) *(Fill only if answer A to **Q8**)*

A. 2-3 times per day or more
B. 1 time a day
C. Less than 1 time a day

Q10. When do you deliver feed to cows? *(Fill only if answer A to **Q8**)(To check if consistent schedule)*

A. Always around milkings (before or/after)
B. Always around milking (before or/after) and at other times (feed 3x or more)
C. Always mid-am and/or mid-pm
D. I do not have a consistent feeding schedule

Q11. How often do you push-up feed to cows? (*Fill only if answer A to **Q8**)*

A. 2-3 times per day or more
B. 1 time a day
C. Less than 1 time a day (eq. to sometimes)
D. I do not push-up feed Specify "why?": ………………………………

Q12. If you do not feed TMR *(Fill only if answer B to **Q8**)*, please fill the following tables about type of feed (forage and concentrate) and distribution schedule (*If no specific schedule, leave blank column time of the day*)

Forage	**Type** (e.g. grass, silage, hay, etc.)	**Time of the day** (hh:mm)
Forage 1		
Forage 2		
Forage 3		
Forage 4		
Forage 5		

Concentrate	**Time of the day** (hh:mm)
Concentrate 1	
Concentrate 2	
Concentrate 3	
Concentrate 4	
Concentrate 5	

SECTION 3 – HEALTH AND WELFARE MANAGEMENT

3.1. MAJOR HERD HEALTH ISSUES

Q13. What are the three main herd health issues that concern you (Please tick all that apply and/or insert other health issues)? *"such as lameness, mastitis, fertility or some other diseases". Prompt for a 3rd answer (milk fever, Johnes, BVD, metritis, calf mortality, etc.)*

Q14. Please rank these in order of the effort you put into controlling them – greatest first.
Q15. Please rank these in order of your opinion of how much they cost your business – greatest first

Q13. Health problem (Tick all that apply and/or insert other health issues)	**Q14. Ranking on effort put into controlling the problem 1 = greatest**	**Q15. Ranking on cost to business 1 = greatest**
Lameness		
Mastitis		
Fertility		
Other disease		
Other disease		
Other disease		

***3.2** LAMENESS IN YOUR DAIRY HERD*

Q16. How serious is the problem of lameness in your herd?

A. Not a problem
B. Minor problem
C. Moderate problem
D. Major problem

Q17. How many lame cows do you have in the herd today? *(To calculate point prevalence of lameness*)

A. Nb of lame cows: ………………………..
B. Nb of cows in the herd: ………………………..

Q18. How many cows have been **treated** for lameness in the last year? (**Treated** includes to treat with antibiotics, to trim, to attach a block, to take out a nail or stone etc) *(Incidence of lameness)*

A. Nb of cows that were treated for lameness: ………………………..
B. Nb of cows that were in the herd: ………………………..
C. Is this figure: AN ESTIMATE or FROM RECORDS

Q19. In the past two years, have you made any management changes to deal with lameness?
A. Yes, what was the reason? ……………………..
Nb of cows treated for lameness before you initiated the change ……………
B. No

In the following 3 (Q20-Q21) sets of questions, you will be asked to rank various issues or factors on a scale from 1 to 5. Please indicate how important you consider each one to be by ticking the appropriate box.

Q20. In your opinion, which of the following are the main causes of lameness? – Please score each factor for its importance (1 not a factor to 5 extremely important factor)

	Not	**Slightly importa**	**Moderatel y**	**Very importa**	**Extreme ly**
	1	**2**	**3**	**4**	**5**
Nutrition					
Uncomfortable stalls					
Bad floorings					
Genetic (leg/feet conformation)					
Claw infection/poor hygiene					
Other (Specify:					

Q21. How important are the following issues resulting from lameness: (1 not at all important to 5 extremely important)

	Not importa	**Slightly importa**	**Moderatel y**	**Very importa**	**Extreme ly**
	1	**2**	**3**	**4**	**5**
Reduced milk production					
Pain for the cow					
Extra time spent working with lame					
Treatment costs					
Having to cull a cow					
Poor cow condition					
Reduced fertility					
Other (Specify:					

Q22. In the following list which factors prevent you from treating lame cows?
Please score each factor for its importance (1 not a factor to 5 extremely important factor)

	Not important Limiting f...	**Slightly important Limiting f...**	**Moderately important Limiting f...**	**Very important Limiting f...**	**Extremely important Limiting**
	1	**2**	**3**	**4**	**5**
Lack of time					
Lack of skilled labor on farm					
Difficulty to get a hoof trimmer					
Difficulty identifying lame cows					
Poor foot trimming facilities on farm					
Hoof trimmer/vet too expensive					
Lack of information/knowledge					
Conflicting advice					
Other					

Q23. **On average**, how much money do you lose for each case of lameness (including hoof trimming, vet treatments, milk lost, etc.)?

A. < $100
B. $100-200
C. $200-400
D. > $400

Q24. How painful is lameness for a cow?

A. Not at all painful
B. Slightly painful
C. Moderately painful
D. Very painful

3.3 *LAMENESS MONITORING*

Q25. Do you routinely check cows to identify new lameness cases?

A. I do not check *go to **Q27***
B. I do visual evaluation as part of my daily routine
C. I do visual evaluation as part of my weekly routine
D. I do visual evaluation once in a while
E. Specialists do that for me (vet/hoof-trimmer) *go to **Q27***

Q26. If you check routinely for lameness *(Fill only if answer B, C or D to **Q25**)*, where and when do you do this?

(Choose one or more answer)

A. When I walk around the barn
B. When I feed cows
C. When I move cows to the milking parlor
D. When cows are exiting the milking parlor
E. Other Specify: …………………

Q27. What sign do you use to detect lame cows? (Choose one or more answer)

A. When a cow limps
B. When a cow does not want to stand up (e.g. for milking, at feeding)
C. When a cow has a back arch
D. Other Specify: …………………

Q28. Do you keep record of lameness? (Choose one or more answer)

A. All cases of lameness you detect
B. All cases of lameness you treat for
C. All cases of lameness the hoof-trimmer reports
D. All cows I culled because of lameness
E. No record

Q29. Once you have identified a lame cow, when do you decide to <u>treat</u> her? (Choose one answer)

A. I treat her immediately (myself)
B. I call in the vet/hoof-trimmer immediately
C. I wait until hoof-trimmer/vet comes next time
D. I wait to see if she gets better
E. I do not treat her

3.4. CLAW HEALTH/HOOF TRIMMING

A) FOOTBATH

Q30. How often do your cows walk through a footbath?

A. Never *go to* ***Q35***
B. ……………… nb of milkings per week

Q31. Do you have seasonal differences? I use footbaths at… (Choose one or more answer) *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

A. Spring
B. Summer
C. Fall
D. Winter
E. Other Specify:………………..

Q32. Which products do you use? *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

Days of the week	**Type** product 1	**Concentration** product 1 (%)	**Type** product 2 *(if combinatio*	**Concentration** product 2 (%) *(if combination*	**Type** product 3 *(if combinatio*	**Concentration** product 3 (%) *(if combination*
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
Sunday						

Q33. How often do you change contents of the footbath? *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

A. At each milking
B. Daily
C. More than once a week
D. Once a week
E. Less than once a week

Q34. How many times do you refill the footbath? *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

A. At each milking
B. Daily
C. More than once a week
D. Once a week
E. Less than once a week

B) *HOOF-TRIMMING*

Q35. What is your hoof-trimming schedule?

A. All cows are trimmed <u>once a year</u>
B. All cows are trimmed <u>twice a year</u>
C. Cows are trimmed <u>routinely</u> Specify: every ……………… weeks
D. I call the hoof-trimmer/I do it myself <u>only if</u> a cow needs it (emergency hoof-trimming)
E. I never call the hoof-trimmer/ I <u>never</u> trim

Q36. Which cows do you do when you trim? (Choose one or more answer)

A. All cows
B. Dry-off cows (2 months before calving)
C. Mid-lactation cows
D. Clinically lame cows
E. Cows with overgrown claw/bad conformation
F. Other Specify:………………..

Q37. Who does <u>routine</u> hoof-trimming? (Choose one or more answer)

A. Yourself/staff certified: yes or no
B. Hoof-trimmer certified: yes or no
C. Vet
D. Other Specify:………………..

Q38. Who does <u>emergency</u> hoof-trimming? (Choose one or more answer)

A. Yourself/staff
B. Hoof-trimmer
C. Vet
D. Other Specify:……………

Q39. Do you keep records of hoof trimming?

A. Yes
B. No

Q40. Have you had any cases digital dermatitis (also known as strawberry footrot, hairy heel warts) diagnosed on your farm in the last 12 months?

A. Yes
B. No

Q41. Do you have a pedometry system on farm?

A. Yes   Specify (brand):………………..
B. No

SECTION 5 – CODE OF PRACTICES

Q62. Have you heard about the Dairy Code of Practices? *(Students will bring a copy of the Code with them)*

A. Yes
B. No   *Go to* ***Q68***

Q63. How did you become aware of the Code? (Choose one or more answer) *If answer No (B.) at* ***Q62****, <u>do not fill</u>*

A. Mail copy
B. Presentation at meeting
C. Newsletter article
D. Other   Specify: …………………

Q64. Have you read it? *N.B. read a part of it = read, flick through = not read If answer No (B.) at* ***Q62****, <u>do not fill</u>*

A. Yes
B. No   *Go to* ***Q66***

Q65. Do you think it is well done? *If answer No (B.) at* ***Q64****, <u>do not fill</u>*

A. Yes
B. No

Q66. Have you made any changes to your practices as a result of the Code?

A. Yes   Specify: …………………
B. No

Q67. Do you still have a copy of the Code?

A. Yes
B. No

Q68. Would you like us to bring you a copy of the Code?

A. Yes
B. No

Additional Management Questions

Q69. How many full-time employees are currently on the farm? …………

Q70. Do the lactating cows have access to pasture?

A. Yes
   How long do they have access to pasture on average? …………….days/year; …………..hours/day
B. No

Q71. Do the dry cows or heifers have access to pasture before calving?

A. Yes
B. No

Q72. What type of facility are the dry cows and heifers in prior to entering lactating herd?

A. Tie stall
B. Free stall
C. Pack bedding
D. Other (specify…………)

Q73. How many animals have had dystocia in the last 12 months? …………….Nb of animals
Q74. How many cases of "downer cows" have you had in the past 12 months? …………….Nb of animals

Q75. How many cows have died or were euthanized on farm due to accidents/disease in the past year?
……………… Nb of animals

Q76. Do you feel that cow comfort is an important issue in the dairy industry today?

A. Yes
B. No
   Comments: ………………………………………………………………………

Appendix B. Questionnaire for on-farm assessments (tie-stalls)

COW COMFORT ASSESSMENT – 1-MANAGEMENT QUESTIONNAIRE (TIE STALL)

Farm ID: *(province-DHI 5 digit e.g. ON10020)*

Date: *(yyyy-mm-dd)*

Observer: *(first name, last name)*

SECTION 1 – ACCOMODATION AND HOUSING

1.3 STALL MANAGEMENT

STALL BASE

Q1. If mat or mattresses are used in the stalls *(Fill only if answer B or C at **Q110** in the checklist)*, please ask:

A. Brand (main type): ………………………………………..
B. Year of installation (main type): …………………………………….. (yyyy)

STALL MANAGEMENT

Q2. How often do you rake out stalls and remove cow patties?

A. Once a day
B. More than once a week
C. Once a week
D. Less than once a week
E. More than once a day

Q3. How often new bedding is added (organic bedding and/or sand)?

A. Once a day
B. More than once a week
C. Once a week
D. Less than once a week
E. More than once a day

MILKING PARLOR, HOLDING PENS AND TRANSFER ALLEYS TO THE MILKING PARLOR

Q6. How often do you milk per day?

A. twice
B. three times

Q122-123. Estimated amount of time to milk all cows in the herd. ………………………..

SECTION 2 – FEED AND WATER

Q8. Do you feed TMR (Total Mixed Ration)?

A. Yes *fill **Q9**, **Q10** and **Q11**, skip **Q12***
B. No *go to **Q12***

Q9. How often do you deliver feed to cows? (does not need to be a fresh mix) *(Fill only if answer A to* ***Q8****)*

A. 2-3 times per day or more
B. 1 time a day
C. Less than 1 time a day

Q10. When do you deliver feed to cows? *(Fill only if answer A to* ***Q8****)(To check if consistent schedule)*

A. Always around milkings (before or/after)
B. Always around milking (before or/after) and at other times (feed 3x or more)
C. Always mid-am and/or mid-pm
D. I do not have a consistent feeding schedule

Q11. How often do you push-up feed to cows? (*Fill only if answer A to* ***Q8****)*

A. 2-3 times per day or more
B. 1 time a day
C. Less than 1 time a day (eq. to sometimes)
D. I do not push-up feed Specify "why?": ………………………………

Q12. If you do not feed TMR *(Fill only if answer B to* ***Q8****)*, please fill the following tables about type of feed (forage and concentrate) and distribution schedule (*If no specific schedule, leave blank column time of the day*)

Forage	**Type** (e.g. grass, silage, hay, etc.)	**Time of the day** (hh:mm)
Forage 1		
Forage 2		
Forage 3		
Forage 4		
Forage 5		

Concentrate	**Time of the day** (hh:mm)
Concentrate 1	
Concentrate 2	
Concentrate 3	
Concentrate 4	
Concentrate 5	

SECTION 3 – HEALTH AND WELFARE MANAGEMENT

Q13. What are the three main herd health issues that concern you (Please tick all that apply and/or insert other health issues)? *"such as lameness, mastitis, fertility or some other diseases". Prompt for a 3rd answer (milk fever, Johnes, BVD, metritis, calf mortality, etc.)*

Q14. Please rank these in order of the effort you put into controlling them – greatest first.

Q15. Please rank these in order of your opinion of how much they cost your business – greatest first

Q13. Health problem (Tick all that apply and/or insert other health issues)	**Q14. Ranking on effort put into controlling the problem 1 = greatest**	**Q15. Ranking on cost to business 1 = greatest**
Lameness		
Mastitis		
Fertility		
Other disease		
Other disease		
Other disease		

Q16. How serious is the problem of lameness in your herd?

A. Not a problem
B. Minor problem
C. Moderate problem
D. Major problem

Q17. How many lame cows do you have in the herd today? *(To calculate point prevalence of lameness)*

A. Nb of lame cows: ………………………..
B. Nb of cows in the herd: ………………………..

Q18. How many cows have been **treated** for lameness in the last year? (**Treated** includes to treat with antibiotics, to trim, to attach a block, to take out a nail or stone etc) *(Incidence of lameness)*

A. Nb of cows that were treated for lameness: ………………………..
B. Nb of cows that were in the herd: ………………………..
C. Is this figure: AN ESTIMATE or FROM RECORDS

Q19. In the past two years, have you made any management changes to deal with lameness?

A. Yes, What was the reason
Nb of cows treated for lameness before you initiated the change
B. No

In the following 3 (Q20-Q21) sets of questions, you will be asked to rank various issues or factors on a scale from 1 to 5. Please indicate how important you consider each one to be by ticking the appropriate box.

Q20. In your opinion, which of the following are the main causes of lameness? – Please score each factor for its importance (1 not a factor to 5 extremely important factor)

	Not important	**Slightly important**	**Moderately important**	**Very important**	**Extremely important**
	1	**2**	**3**	**4**	**5**
Nutrition					
Uncomfortable stalls					
Bad floorings					
Genetic (leg/feet conformation)					
Claw infection/poor hygiene					
Other (Specify:					

Q21. How important are the following issues resulting from lameness: (1 not at all important to 5 extremely important)

	Not important	**Slightly important**	**Moderately important**	**Very important**	**Extremely important**
	1	**2**	**3**	**4**	**5**
Reduced milk production					
Pain for the cow					
Extra time spent working with lame					
Treatment costs					
Having to cull a cow					
Poor cow condition					
Reduced fertility					
Other (Specify:					

Q22. In the following list which factors prevent you from treating lame cows?
Please score each factor for its importance (1 not a factor to 5 extremely important factor)

	Not important Limiting factor	**Slightly important Limiting factor**	**Moderately important Limiting factor**	**Very important Limiting factor**	**Extremely important Limiting factor**
	1	**2**	**3**	**4**	**5**
Lack of time					
Lack of skilled labor on farm					
Difficulty to get a hoof trimmer					
Difficulty identifying lame cows					
Poor foot trimming facilities on farm					
Hoof trimmer/vet too expensive					
Lack of information/knowledge					
Conflicting advice					
Other					

Q23. On average, how much money do you lose for each case of lameness (including hoof trimming, vet treatments, milk lost, etc.)?

A. < $100 B. $100-200 C. $200-400 D. > $400

Q24. How painful is lameness for a cow?

A. Not at all painful
B. Slightly painful
C. Moderately painful
D. Very painful

Q25. Do you routinely check cows to identify new lameness cases?

A. I do not check *go to* ***Q27***
B. I do visual evaluation as part of my daily routine
C. I do visual evaluation as part of my weekly routine
D. I do visual evaluation once in a while
E. Specialists do that for me (vet/hoof-trimmer) *go to* ***Q27***

Q26. If you check routinely for lameness *(Fill only if answer B, C or D to **Q25**)*, where and when do you do this? (Choose one or more answer)

A. When I walk around the barn
B. When I feed cows
C. When I move cows to the milking parlor
D. When cows are exiting the milking parlor
E. Other Specify: …………………

Q27. What sign do you use to detect lame cows? (Choose one or more answer)

A. When a cow limps
B. When a cow does not want to stand up (e.g. for milking, at feeding)
C. When a cow has a back arch
D. Other Specify: …………………

Q28. Do you keep record of lameness? (Choose one or more answer)

A. All cases of lameness you detect
B. All cases of lameness you treat for
C. All cases of lameness the hoof-trimmer reports
D. All cows I culled because of lameness
E. No record

Q29. Once you have identified a lame cow, when do you decide to <u>treat</u> her? (Choose one answer)

A. I treat her immediately (myself)
B. I call in the vet/hoof-trimmer immediately
C. I wait until hoof-trimmer/vet comes next time
D. I wait to see if she gets better
E. I do not treat her

3.4. CLAW HEALTH/HOOF TRIMMING

C) FOOTBATH

Q30. How often do your cows walk through a footbath?

A. Never *go to **Q35***
B. ……………… nb of milkings per week

Q31. Do you have seasonal differences? I use footbaths at… (Choose one or more answer) *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

A. Spring
B. Summer
C. Fall
D. Winter
E. Other Specify:………………..

Q32. Which products do you use? *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

Days of the week	**Type** product 1	**Concentration** product 1 (%)	**Type** product 2 *(if combination of products)*	**Concentration** product 2 (%) *(if combination of products)*	**Type** product 3 *(if combination of products)*	**Concentration** product 3 (%) *(if combination of products)*
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
Sunday						

Q33. How often do you change contents of the footbath? *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

A. At each milking
B. Daily
C. More than once a week
D. Once a week
E. Less than once a week

Q34. How many times do you refill the footbath? *(If no use of footbath, answer A to **Q30**, <u>leave blank</u>)*

A. At each milking
B. Daily
C. More than once a week
D. Once a week
E. Less than once a week

D) *HOOF-TRIMMING*

Q35. What is your hoof-trimming schedule?

A. All cows are trimmed once a year
B. All cows are trimmed twice a year
C. Cows are trimmed routinely Specify: every ……………… weeks
D. I call the hoof-trimmer/I do it myself only if a cow needs it (emergency hoof-trimming)
E. I never call the hoof-trimmer/ I never trim

Q36. Which cows do you do when you trim? (Choose one or more answer)

A. All cows
B. Dry-off cows (2 months before calving)
C. Mid-lactation cows
D. Clinically lame cows
E. Cows with overgrown claw/bad conformation
F. Other Specify:………………..

Q37. Who does routine hoof-trimming? (Choose one or more answer)

A. Yourself/staff certified: yes or no
B. Hoof-trimmer certified: yes or no
C. Vet
D. Other Specify:…………….

Q38. Who does emergency hoof-trimming? (Choose one or more answer)

A. Yourself/staff
B. Hoof-trimmer
C. Vet
D. Other Specify:……………

Q39. Do you keep records of hoof trimming?

A. Yes
B. No

Q40. Have you had any cases digital dermatitis (also known as strawberry footrot, hairy heel warts) diagnosed on your farm in the last 12 months?

A. Yes
B. No

Q41. Do you have a pedometry system on farm?

A. Yes Specify (brand):………………..
B. No

SECTION 5 – CODE OF PRACTICES

Q62. Have you heard about the Dairy Code of Practices? *(Students will bring a copy of the Code with them)*

A. Yes
B. No   *Go to **Q68***

Q63. How did you become aware of the Code? (Choose one or more answer) *If answer No (B.) at **Q62**, do not fill*

A. Mail copy
B. Presentation at meeting
C. Newsletter article
D. Other   Specify: …………………

Q64. Have you read it? *N.B. read a part of it = read, flick through = not read If answer No (B.) at **Q62**, do not fill*

A. Yes
B. No   *Go to **Q66***

Q65. Do you think it is well done? *If answer No (B.) at **Q64**, do not fill*

A. Yes
B. No

Q66. Have you made any changes to your practices as a result of the Code?

A. Yes   Specify: …………………
B. No

Q67. Do you still have a copy of the Code?

A. Yes
B. No

Q68. Would you like us to bring you a copy of the Code?

A. Yes
B. No

Additional Questions

Q69. How many full-time employees are currently on the farm? ………………

Q70. Do the lactating cows have access to pasture?

A. Yes
B. No

How long do they have access to pasture on average? …………….days/year; …………..hours/day

Q71. Do the dry cows or heifers have access to pasture before calving?

A. Yes
B. No

Q72. What type of facility are the dry cows and heifers in prior to entering lactating herd?

A. Tie stall
B. Free stall
C. Pack bedding
D. Other (specify…………)

Q73. How many animals have had dystocia in the last 12 months? …………….Nb of animals

Q74. How many cases of "downer cows" have you had in the past 12 months? …………….Nb of animals

Q75. How many cows have died or were euthanized on farm due to accidents/disease in the past year? ……………… Nb of animals

Q76. Do you feel that cow comfort is an important issue in the dairy industry today?

A. Yes
B. No

Comments: ………………………………………………………………………

Appendix C. Quiz for hoof trimmer agreement

IMAGE A

IMAGE B

IMAGE C

IMAGE D


IMAGE E


IMAGE F


IMAGE G

IMAGE H

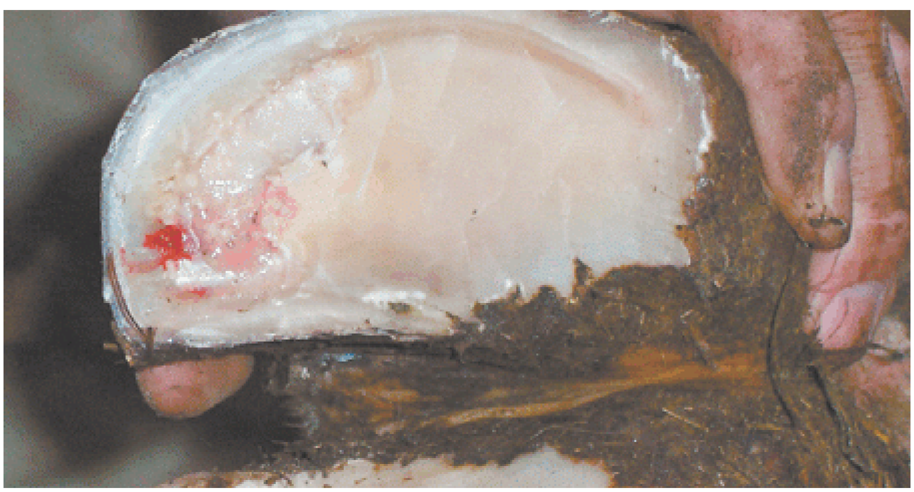


IMAGE I

IMAGE J

IMAGE K

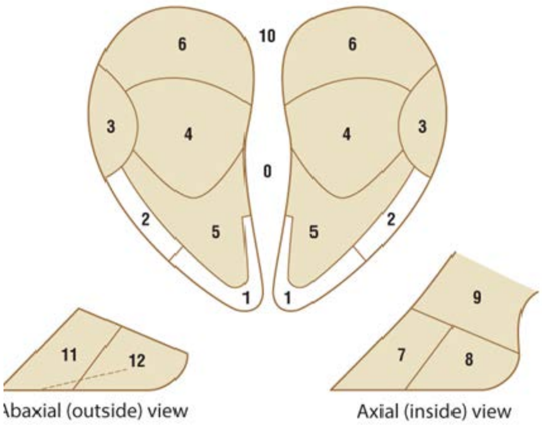

IMAGE L


IMAGE M

Appendix D. Hoof trimmer record sheet

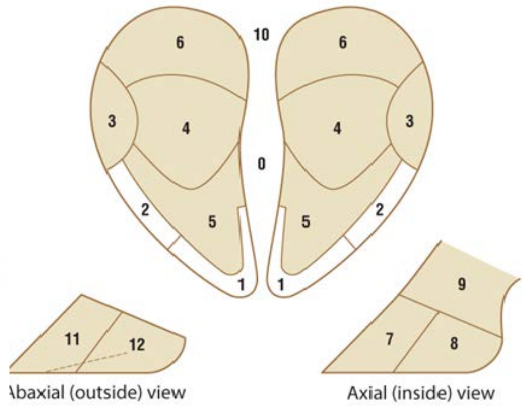
Cow ID # ____________

Left Front Foot



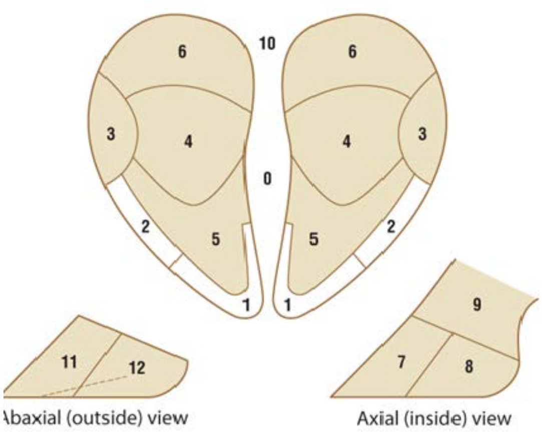
Comments:

Right Front Foot



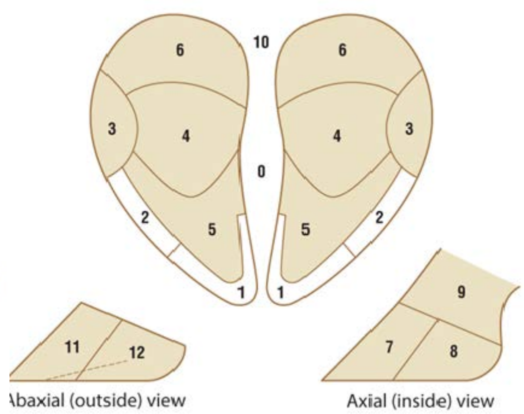
Comments:

Left Rear Foot



Comments:

Right Rear Foot



Comments:

Appendix E. Questionnaire for management changes between first and second visits

Herd-ID: ________________________
Date: ___________________________
Observer: _______________________

Questions regarding environmental or management changes

1. Have any changes been made to the stalls/stall management in the last year?

Stall Base	Stall Dimensions	Bedding Type	Bedding amount
Spring 2016	Spring 2016	Spring 2016	Spring 2016
Summer 2016	Summer 2016	Summer 2016	Summer 2016
Fall 2016	Fall 2016	Fall 2016	Fall 2016
Winter 2017	Winter 2017	Winter 2017	Winter 2017
Not applicable	Not applicable	Not applicable	Not applicable

Specify…………. Specify………….. Specify………….. Specify……………

2. Have you made any major changes in the ration within the last year? (Example started feeding TMR, started feeding different forages)

a. Yes. Specify………………………..
1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017

b. No

3. Have you made any changes in the feeding schedule within the last year?

Feeding frequency	Feeding time
Spring 2016	Spring 2016
Summer 2016	Summer 2016
Fall 2016	Fall 2016
Winter 2017	Winter 2017
Not applicable	Not applicable

Specify………………………………… Specify……………………………………

4. Have you made any changes in keeping records for lameness within the last year?

Recording treatment	**Reports from hoof trimmer**	**Reporting reason for culling**
Spring 2016	Spring 2016	Spring 2016
Summer 2016	Summer 2016	Summer 2016
Fall 2016	Fall 2016	Fall 2016
Winter 2017	Winter 2017	Winter 2017
Not applicable	Not applicable	Not applicable

5. Have you increased the amount of time spent observing cows for lameness within the last year?

a. Yes

1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017

b. No

6. Have you changed when you decide to treat lame cows within the last year?

a. Yes. Specify………………………..

1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017

b. No

7. Have you made any changes in the frequency of footbaths or product in footbath (if used) within the last year?

Frequency of footbath	**Product in footbath**
Spring 2016	Spring 2016
Summer 2016	Summer 2016
Fall 2016	Fall 2016
Winter 2017	Winter 2017
Not applicable	Not applicable

Specify……………………………….. Specify……………………………………

8. Have you made any changes in the frequency you or a hoof trimmer performs routine trimming within the last year?
a. Yes. Specify………………………..
1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017
b. No
9. Have you made any changes in keeping records of hoof trimming within the last year?
a. Yes
1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017
b. No

Questions specific to FS
10. Have you made any changes to the pen(s) within the last year?

Flooring Type	**Dimensions**
Spring 2016	Spring 2016
Summer 2016	Summer 2016
Fall 2016	Fall 2016
Winter 2017	Winter 2017
Not applicable	Not applicable

Specify………………………………….. Specify…………………………………..

11. Have you increased the amount of times the alleys are scraped (automatically or manually) within the last year?
a. Yes. Specify………………………..
1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017
b. No

12. Have you made any changes to decrease the amount of time it takes to milk the entire herd within the last year?
a. Yes. Specify………………………..
1. Spring 2016
2. Summer 2016
3. Fall 2016
4. Winter 2017
b. No

13. Have you made any changes to the feedbunk rail within the last year?

Partitions added	**Neck rail position**
Spring 2016	Spring 2016
Summer 2016	Summer 2016
Fall 2016	Fall 2016
Winter 2017	Winter 2017
Not applicable	Not applicable

Specify………………………………… Specify………………………………….

Questions specific to TS

14. Have there been any changes made in the placement of the electric trainers within the last year?

a. Yes. Specify………………………..
    1. Spring 2016
    2. Summer 2016
    3. Fall 2016
    4. Winter 2017

b. No

Questions regarding effect of tool

15. Do you think there has been a reduction in the number of lame cows in your herd within the last year?

a. Yes.
b. No
c. Not observed

16. Do you think there has been a reduction in the number of cows with injuries in your herd within the last year?

a. Yes.
b. No
c. Not observed

17. Have there been any improvements in milk production within the last year?

a. Yes.
b. No
c. Not observed

18. On a scale of 1-5 how helpful was the cow comfort assessment in identifying any potential problems in your herd?

Not Helpful		Neutral		Very Helpful
1	2	3	4	5

19. On a scale of 1-5 please rank how influential the benchmarking website and assessment results were in motivating you to make changes?

No Influence		Neutral		Very Influential
1	2	3	4	5

If modifications were made on the herd (Answer yes to any question 1-14)

20. On a scale of 1-5 please rank how influential the following factors were in motivating you to make changes?

	No Influence		Neutral		Very Influential
	1	2	3	4	5
Improve quality of life for you					
Improve quality of life for animals					
Increase profitability of farm					
Make farm desirable for successors					
Allow farm to compete with other farms					
Other (Specifiy):______________					

21. Did you refer to the Dairy Code of Practice when making these modifications?
a. Yes
b. No

If modifications were not made on the herd

22. On a scale of 1-5 please rank the following factors on how they influenced you to not implement changes to your farm since the last assessment.

	No Influence 1	2	Neutral 3	4	Very Influential 5
Cost					
Lack of time					
Conflicting advice					
Do not feel changes are necessary					
Other (Specify):______________					

23. Do you plan to make changes in the near future? If so what area? (If no skip to question 26)
a. Stall design
b. Stall management
c. Pen management
d. Milking area
e. Feedbunk
f. Other. Specify…………………………..
24. When making modifications will you be referring to the Dairy Code of Practice?
a. Yes
b. No

25. On a scale of 1-5 rank what factors are preventing you from implementing changes to your farm in the near future?

	Not a Factor 1	2	Neutral 3	4	Factor 5
Cost					
Lack of time					
Do not feel changes are necessary					
Other (Specify):______________					