MANAGEMENT OF VULNERABLE DAIRY COWS

by

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M.Sc., The University of British Columbia, 2014

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Applied Animal Biology)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

September 2019

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The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

MANAGEMENT OF VULNERABLE DAIRY COWS

submitted by Jane Stojkov in partial fulfillment of the requirements for

the degree of Doctor of Philosophy

in Applied Animal Biology

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Abstract

Dairy farmers, scientists and critics have raised concerns over the current management of non-ambulatory and cull dairy cows at the farm and after they enter the marketing system. Inadequate management of non-ambulatory cows is indicated by low recovery rate and insufficient nursing care provided to these animals. Similarly, the large number of compromised cull dairy cows observed at livestock markets and abattoirs indicates poor on-farm culling decisions and/or a prolonged marketing process that significantly reduces animal welfare. The goals of this thesis were to quantify factors that may increase recovery of non-ambulatory cows, to describe the diverse management of cull dairy cows in Canada particularly the movement of cull dairy cows in British Columbia, and to quantify changes in the cows' condition when moved from the farm to an abattoir. In Chapter 1, I describe the culling process as part of herd management and underline the most common culling reasons and their effects on animal welfare. In Chapter 2 I quantified factors that could improve recovery of cows subjected to flotation therapy, and found that shorter recumbency duration and provision of good nursing care can improve recovery. To describe the diverse management of cull dairy cows in Canada I used input from a meeting that involved a diverse group of experts from different regions of the country; this also resulted in 9 recommendations to guide future research and policy (Chapter 3). In Chapter 4, I evaluated the condition of cull dairy cows sold at livestock markets and found that 30% of the cows were compromised, and that compromised cows were more often observed during months with increased milk demand, likely because of delayed culling. To evaluate changes in the condition of cull dairy cows while in the marketing system, I monitored cows from farm to slaughter. I found that most cows spent more than 3 days in the marketing system,

and many lost body condition and developed an engorged or inflamed udder (Chapter 5). These findings improve our understanding how vulnerable cows are managed and will help to guide future research, policy and development of better industry practices.

Lay Summary

Management of downers (cows unable to stand) and cull dairy cows (cows removed from the herd) is a challenge for producers and a welfare concern of the industry. Low recovery of downers is associated with poor management which can be improved by initiating timely treatment and provision of good nursing care. Poor and delayed culling decisions are sometimes related to increased milk demand which in turn increases the number of compromised cows removed from the farms and sold at livestock markets at lower prices. The time cows spend in the marketing system (from farm to slaughter) affects the condition of cull dairy cows and their ability to withstand transport. In British Columbia cull cows spend more than 3 days in the marketing system during which many lose body condition and develop an engorged or inflamed udder. Producers may consider removing cows with better body condition and dry-off cows before transport.

Preface

A version of Chapter 2 has been published as Stojkov, J., D. M. Weary, and M. A. G. von Keyserlingk. 2016. Nonambulatory cows: Duration of recumbency and quality of nursing care affect outcome of flotation therapy. J. Dairy Sci. 99:2076-2085. J. Stojkov designed the study, collected data, performed the statistical analyses and wrote the manuscript. M. A. G. von Keyserlingk and D. M. Weary provided assistance with statistical analysis, and provided input in preparation of the manuscript. This project was approved by the UBC Animal Care Committee (certificate number A15-0139).

A version of Chapter 3 has been published as Stojkov, J., G. Bowers, M., Draper, T. Duffield, P. Duivenvoorden, M. Groleau, D. Haupstein, R. Peters, J. Pritchard, C. Radom, N. Sillett, W. Skippon, H. Trépanier, and D. Fraser. 2018. Management of cull dairy cows - Consensus of an expert consultation in Canada. J. Dairy Sci. 101:11170-11174. J. Stojkov designed the study, collected data, performed the content analyses and wrote the manuscript. D. Fraser provided input in the study design, data collection, content analysis, and in preparation of the manuscript. All other co-authors provided input in preparation of the manuscript. This project was approved by the UBC Behavioural Research Ethics Board (certificate number H16-00387).

Chapter 4 is being prepared for publication. J. Stojkov developed the methodology of the study, collected data, performed the statistical analyses and wrote the manuscript. Fraser, D., von Keyserlingk, M. A. G., and Duffield, T. provided assistance with the study design and provided input in preparation of the manuscript. This project was approved by the UBC Animal Care Committee (certificate number A16-0336).

Chapter 5 is being prepared for publication. J. Stojkov developed the study design, collected data, performed the statistical analyses and wrote the manuscript. Fraser, D., von Keyserlingk, M. A. G., and Duffield, T. assisted in improving the study design and provided input in preparation of the manuscript. This project was approved by the UBC Animal Care Committee (certificate number A16-0336) and the UBC Behavioural Research Ethics Board (H17-00009).

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List of Abbreviations

AHA = Animal Health Australia

BC = British Columbia

BCS = Body Condition Score

BHB = β-hydroxybutyrate

BI = Bias Index

CAD = Canadian Dollars

CARC = Canadian Agri-Food Research Council

CBQA = Canadian Beef Quality Audits

CDC = Canadian Dairy Commission

CDIC = Canadian Dairy Information Center

CHDL = Claw Horn Disruption Lesions

CLAL = Italian Dairy Economic Consulting Firm

DA = Displaced Abomasum

DFC = Dairy Farmers of Canada

DHI = Dairy Herd Improvement System

DIM = Days in Milk

EU = European Union

FARM = Farmers Assuring Responsible Management

FWD = Feed and Water Deprivation

HF = High Frequency

HRM = Heart Rate Monitor

HRV = Heart Rate Variability

JLW = Justice Laws Website

K = Unweighted Kappa Coefficient

K_w = Weighted Kappa Coefficients

LF = Low Frequency

LS = Locomotion Score

LSM = Least Squared Means

LDA = Left Displacement of the Abomasum

MAP = *Mycobacterium Avium ssp. Paratuberculosis*

MMB = Milk Marketing Board

MSQ = Market Sharing Quota

NAHMS = National Animal Health Monitoring System

NAL = National Agricutural Library

NASS = National Agricultural Statistics Service

NAWAC = National Animal Welfare Advisory Committee

NBQA = National Beef Quality Audit

NEFA = Non-Esterified Fatty Acid

NFACC = National Farm Animal Care Council

NFAHWC = National Farmed Animal Health and Welfare Council

NSAID = Non-Steroidal Anti-Inflammatory Drug

NRS = Numeric Rating System

OR = Odds Ratio

PI = Prevalence Index

RDA = Right Displacement of the Abomasum

RP = Retained Placenta

RR = Relative Risk

SCC = Somatic Cell Count

SD = Standard Deviation

SE = Standard Error

SOP = Standard Operating Procedure

SPCA = Society for the Prevention of Cruelty to Animals

UC = Udder Condition

USA = United States of America

USDA = United States Department of Agriculture

VLF = Very Low Frequency

Glossary

‘Additional quota allocation’ (in the Canadian milk marketing system) is a permanent increase in the daily butterfat production that a farm is required to achieve

‘Flotation therapy’ involves immersion of a cow in a tank filled with warm water where the cow’s weight is largely supported by the buoyancy of the water

‘Heifer’ is a female bovine before her first calving

‘Incentive day’ (in the Canadian milk marketing system) requires each farm to increase its monthly butterfat production by the equivalent of one additional day of production in the month when the incentive day was assigned

‘Lameness’ refers to changes in cow’s gait in response to pain in cows’ hoof, leg or back

‘Multiparous’ cow is a cow that has calved more than once

‘Non-ambulatory cow’ is a cow that is unable or unwilling to stand and remains recumbent for ≥ 12 hours

‘Parity’ refers to the number of calvings or lactations a cow has had

‘Primiparous’ cow is a cow that has calved once

‘Quota’ (in the Canadian milk marketing system) is a daily quantity of butterfat in kilograms that a farm is required to produce and is allowed to market

Acknowledgements

During my graduate studies I was supported by many individuals and organizations. I owe my deepest gratitude to Dr. David Fraser, who with his elaborate knowledge, candid spirit and warm heart is a perfect example of how to be a good scientist, educator and a diplomat. It was a privilege to have you as a supervisor. I am grateful to Dr. Nina von Keyserlingk who acted as a co-supervisor during my 6-year research journey, helped me observe animal welfare from different perspectives and shaped me as a good researcher. I thank Dr. Todd Duffield for his interest and support of my research endeavors and sincere enthusiasm to make changes in the industry. I will forever be in debt to Dr. Dan Weary who provided me with an opportunity to conduct my first research and has always been a powerful source of inspiration.

I also thank individuals from the Faculty of Land and Food Systems and the Dairy Education and Research Center particularly Dr. Ronaldo Cerri for providing much professional and life-related advice, Dr. James Thompson for running the center for many years and sharing the history of the center and how it all started, Nelson Dinn for providing valuable information about on-farm culling decisions, Chris McGill, Marry-Ann La Fond and Lia Maria Dragan for their patience and administrative support. I want to acknowledge all students that provided me with support through this adventure: Laura for being the most positive officemate, Hanna for bringing the joy of running in the woods, Ruan for initiating interesting conversations, mostly while barbequing, Alexi for the Mediterranean input, Joao for the most adventurous trips, Heather & Tracy for being the true Canadian friends, Lucia for the Mexican parties, Ben and Eugénie for being great hosts, Devon for helping with data collection, Bruna for keeping the data safe, and thanks to Julia, Christine, Augusto, Anne-Marieke and others.

Also I would like to thank: all participating dairy farmers, the BC Abattoir Association and the slaughter plants that kindly gave us access to their facilities, BC Food Safety and Inspection Branch, especially Michelle Da Silva, Canadian Food Inspection Agency, especially Geneviève Bénard, Nancy Simmons, Krista LaFrenière, Rick Armstrong, Michelle Meredith, Betty Moch, United States Department of Agriculture - Food Safety and Inspection Service, especially Drs. Lucy Anthenill, Arthur Whitfield, Michael Mikhaiel, and Darla Sullivan, the Livestock Markets Association of Canada, the auction markets that kindly cooperated, and the veterinary clinics that helped in many ways, especially Drs. Lisa McCrea and Brent Fawcett from Agwest Veterinary Group for supporting my research. I am grateful to the colleagues in the BC Ministry of Agriculture for their support and cooperation, particularly Dr. Jane Pritchard, Terri Giacomazzi, Tom Droppo, Dr. Brian Radke and Erin Cuthbert.

Funding for my graduate studies and research came from multiple sources including: the Investment Agriculture Foundation of BC, Westgen Endowment Fund, Agwest Veterinary Group ltd, the BC Dairy Association's Dairy Industry Research and Education Committee, Loblaw Companies Limited, the National Farmed Animal Health and Welfare Council, BC Ministry of Agriculture through *Growing Forward 2*, a federal-provincial-territorial initiative, Elizabeth R. Howland Fellowship, Walter C. Koerner Fellowship and Canada's Natural Sciences and Engineering Research Council - Alexander Graham Bell Canada Graduate Scholarship.

Finally, I thank Biljana who was a stronghold during this adventure and provided me with enormous amounts of LOVE, good nursing care and when necessary, statistical advice. You are a big part of this thesis. I thank my cousin who was always willing to chat and cheer me up. And I am forever grateful to my mother (Ivanka) and father (Todor) and my sisters (Svetlana & Aleksandra) who each on their own beautiful way shaped me as the person I am today.

Dedication

To all visionaries and trailblazers who were able to see and question what others could not and had the courage to stand their ground

Chapter 1: Introduction

Management of non-ambulatory and cull dairy cows is a major animal welfare challenge. The concerns are mainly related to lack of specific and clear guidelines for dealing with these vulnerable animals. For example, available information about management of non-ambulatory cows reveals that these cows are often provided with poor nursing care and the current treatments are frequently associated with low chance of recovery. Similarly, cull dairy cows are removed from herds through complex culling decisions influenced by multiple factors, followed by poorly understood post-farm-gate management which includes transport to livestock markets and then to an abattoir for slaughter. The current management of cull dairy cows varies tremendously across North America and the negative effects of this process are evidenced by the large number of cows that arrive at livestock markets and abattoirs in compromised condition.

1.1 Background

Influenced by economic pressure, technological advances and consumer expectations, the dairy industry in North America has undergone important changes in the last few decades (reviewed by Barkema et al., 2015). Dairy herds have increased in size but the number of farms has declined, while milk production has increased (Barkema et al., 2015). Despite the dairy industry in Canada being regulated through a supply-management system, the Canadian dairy industry has still followed the global trend, resulting in the number of dairy farms in the last decade declining by about 20%, accompanied with a slight increase in herd size and a 4% reduction in the number of dairy cows (CDIC, 2018a, b). Yet, even with the reduction of dairy farms and number of cows, milk production in Canada has increased by about 18% since 2008

(CDIC, 2018c). These increases in milk production are attributed to improved herd management, nutrition and genetic selection (Barkema et al., 2015).

The changes in the dairy industry, particularly increased milk production, have also influenced herd management. In the 1990s, the replacement rate in 10 US states was about 35% (Hadley et al., 2006). In the following period, based on the National Animal Health Monitoring System, the replacement rate in US dairy herds ranged from 29-33% (USDA-NAHMS, 2002, 2007, 2016). The replacement rates in Canada held constant with a mean replacement rate of 38% reported from 2010 to 2014, paralleled by a relatively constant milk production with only a 1-million-hectolitre increase over the same period (CDIC, 2018c). However, in the following 3-year period from 2015 to 2017, milk production was mandated to increase by 8 million hectoliters, and the replacement rate declined from 38% in 2014 to 33% in 2017 (CDIC, 2018c). These trends suggest that an increase in milk production (in response to demand) may influence the management of dairy herds and reduce replacement rates probably by delaying culling decisions.

As a consequence of improved knowledge about cattle nutrition and continuous genetic selection for milk production, average milk production per cow in the last decade has increased by 12.5% (reviewed by Barkema et al., 2015; USDA-NASS, 2018). However, increased milk production has been linked with increased occurrence of mastitis and lameness (Barkema et al., 1994; Ingvartsen et al., 2003; Amory et al., 2008; Bicalho et al., 2009). These two conditions, together with reproductive issues and low milk production, are the most cited reasons for removing cows from dairy herds (USDA-NAHMS, 2007; CDIC, 2018d). Both mastitis and lameness are painful conditions and transport of cows with these conditions is, according to Canadian regulations, either limited to short transport under special provisions (e.g. directly to slaughter plants) or, depending on severity of the condition, transport may be prohibited (Justice Laws Website [JLW], 2018; CARC, 2001). Regardless, studies from Canada and the US have reported a large percentage of lame cows and cows with mastitis arriving at livestock markets and slaughter plants (Ahola et al., 2011a; Harris et al., 2017; Moorman et al., 2018).

While the above changes occurred in the dairy industry, two other sectors involved in the marketing and transport of cattle remain practically unchanged. First, the marketing system in North America commonly involves sales of cattle through a livestock market which may include exposure to novel environments, multiple handling events, mixing with unfamiliar animals, segregation, confinement, overnight stays and potential feed and water deprivation. As a consequence of the marketing system, perhaps in combination with the previous condition at the farm of origin, cattle coming from livestock markets often have reduced meat quality (Warren et al., 2010a) and have increased chances of becoming non-ambulatory or dying during transport (González et al., 2012a). Secondly, the transport sector has remained largely unchanged in Canada since the release of the *Code of Practice for the Care and Handling of Farm Animals: Transportation* in 2001 (CARC, 2001), and in the US the 28-h law, which originates from 1906 and was amended in 1994 (USDA-NAL, 2018). The current transport regulations in Canada and the US allow for continuous transport without feed and water for 48 h and 28 h, respectively (see Table 1.1). Although these maximum transport times are long, in practice the mean transport time in Canada is around 5 h (Warren et al., 2010b) and in the US slightly less then 7 h (Harris et al., 2017). However, these transport times only report the final leg of the journey cattle experience and must be interpreted with caution. Cattle that are sold through the marketing system cannot be easily followed because they change ownership. Once they enter the marketing system cattle could be resold up to several times through livestock markets or buying stations before reaching the slaughter plants. Thus, they may experience the adverse effects of the livestock markets and multiple shorter transportations which cumulatively could exacerbate the condition of the cattle and potentially reduce their welfare (Schwartzkopf-Genswein et al., 2012, 2016).

The goal of this chapter is to examine four topics important for understanding the management of cull dairy cows and how their welfare is affected. The first section describes culling and herd turnover, the culling decision process, and the subsequent effects on herd management and milk production. The second section highlights the most common culling conditions and reasons, and how these conditions may influence cows' welfare, behaviour, productivity and longevity. The third section focuses on the effects of transport duration together with feed and water deprivation on cattle. The final section summarizes the concerns observed in cattle sold at livestock markets and arriving at slaughter plants.

1.2 Herd turnover rate in dairy herds

Dairy herd management is a dynamic process in which farm managers continuously balance herd size with the aims of constantly producing the demanded amount of milk, maintaining a healthy herd, and running a profitable enterprise (Beaudeau et al., 1993; Gröhn et al., 2003; Langford and Stott, 2012). However, a cow's milk production varies depending on lactation stage, parity, and health status (Bascom and Young, 1998; Pinedo et al., 2010; De Vries et al., 2010). To achieve a steady milk supply, producers continually make decisions to eliminate cows with reduced performance and introduce new animals into the herd. Thus, replacement is a continuous process, yet a useful tool for farm mangers to maintain health, welfare and high milk production.

Cows may be replaced because of diseases and conditions such as metritis, lameness[1], mastitis and other diseases that reduce their productivity or even cause death (reviewed by Beaudeau et al., 2000; Dechow and Goodling, 2008). However, healthy productive cows will have reduced milk production after the fifth lactation and with increasing age their risk of contracting diseases also increases (Hadley et al., 2006; Hare et al., 2006; Dechow and Goodling, 2008). To facilitate these continuous replacements, farm managers make ongoing culling decisions and maintain a pool of (pregnant) heifers that serve as replacements.

1.2.1 Definitions related to culling and herd turnover rate in dairy herds

Removing cows from dairy herds is commonly referred as "culling", but many different terms, definitions and calculations have been used. Fetrow et al. (2006) define culling as: "departure of cows from the herd because of sale, slaughter, salvage, or death". However, there is lack of agreement whether cows that die or are sold for dairy purposes should be included in this classification. For example, the Canadian Dairy Information Center (CDIC) does not include cows sold for dairy or that died in their "culling" classification (CDIC, 2018d). This inconsistency may be because the term "cull" usually describes removing cows due to undesirable traits and reasons (Fetrow et al., 2006). To avoid this negative association, a term with more neutral tone such as "herd turnover rate" has been proposed, with the aim to capture all cows that leave the herd, regardless of reason and destination (Fetrow et al., 2006).

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[1] Although lameness is not a disease but rather a sign of pain, for the purposes of this review lameness will be considered as a condition.

Traditionally, culling has been classified as voluntary or involuntary culling (Hadley et al., 2006; Fetrow et al., 2006). Selling healthy cows only because of low milk production or selling them for dairy purposes (i.e. sold for milk production on another dairy farm) is considered voluntary culling. Involuntary culling includes cows sold because of infertility or health problems (e.g., mastitis, lameness) and cows that died or were euthanized on-farm (Hadley et al., 2006; Fetrow et al., 2006). This classification has been challenged because cows are usually culled for multiple reasons and the culling decisions are more complex than traditionally described (Lehenbauer and Oltjen, 1998; Bascom and Young, 1998; Fetrow et al., 2006). The reason for culling is straightforward for cows sold for dairy purposes; but these only make up around 2% of cows culled from US herds (USDA-NAHMS, 2002, 2007) and 6% from Canadian herds (CDIC, 2018d). However, various diseases involved in involuntary culling might have different weight in the culling process. Some conditions promote culling without delay (e.g., dystocia, mastitis, high somatic cell count (SCC) and teat injury), while other conditions such as metritis, retained placenta, cystic ovaries may reduce productive performance, and thus contribute to later culling (Gröhn et al., 1998; Hadley et al., 2006).

Regarding the destination, cull cows may be designated for: (1) dairy purposes, (2) slaughter, (3) salvage (see definition below) or (4) might die[2] (Fetrow et al., 2006). Compared to the European Union (EU) where livestock markets are losing popularity and slaughter cows are often shipped directly to a slaughter plant (Gregory, 2008), in North America most cows destined for slaughter enter the marketing system which includes transport and sales at livestock markets

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[2] For the purposes of this review "death" will be considered as destination because the cows that die on farm will be removed from the herd by composting, rendering or other available means.

(64%; Glaze and Chahine, 2009) or assembly yards, followed by transport to a processing plant. Salvage cows are those that are labeled unsuitable for human consumption because of certain health conditions (e.g., leukosis) or because of drug withdrawal. Cows that died or were euthanized on-farm are placed in the “death” category (Fetrow et al., 2006).

1.2.2 Decision-making processes when managing a dairy herd

Decisions for removing cows from the herd influence both short- and long-term herd dynamics and profitability, and are usually made through an unsystematic process based in part on the manager’s intuition (Lehenbauer and Oltjen, 1998). Generally, the reasons for replacing cows from the herd involve three elements: (1) individual cow factors, (2) herd factors and, (3) the farmers’ management style (Beaudeau et al., 1996; Bascom and Young, 1998).

Removing a cow from the herd usually starts with an overview of the individual cow characteristics (Bascom and Young, 1998; Lehenbauer and Oltjen, 1998). The farm manager considers several cow factors which have different weight on the decision-making process. Failure to reproduce, followed by lameness and mastitis, have the largest impact on the decision to cull a cow (Bascom and Young, 1998; Gröhn et al., 1998). Some factors such as pregnancy reduce the chances of removal, while mastitis increases the chances of removal because of the disease itself (direct effect) and indirectly by reducing milk yield (Gröhn et al., 1998). Stage of lactation, parity, genetic potential, production ability, and chronic health issues are also considered before the herd manager examines herd-related factors (Beaudeau et al., 1993, 2000; Lehenbauer and Oltjen, 1998; Hadley et al., 2006).

After screening individual cow factors, farm managers may proceed by considering herd factors. These may include the number of dry cows and pregnant heifers available (short-term effect) and/or certain long-term goals such as herd expansion, contraction or maintenance of the herd size (Lehenbauer and Oltjen, 1998; Hadley et al., 2006). Herd expansion generally reduces removal rate (Hadley et al., 2006); producers with expanding herds are more inclined to remove cows with health problems but retain low-producing cows (Weigel et al., 2003). Herd characteristics such as herd average milk production, herd size, breed and reproductive management might influence the decisions to remove cows (Bascom and Young, 1998; Smith et al., 2000; Hare et al., 2006; De Vries et al., 2010). For example, farms with higher milk production (greater than 11,400 kg rolling herd average per cow) remove more cows from their herds compared to low-producing farms. Similarly, larger herd size is associated with a higher percentage of cows removed from the herd compared to farms with small herds (Smith et al., 2000).

In combination with the cow and herd factors, farmers might be guided by their individual perception of the risks and benefits associated with each of these factors; hence, the culling decisions may reflect the farmer's management style (Beaudeau et al., 1996). The farmers' socio-psychological characteristics have been reported to explain 24% of the variation in removal rate among Canadian Holstein farmers (Bigras-Poulin et al., 1985). In France farmers who had more and open relationships with their peers and external advisers had different replacement criteria compared to farmers that lacked a well-developed professional network (Beaudeau et al., 1996). For example, while the objectives of certain "proactive" famers were related to voluntary culling, genetic selection and longevity (i.e. keeping cows longer in the herd), other more "traditional" farmers completed many emergency cullings and showed less interest in selection and voluntary replacement (Beaudeau et al., 1996).

Farmers’ culling decisions are also influenced by external factors such as veterinarians and other advisors (Willock et al., 1999). A recent study from Quebec compared the decision-making process between dairy producers and external advisers (Haine et al., 2017). Farmers were more oriented toward individual cow production and udder health as culling criteria, while some external advisers placed higher consideration on reproductive performance but still considered udder health and production as important (Haine et al., 2017). Collectively, these findings indicate that there is no uniform approach to making culling decisions; instead, culling is an individualized process that farmers use to achieve their goals.

The milk management system, which may be a free-market or supply-management system, may also influence herd management. The free-market system is characterized by large price fluctuations and periodic production of milk surplus (Muirhead, 2014; CLAL, 2018). In contrast, the government-controlled Canadian supply-management system matches the country’s demand for milk products by regulating milk production and avoiding milk surplus. The Canadian Dairy Commission (CDC) has a central role in this system and has two objectives: (1) to estimate the milk price that will provide a fair return to producers’ costs and investments, and (2) to estimate the demand of milk products in the country and maintain a continuous supply of milk to consumers (Muirhead, 2014; CDC, 2018). Based on the National Milk Marketing Plan, the CDC distributes the national milk production target to the provinces using Market Sharing Quota (MSQ). The provincial Milk Marketing Boards (MMB) further allocate their share of the MSQ to the producers. Each dairy farmer holds a certain “daily quota”; quota is purchased from the provincial MMB and represents a daily quantity of butterfat in kilograms that the farmer is required to produce. For example, 150 kg of butterfat could be a daily quota for a 100-cow dairy farm and this converts into producing 4,500 kg of butterfat in a 30-day month. On occasion and when warranted by demand, the MMB may demand an increase in butterfat production using tools such as “additional quota allocation” and “incentive day/s”.

1.2.3 Herd turnover - implications for herds and individual cows

Herd turnover dynamics can be described as conservative, moderate or aggressive (i.e., high culling rate) and can vary depending on the farmer’s culling strategy (Beaudeau et al., 1996; Hadley et al., 2006). For example, progressive and proactive farmers might remove cows due to selection for health or certain productivity traits and have increased herd turnover rate, whereas more traditional farmers might practice involuntary culling and emphasize profitability by lower herd turnover (Beaudeau et al., 1996). In some cases, for example in the Canadian supply-management system or in cases where producers have limited barn capacity, producers might benefit from maintaining a stable herd size and constant milk production, thus having a moderate and constant herd turnover rate. However, if certain economic indicators such as milk and replacement heifer prices are favourable, and given there is enough milk demand, producers might decide to expand the herd. In the expanding herd scenario, culling will be reduced (Fetrow et al., 2006; Hadley et al., 2006) and limited to culling due to health problems (Weigel et al., 2003).

Farm managers and advisors generally try to optimize herd turnover rate as it can have a profound impact on farm profitability. Based on previous literature, the optimal herd turnover rate was considered to be ≤ 30% (Rogers et al., 1988a, b; Stott, 1994). These optimal replacement rates, established 30 to 40 years ago, were calculated with the goal to maximize farm profitability and provide guidance on herd management. Recommendations included removing cows at the end of the sixth lactation to achieve optimal profitability (Bauer et al., 1993). However, reasonable economic returns can be achieved even when culling ranges from third to tenth lactation (Bauer et al., 1993). Moreover, these estimates of optimal replacement rate were sensitive to certain factors such as fluctuations in the price of replacement heifers (Rogers et al., 1988a) which could be associated with the costs of feed and price of milk.

Reaching the recommended herd turnover rate of ≤ 30% may not translate into best on-farm management practices, high profitability, or good animal health and welfare. For example, lower herd turnover rate might occur if there is a lack of suitable replacement heifers because of high morbidity and mortality. In contrast, higher herd turnover might be used as a management strategy to control increased prevalence and incidence of a given disease (Gröhn et al., 2003). In both scenarios, the health status of individual cows plays an important role when producers reach their culling decisions. Therefore, if the herd manager reaches culling decisions by combining individual cow factors (disease status, fertility, milk production), herd factors (herd size, herd milk production, available replacement heifers) and economic factors (milk price, replacement costs) then herd turnover may be optimized at the individual farm level (Fetrow et al., 2006).

Health disorders can have direct and indirect effects on the productivity and fertility of cows and, thus, may also influence culling decisions (Beaudeau et al., 1993; Gröhn et al., 2003). Diseases that occur in different periods of lactation can affect culling differently. Some diseases influence culling at the time they occur and again at the end of the lactation (e.g., dystocia, milk fever, metritis), others only when they occur (e.g., teat injury), while conditions such as mastitis and lameness influence culling throughout the entire lactation (Rajala-Schultz and Gröhn, 1999a, b). Stage of lactation, particularly the first 60 days after calving, has been associated with high culling rates due to diseases and injuries (Dechow and Goodling, 2008). The risk of culling and mortality caused by health disorders also increases with parity. For example, culling can range from 13% in primiparous cows to over 40% in cows with seven or more lactations, while mortality can range from 2% in primiparous cows to over 6% in cows with six or more lactations (Hadley et al., 2006).

Cows might develop several conditions before the producer reaches a culling decision. A limited number of studies have described the compound effect of various conditions on culling decisions, but if given the opportunity, farmers would cite more than one culling reason (Bascom and Young, 1998). In North America, farm managers usually report the culling reasons in the dairy herd improvement (DHI) system which provides several pre-defined reasons for culling (e.g., reproduction, mastitis, feet and leg problems) that farmers may select. However, farmers are only permitted to select only a single culling reason, thus leaving room for ambiguity when animals are culled for multiple reasons or reasons not available in the system. Today, according to the Canadian DHI records, a large portion (22%) of cows are culled because of an “unknown” reason (CDIC, 2018d).

Removing cows from dairy herds is a continuous process and part of the herd management and milk production cycle. Culling decisions are influenced by multiple factors including external advisers who promote optimal culling rates to achieve profitability. However, culling rates promoted by advisors usually emphasize the economic effect of herd management and disregard the welfare of the animals and the post-farm-gate events and management of removed cows. Although herd replacement data might provide a good overview about the most common culling reasons, the replacement rate should not be used as a single indicator of disease incidence, welfare and productivity.

1.3 The most common culling reasons and their effect on welfare, productivity and longevity/mortality of dairy cows

This section describes the most common reasons for removing cows from Canadian dairy herds as reported by dairy farmers (CDIC, 2018d). The prevalence and incidence of these conditions in the dairy herds will be reported and how certain factors such as parity, stage of lactation and season may affect their occurrence. This section also links the conditions with the welfare of the animals, and explains how these conditions influence the longevity of dairy cows especially by how they contribute (directly or indirectly) to the culling decision. These conditions are reported individually, although diseases often interact; for example, hypocalcemia and ketosis may lead to increased likelihood of other postpartum diseases such as retained placenta, metritis and displaced abomasum. The first condition described in this section, the downer cow syndrome, is not a very common culling reason, but it involves extremely poor welfare and low recovery which causes large number of cows to be euthanized or die on-farm.

1.3.1 Mobility problems: non-ambulatory cattle (downer cow syndrome)

Cows that are unable or unwilling to stand and remain recumbent for ≥ 12 hours are defined as non-ambulatory or downer cows (Burton et al., 2009). Canadian *Health of Animal Regulations* define non-ambulatory animals as: “livestock that is unable to stand without assistance or to move without being dragged or carried” (Justice Laws Website [JLW], 2018). Other definitions use different durations of recumbency as cut-off points and include descriptions of downer cows. For example, downer cow has been defined as “being recumbent on the sternum for > 24 h for no obvious reason” (Cox et al., 1986), or “cattle that were unable to stand or walk without assistance for any length of time” (Green et al., 2008).

The reasons for recumbency can be classified as: (1) metabolic disorders (e.g., hypocalcaemia), (2) infectious disorders (e.g., endotoxic mastitis), (3) calving-related injuries (e.g., dystocia-induced calving paralysis) and (4) other musculoskeletal injuries (e.g., hip luxation; Cox, 1988; Burton et al., 2009). Regardless of the primary cause of recumbency, cows that remain recumbent for longer periods (6-12h) often develop secondary recumbency which is associated with pressure damage on affected muscles and nerves (Cox et al., 1982).

Most cases of recumbency occur at the beginning of the lactation, even as early as the first day of lactation (58%), with 95% of cases during the first 100 DIM (Cox et al., 1986). A study performed a decade ago reported that 63% of the non-ambulatory cases occurred within 14 days after calving (Burton et al., 2009). An earlier study focusing on Minnesota dairy herds reported a high incidence in the cold winter months from December to February (39%) and the lowest incidence (16%) in the period from April to June (Cox et al., 1986). The latter study also reported a breed effect on this condition, indicating that Holstein and Guernsey breeds have similar incidence (around 22 per 1000 cow-years), while the incidence for the Jersey breed was 18 and for Brown Swiss was lowest at 16 per 1000 cow-years. Similarly, there was slight variation in the recovery rate across breeds ranging from 27% to 34% in Guernsey and Holstein, respectively (Cox et al., 1986).

Given the different definitions used to describe non-ambulatory cows, it is not surprising that the incidence and prevalence of this condition vary from study to study. When using 24 hours of recumbency as a cut-off definition, the reported incidence was 21.4 cases per 1,000 cow-years at risk (Cox et al., 1986). Recent estimates from the US indicate that 1.2% of the dairy cattle inventory became non-ambulatory during 2004 or that the majority of dairy farms reported at least one non-ambulatory cow annually (Green et al., 2008). A slightly higher percentage of non-ambulatory cows (2.6%) during 2013 was reported by the most recent National Animal Health Monitoring System (USDA-NAHMS, 2016).

Before the ban on transport and slaughter of non-ambulatory cows (which occurred in December 2003 in the United States and June 2005 in Canada), surveys at 21 slaughter plants in the US reported 71,117 and 49,520 non-ambulatory cattle in the holding pens in 1994 and 1999, respectively (reviewed by Stull et al., 2007). Similarly, a Canadian survey at 19 slaughter plants and 3 livestock markets reported 7,382 non-ambulatory cattle arriving at these facilities, consisting of 90% dairy breeds (Doonan et al., 2003).

The downer cow syndrome is considered a major welfare problem for the affected cows. First, the initial cause of recumbency is often related to health problems such as metabolic disorders, infectious diseases or musculoskeletal injuries (Cox, 1988). The nerve and muscle damage cause secondary recumbency making the cows lethargic with reduced reactivity, and the inability to move makes the cows unable to reduce their proximity from other cows and humans, which increases stress and fear. In addition, non-ambulatory cows are unable to seek shelter, feed and water.

Since this condition clearly reduces animal welfare, the dairy industry might be expected to provide good nursing care to non-ambulatory cows and establish a prompt decision-making process for end-of-life decisions. However, the USDA-NAHMS (2016) report suggests that this does not generally occur. For example, only 23% of the dairy operations had developed a standard operating procedure (SOP) for handling non-ambulatory cows. Five of the dairy farms in the US waited 12 h post-recumbency before providing feed and water, and 6% waited 12 h before providing shelter. Moreover, feed and water were not offered on 3% of the farm operations, while 9% did not provide shelter for non-ambulatory cows. At 22% of the dairy operations non-ambulatory cows were never assisted to rise, while the rest (78%) of farms assisted the cows using slings, flotation therapy or other means. Around 35% of the dairy farms needed between 2 and 6 days to reach a decision to euthanize non-ambulatory cows, and slightly over 6% of farms needed more than 6 days to make the end-of-life decisions (USDA-NAHMS, 2016). Collectively, these reports indicate that change is needed to improve the welfare and treatment of non-ambulatory cows including prompt decision-making for euthanasia.

In general, the outcome of non-ambulatory cows has been characterized as low recovery and high mortality. Earlier studies, completed before the North American ban on transport and slaughter of non-ambulatory cows, reported low recovery rates and indicated that a large portion of these cows were slaughtered and many have entered the food chain. One survey gathered information about the outcome of non-ambulatory cows in 723 US dairy herds, and reported that 33% of the affected cows recovered, 23% were slaughtered and 44% died or were euthanized (Cox et al., 1986). Non-ambulatory cows have a high likelihood of being removed from the dairy herd or dying. For example, non-ambulatory cows were 3.5 times more likely to be culled compared to healthy cows and were usually culled immediately after the diagnosis of the condition or within the next 30 days (Milian-Suazo et al., 1988). Similarly, non-ambulatory cows had 26 times greater odds of dying compared to ambulatory cows (Milian-Suazo et al., 1989). A more recent survey, conducted in 21 major US dairy states and covering 84% of the dairy operations, reported a recovery rate of 33% for non-ambulatory cows that were recumbent for $<$ 24 h and 8% recovery if recumbency was $\geq$ 24h (Green et al., 2008). Based on the NAHMS report, which covered 17 states and 81% of the dairy operations in the US, only 30% of the non-ambulatory cows during 2013 recovered, whereas 50% were euthanized, slightly more than 2%

were slaughtered for personal consumption and 18% died at the dairy operation without being euthanized (USDA-NAHMS, 2016).

Higher recovery rates of non-ambulatory cows have been reported when the secondary recumbency was treated with flotation therapy. For example, Burton et al. (2009) treated all non-ambulatory cows (51) arriving at the Cornell University Hospital using the flotation therapy and reported 37% recovery rate. Moreover, when cows were provided with good nursing care while recumbent, the recovery rate increased to 45% (Poulton et al., 2016).

1.3.2 Mobility problems: lameness

Lameness is a sign of pain caused by multiple conditions that affect locomotion. The majority of these conditions are related to foot lesions (Murray et al., 1996) which, according to their etiology, can be classified as infectious (e.g., digital dermatitis, interdigital dermatitis) and non-infectious lesions (e.g., sole ulcer, sole hemorrhages, white line disease) also known as claw horn disruption lesions (CHDL; Mason, 2009; Potterton et al., 2012). Lameness can also be caused by other conditions such as skeletomuscular trauma, diseases of the joints, neurological conditions (e.g., postpartum nerve damage) and other skeletomuscular conditions (Radositits et al., 2007).

The modified locomotion of cows affected by the various lesions is assessed by the use of lameness scales. One frequently used lameness scoring scale is based on observing and assessing the alteration of cows' gait and usually includes the inability to maintain long and even strides (asymmetric gait), joint stiffness, presence of arched back, limping and head bob (Flower and Weary, 2006). This 5-point numeric rating system (NRS) assigns a score of 1 for sound and 5 for severely lame cows. Moreover, lameness has been categorized as 'clinical lameness' which includes cases with lameness score ≥ 3, and 'severe lameness' for cases with a score ≥ 4 (von Keyserlingk et al., 2012).

Lameness prevalence in dairy herds in Canada ranges from 19% in herds in Alberta, 22% in Ontario, 24% in Quebec, (Solano et al., 2015) and 35% in herds in British Columbia (von Keyserlingk et al., 2012). Similarly, large variations of lameness prevalence have been reported in the dairy herds in the United States: 25% in the midwestern states, 34% in California and 63% in some northeastern states (Cook, 2002; Espejo et al., 2006; von Keyserlingk et al., 2012). The lactation incidence of clinical lameness ranges from 1.8% to 30%, with median lactation incidence of 7% (Kelton et al., 1998). Studies in Europe have also reported high lameness prevalence with 37% in British and 48% in German dairy herds (Dippel et al., 2009; Barker et al., 2010).

Lameness prevalence increases with parity. Compared to primiparous cows, the odds of developing lameness are increased in subsequent lactations with OR of 1.6, 3.3 and 4 for cows in their second, third and fourth and higher lactations, respectively (Solano et al., 2015). Similarly, cows in their third or higher lactation were more likely to develop lameness and less likely to recover compared to cows in the first and second lactation (Reader et al., 2011). The incidence of claw lesions that contribute to lameness was reported to be relatively high at the beginning of lactation (1-15 days in milk - DIM), in mid lactation (60-150 DIM), and again in late lactation (>240 DIM; Sanders et al., 2009). Also, compared to spring and winter months, the incidence of claw horn lesions almost doubled in the fall and tripled in the summer months (Sanders et al., 2009).

Regardless of the etiology (i.e., infectious or non-infectious), foot lesions presumably cause pain and they modify cows' posture and locomotion. For example, lesions associated with sole ulcer and white line disease appear to cause pain that may persist for more than 28 days (Whay et al., 1998). Similarly, digital dermatitis causes chronic painful ulceration on the heel and affects cows' locomotion (Döpfer et al., 2012; Bruijnis et al., 2012; Evans et al., 2016). The stoic nature of cows might mask the presence of pain and reduce the locomotion score. However, when cows with altered locomotion and high lameness scores were provided with analgesics, they improved their locomotion and received lower lameness scores (Rushen et al., 2007).

Dairy farmers and veterinarians have similar perception of pain associated with lameness, and both groups consider lameness a painful condition (Leach et al., 2010; Fajt et al., 2011). Veterinary practitioners, when asked to score conditions for painfulness on a scale from 0-10, gave lameness a score of 6 and ranked acute lameness slightly higher than chronic lameness (Fajt et al., 2011). The majority of surveyed dairy farmers associated lameness with pain and suffering of the animals, and also largely related lameness with reduced productivity (Leach et al., 2010).

Numerous studies have linked lameness with reduced milk production and reproductive performance and with altered feeding and lying behaviour (reviewed by Huxley, 2013; Solano et al., 2016). Regardless of the lameness etiology and the scales used to assess this condition, there is generally agreement that lameness reduces milk production. In a study by Amory et al., (2008), cows affected with white line disease and sole ulcer reduced milk production by around 370 kg and 570 kg per lactation, respectively. The same study failed to find an association between digital dermatitis and milk production; however, other studies have reported reduced milk yield in cows with digital dermatitis by 200-330 kg per lactation (Gomez et al., 2015) and reduced milk production of around 0.5 kg/d to 0.8 kg/d, depending on the severity of the condition and on parity (Relun et al., 2013). The overall losses in milk production per lactation due to lameness have been estimated to be in the range from 270-574 kg (Huxley (2013). In addition, high-producing cows are reported to have a higher likelihood of developing lameness (Barkema et al., 1994; Amory et al., 2008; Bicalho et al., 2009). This correlation might influence the culling decisions farmers make for cows with high milk production suffering from lameness.

The effect of lameness on feeding behaviour is ambiguous (reviewed by Huxley, 2013). Several studies have reported altered feeding behaviour in lame cows including reduced feeding time, reduced dry matter intake and meals per day, and increased feeding rate (Bach et al., 2007; Gonzalez et al., 2008; Gomez and Cook, 2010). On the contrary, other studies have failed to confirm differences in feeding time or grazing and rumination time between sound and lame cows (Galindo and Broom, 2002; Walker et al., 2008). In addition, cows diagnosed with sole lesions showed modified feeding behaviour 2 weeks before calving, including faster eating rate and more frequent meals (Proudfoot et al., 2010), thus, adding to the complexity of the relationship between feeding behaviour and lameness.

Cows are strongly motivated to lie down (Metz, 1985) and will spend around 11 h per day lying (von Keyserlingk et al., 2012). However, increased resting time can be associated with illness (Weary et al., 2009) and lameness (Ito et al., 2010). An association of lameness with increased lying time and longer lying bouts has been reported by several studies (Chapinal et al., 2009; Ito et al., 2010; Solano et al., 2016). For example, cows with sole ulcers spent approximately 14 h lying down compared to non-lame cows (12 h) and performed longer lying bouts of 93 min versus 80 min for non-lame cows (Chapinal et al., 2009). However, these changes in lying behaviour might be influenced by certain individual cow characteristics such as parity and stage of lactation, and by farm management factors including facility design, stall design and bedding, thus reinforcing the importance of these factors when interpreting lying behaviour in cows (von Keyserlingk et al., 2012; Ito et al., 2010, 2014; Solano et al., 2016).

Lameness has a more straightforward relationship with the reproductive performance of dairy cattle. The negative effects of lameness on various reproductive measures have been reported by a plethora of studies (i.e. Barkema et al., 1994; Hernandez et al., 2001; Bicalho et al., 2007). In summary, these studies reported that lame cows were more likely to show delayed cyclicity and presence of ovarian cysts; they also received more hormonal treatments, had lower estrus expression and mounting events, and were less likely to ovulate (reviewed by Huxley, 2013).

Lameness is the third most cited reason for removing cows from Canadian dairy herds (CDIC, 2018d). Studies have indicated that lameness has a negative effect on longevity in dairy cows and increases the likelihood of culling (reviewed by Huxley, 2013). For example, cows with claw horn lesions had increased probability of culling and death (Machado et al., 2010), and farms classified with moderate and high level of lameness tended to have higher cow mortality (McConnel et al., 2008). In one study the median time of culling was 31 days earlier in the lactation for cows with hoof lesions compared to cows without lesions (Cramer et al., 2009). Moreover, if cows were lame in the first 70 days after calving the risk ratio for culling and death increased for both lame and severely lame cows (Bicalho et al., 2007). Similarly, a study involving 40,000 Ayrshire dairy cows in Finland reported that lameness increased the chances of culling (Rajala-Schultz and Gröhn, 1999a). On the contrary, some studies either did not find a relationship between lameness (sole ulcer) and culling (Hultgren et al., 2004) or reported the opposite, meaning that lame cows had lower probability of being culled than sound cows (Barkema et al., 1994). The latter authors suggested that these findings might by due to high milk production leading to delayed culling decisions. This might be accurate as some farm managers may delay culling lame cows with high milk production in order to increase profit, without considering the welfare of the animal. During such delays, if these cows do not receive appropriate treatment they might deteriorate to the point of having to be euthanized.

1.3.3 Udder health: clinical and subclinical mastitis

Inflammation of the mammary gland predominantly caused by bacterial intramammary infection is defined as mastitis (reviewed by Klaas and Zadoks, 2018). Based on the severity of the clinical signs, intramammary infections can be classified as mild, moderate and severe (Fitzpatrick et al., 1998). Clinical signs of mastitis can include changes in the milk (e.g., milk clots or flakes), changes of the size, consistency and temperature of the mammary gland or the affected quarter, and a systemic response that might include toxemia, fever, tachycardia, ruminal stasis, depression, recumbency and anorexia (Radositits et al., 2007).

Cows with subclinical mastitis lack clinical signs, although the intramammary infection is present and manifested as increased somatic cell count (SCC), consisting of leucocytes and epithelial cells, in the milk of the affected quarter (Bradley, 2002). Increased SCC measured at the bulk tank level is usually an indicator associated with increased prevalence of subclinical mastitis in the herd. Accepted thresholds of bulk tank SCC have been established in many countries across the world and used as indicators of milk quality (reviewed by Ruegg, 2017).

Based on the etiology, mastitis can be classified as contagious or environmental (reviewed by Ruegg, 2017). Contagious mastitis can spread among other quarters and cows in contagious manner. Other pathogens, usually present in the barn environment and known as opportunistic invaders, colonize the mammary gland via the teat canal and cause environmental mastitis (reviewed by Klaas and Zadoks, 2018). Initially, the environmental pathogens were associated with more severe clinical forms of mastitis, particularly the coliform species, while the contagious pathogens were considered to persist in the udder and cause subclinical mastitis and increased SCC. However, recent work has shown that both contagious and environmental pathogens can cause subclinical, mild and severe cases of mastitis (reviewed by Klaas and Zadoks, 2018).

Compared to some conditions that develop only in the weeks after calving (e.g., retained placenta, metritis), cows are at risk of developing mastitis during the entire lactation (Barkema et al., 1998). However, this risk is dramatically increased during the first 2 weeks after calving and it increases with increasing parity (Barkema et al., 1998; Olde Riekerink et al., 2008). Similarly, summer months and early lactation (within 90 DIM) were associated with increased occurrence of clinical mastitis (Hogan et al., 1989). The incidence of clinical mastitis in Canadian dairy farms is on average 23 cases per 100 cow-years, with reported minimum and maximum range of 7.6 to 31.6 cases per 100 cow-years in farms in Manitoba and Ontario, respectively (Olde Riekerink et al., 2008). Dairy herds in the Netherlands reported a mean incidence of 0.26 cases per 365 cow-days at risk (annual incidence; Barkema et al., 1998) while in New Zealand the lactation incidence was 0.19 cases per 305 cow-days at risk (Petrovski et al., 2011). In US dairy farms, despite an overall decline in bulk tank SCC (average 194,000 cells/ml in 2015), the incidence of clinical mastitis increased from 13% in 1996 to 25% in 2014 (reviewed by Ruegg, 2017). In summary, the incidence of clinical mastitis can range from 13 to 40 cases per 100 cow-years; hence, it is considered the most frequently occurring disease in dairy cows and a disease characterized by its recurrent nature (reviewed by Jamali et al., 2018).

Regardless of the etiology and the severity, mastitis causes physiological and behavioural changes that are associated with pain in cows (Fitzpatrick et al., 1998, 2013; Kemp et al., 2008; des Roches et al., 2017). For example, testing responsiveness to pain using a mechanical stimulus indicated that cows with clinical mastitis had increased sensitivity to pain on the leg closer to the affected quarter (Fitzpatrick et al., 1998). When comparing pain sensitivity between cows that received only antibiotic and those that were treated with antibiotics plus NSAID (i/v flunixin), the latter group showed reduced pain sensitivity for 1 day (the expected duration of clinical activity of the NSAID), after which the pain sensitivity returned to the previous state (Fitzpatrick et al., 1998). Similarly, increased pain sensitivity in infected quarters has been reported when measured directly on the udder using a pressure algometer (Fitzpatrick et al., 2013). Mild, moderate and *E. coli*-caused mastitis affect certain physiological measures; these include increased levels of acute-phase proteins such as haptoglobins and serum amyloid A (Eckersall et al., 2001) and increased plasma cortisol and rumen temperature (des Roches et al., 2017). Compared to healthy cows, those with clinical mastitis commonly have higher rectal temperature, higher heart rate and higher respiratory rate (Kemp et al., 2008).

Both dairy farmers and bovine veterinarians seem to be in agreement about the pain caused by severe mastitis in cattle. Dairy farmers ranked severe mastitis as the most painful condition together with dystocia and fracture of the tuber coxae (Kielland et al., 2010). Similarly, veterinarians recognized severe mastitis as painful and reported frequent use of NSAIDs when treating this condition (Fajt et al., 2011). However, dairy farmers scored cases of mild mastitis low on the pain scale (Kielland et al., 2010), even though mild mastitis initiates pain and is associated with reduced welfare (Leslie and Petersson-Wolfe, 2012). More recent research suggests that even subclinical mastitis could increase the sensitivity to pain, suggesting a linear relationship between the SCC increase and pain sensitivity (Peters et al., 2015).

Mastitis also modifies cows’ behaviour. For example, cows with mild and moderate mastitis show increased hock-to-hock distance compared to a control group (Kemp et al., 2008), and they reduced weight-shifting between the rear legs (Chapinal et al., 2013), suggesting that the friction between the legs and the udder, caused by these behaviours, might increase the painful sensation. In contrast with typical sickness behaviour (e.g., increased lying), mastitis has been associated with reduced lying (Medrano-Galarza et al., 2012), particularly on the side of the affected quarter (Siivonen et al., 2011). When mastitis was associated with fever and udder edema cows reduced the time spent lying and ruminating, drinking, and self grooming (Siivonen et al., 2011; Fogsgaard et al., 2012). A more recent study reported that cows with mastitis became less attentive towards their surroundings and made fewer postural changes (lying/standing; des Roches et al., 2017). Cows with mastitis change their feeding behaviour, with reduced feed intake 5 to 10 days before diagnosis (Fogsgaard et al., 2015; Sepúlveda-Varas et al., 2016) and up to 10 days after antibiotic treatment (Fogsgaard et al., 2015). Clinical mastitis affects the reproductive performance of cows as evidenced by reduced chances for pregnancy, increased days until conception, days open and times bred, and reduced percentage of pregnant cows by 200 DIM (Wilson et al., 2008).

Both clinical and subclinical forms of mastitis are associated with reduced milk production (Detilleux et al., 2015); this applies to the entire population of dairy cows, but especially high-producing cows (Gröhn et al., 2004; Bar et al., 2007). The pattern of milk loss has been described as a slight milk drop 1-2 weeks before diagnosis, followed by the greatest loss on the day of diagnosis, and a continued reduction in milk yield for 70 days (Gröhn et al., 2004). For losses caused by mastitis during the entire lactation, estimates vary from around 700 kg in primiparous cows and 1,200 kg in multiparous cows (Wilson et al., 2004). In most cases cows do not recover their previous yield potential after contracting mastitis (Wilson et al., 2004; Bar et al., 2007). Moreover, the recurrent nature of mastitis causes some dairy cows to have more than one episode (Bar et al., 2007). Similarly, subclinical mastitis, identified through increased SCC, increases the risk of clinical mastitis and reduces milk production (Beaudeau et al., 1998; Steeneveld et al., 2008; Hagnestam-Nielsen et al., 2009).

Mastitis has been identified as an important culling reason (CDIC, 2018d) and numerous studies have reported that mastitis reduced cow longevity by increasing the likelihood of culling and death (Gröhn et al., 1998; Bascom and Young, 1998; Bar et al., 2008; Hertl et al., 2011; Cha et al., 2013). Death caused by mastitis occurs in some severe clinical cases (usually due to bacteraemia), with estimated annual mortality rate in lactating cows of around 0.6% (Bradley and Green, 2001; Klaas and Zadoks, 2018). The recurrent nature of the disease also influences the chances of culling and death (Bar et al., 2008). For example, compared to healthy cows the mortality risk of first lactation (primiparous) cows has been reported to be grater than healthy cows by 6, 23 and 28 times during the first, second and third mastitis event, respectively (Bar et al., 2008). In comparison, cows that contract mastitis in a later lactation (multiparous) experience greater mortality risk during the first mastitis event (OR 10), but the risk remains similar during the second and third mastitis event (OR 12; Bar et al., 2008).

Cows that experienced at least one episode of clinical mastitis have increased culling risk, and this risk was maintained as much as two months after the mastitis episode had occurred (Bar et al., 2008). The number of mastitis episodes a cow has during the lactation increases the chances for culling. For example, one study reported that around 8% of cows that had one mastitis episode were removed from the herd, whereas 26% were removed if they experienced recurrent cases of mastitis in the same lactation (Pinzón-Sánchez and Ruegg, 2011). Moreover, cows with three mastitis events during a lactation had 4 times higher odds of being culled compared to cows without mastitis events (Bar et al., 2008). Similarly, cows with high SCC have lower milk quality and milk price (Hadley et al., 2006); hence, these animals have higher chances of being removed from dairy herds (Beaudeau et al., 1993; Hadley et al., 2006).

1.3.4 Udder health: teat injuries

Traumatic injuries of the teats can occur any time during the lactation and can range from superficial wounds to deep lacerations or entire teat amputation (Radositits et al., 2007). Teat injuries cause discomfort and pain especially during milking and increase the risk of mastitis (Gröhn et al., 1990; Radositits et al., 2007; Guélat-Brechbuehl et al., 2010). These injuries are common on dairy farms, with an estimated lactation incidence of around 2% (Dohoo et al., 1983; Sargeant et al., 1998; Bareille et al., 2003). Cows in early lactation are more likely to have teat injuries, and cows of parity three and higher have larger chances of developing teat injuries (Bareille et al., 2003; Azizi et al., 2007).

Cows with teat injuries tend to reduce their feed intake and milk production (Bareille et al., 2003). Similarly, cows with lesions of the teat canal, without major outer skin injury, have high risk of developing subclinical mastitis as well as higher SCC and reduced milk production (Geishauser et al., 1999). Numerous studies have reported that cows with teat injuries have increased chances of being removed from the herd throughout the entire lactation (Milian-Suazo et al., 1989; Rajala-Schultz and Gröhn, 1999a, b; Beaudeau et al., 2000). However, the likelihood of culling because of teat injuries was somewhat reduced after adjusting for the reduced milk production and increased mastitis that is often associated with teat injuries (Rajala-Schultz and Gröhn, 1999a, b).

1.3.5 Reproductive diseases: metritis

Clinical metritis is defined as bacterial contamination of the uterus followed by inflammation of the uterine wall which causes an enlarged uterus and fetid, watery red-brown uterine discharge during the first 21 days after calving (Sheldon et al., 2006). When this condition causes systemic signs of illness such as decreased milk yield, dullness and fever >39.5 °C, in addition to the previously described symptoms, it is defined as acute puerperal metritis (Sheldon et al., 2006). During calving and in the early post-partum period, the uterus is vulnerable to bacterial contamination because the physical barriers such as the cervix, vagina and vulva are compromised (Sheldon and Dobson, 2004). Thus, the postpartum uterus is commonly contaminated with multiple bacteria species (LeBlanc, 2008).

Studies have reported a large range of incidence of metritis, likely because of the low sensitivity and specificity of methods for detecting this condition (reviewed by Haimerl and Heuwieser, 2014). For example, a study involving 1,600 Holstein dairy cows from herds in Argentina reported an incidence of 30% for puerperal metritis and 10% for clinical metritis (Giuliodori et al., 2013). In contrast, a much lower incidence of metritis has been reported in Holstein herds from New York State: around 8% in the period from 1990-1993 and 4% in 1994 (Gröhn et al., 1995, 1998). A more recent study involving Holstein herds from Ontario and New York State reported 20% incidence of metritis (Dubuc et al., 2011). In British Columbia, Huzzey et al. (2007) reported 12% incidence of severe metritis and 27% incidence of mild metritis in a single herd, while Urton et al. (2005) reported that 69% of the observed cows from the same herd showed some signs of metritis. A tendency for a higher incidence of metritis has been reported for primiparous cows (Giuliodori et al., 2013) and during the period from September to

December (Oltenacu et al., 1990). Overall, the incidence of puerperal metritis is considered to range from 5-20% and clinical metritis from 5-25% (reviewed by LeBlanc, 2014).

During transrectal palpation of the uterus, cows with metritis showed changes in their posture (i.e., increased back arch) and changes in heart rate variability measures (i.e., increased sympathetic activation) associated with visceral pain (Stojkov et al., 2015). Cows with metritis also show changes in behaviour weeks before and after the diagnosis. For example, cows with metritis showed reduced dry matter intake and time spent feeding during 1-2 weeks before developing the condition and 1-3 weeks after diagnosis (Huzzey et al., 2007; Wittrock et al., 2011). Similarly, water intake tended to be reduced before diagnosis, and continued to be reduced 1-3 weeks after diagnosis (Huzzey et al., 2007). A more recent study observed feeding behaviour after calving (1-3 days before diagnosis) and reported reduced dry matter intake, fewer feed bin visits, reduced feeding rate and fewer meals per day in cows with metritis compared to healthy cows (Neave et al., 2018); these differences were no longer present after diagnosis, except that meals per day remained low in cows with metritis (Neave et al., 2018). Lying time was reduced before calving, while lying bouts were reduced before calving and 3 days after calving (Neave et al., 2018). Cows with metritis were observed to be less competitive at the feed bunk; sick cows avoided interactions at the feed bunk 1 week before calving (Huzzey et al., 2007), and were replaced more frequently at the feed bunk 3 days before diagnosis (Neave et al., 2018).

While milk production of primiparous cows does not appear to be influenced by metritis, multiparous cows with metritis showed 3.7 kg of milk reduction during the first milk test and 259 kg of milk reduction during the entire 305-day lactation (Dubuc et al., 2011). Another study confirmed metritis-related milk reduction of around 4 kg per day only in multiparous cows

(Wittrock et al., 2011). However, Huzzey et al. (2007) reported that both mild and severe metritis reduced milk production during the first 3 weeks of lactation by 6 to 8 kg/d, respectively. Similarly, cows with clinical and puerperal metritis had reduced milk yield for the first 90 days of lactation (Giuliodori et al., 2013).

The effects of metritis on reproductive performance vary among studies. For example, no differences were reported between metritic and healthy cows in the number of services and days open in either primiparous or multiparous cows (Wittrock et al., 2011). However, other studies reported negative effects on reproduction including lower risk for pregnancy by 100 DIM for cows with puerperal metritis, and more days needed to become pregnant for cows with puerperal metritis versus cows with clinical metritis and healthy cows (Giuliodori et al., 2013).

Metritis contributes to poor welfare and, if not treated with antibiotics, severe cases can cause death (reviewed by LeBlanc, 2008). Post-mortem analysis of 94 cows from one Colorado dairy farm indicated metritis as the proximate cause of death in 6% of the animals examined. The effect of metritis on culling also varies among studies. Some studies reported that metritis does not have a direct effect on culling after adjustment for reproductive performance in the analysis (Gröhn et al., 1998). In contrast, other studies have reported that cows with metritis had higher probability (0.2) to be culled and increased relative risk (RR of 1.2) compared with healthy cows (Milian-Suazo et al., 1989). One downside of the latter study is that the 14 diseases included in the study were not mutually exclusive; in that case cows might have multiple diseases, thus confounding the culling effect of any single disease.

1.3.6 Reproductive diseases: retained placenta

Retained placenta (RP) involves the inability to promptly break the contyledon-caruncle attachment after calving and pass the placenta within 24 h postpartum (Kelton et al., 1998). This unsuccessful detachment of the placenta is caused by suppressed immune function (reviewed by LeBlanc, 2008), which could be triggered in part by hypocalcaemia (Kimura et al., 2006) and severe negative energy balance in prepartum cows (LeBlanc et al., 2004). Other risk factors include dystocia, abortion, high parity and sometimes a seasonal effect (reviewed by LeBlanc, 2008). Based on a study that reviewed the occurrence of RP in studies published from 1975-1995, the lactation incidence ranged from 1-39% with median lactation incidence of around 9% (Kelton et al., 1998).

Studies have reported inconsistent effects of RP on milk production, fertility and culling. From 13 reviewed studies that reported the association between RP and reduced milk production, only five studies reported milk loss of 0.8 kg per day during a 305-day lactation and losses of 2.5 kg per day across 100 days in milk (reviewed by Fourichon et al., 1999). RP was found to reduce milk production by about 4% per day during the first 30 days after diagnosis (see Gröhn et al., 2003) and around 3 kg per day in multiparous cows (Dubuc et al., 2011). The negative effect of RP on the reproductive performance of dairy cows was observed through reduced fertility by 14% (see Gröhn et al., 2003), prolonged days to first service (2-3 days), reduced conception rate by 4-10% and prolonged days to conception (reviewed by Fourichon et al., 2000).

Cows with RP had higher risk of being culled in later lactation. Possibly the culling decisions were delayed because RP influences milk production and fertility, suggesting an indirect effect of RP on culling (Gröhn et al., 1998). Out of 15 health disorders studied in Finnish Ayrshire cows, all except RP had an impact on culling (Rajala-Schultz and Gröhn, 1999a).

Similarly, no effect of RP on culling was reported by Dubuc et al. (2011). On the contrary, RP increased the risk of culling by approximately 1.2 times compared to healthy cows (Beaudeau et al., 1994; Oltenacu et al., 1990) and was considered as a risk factor for postpartum culling by Dubuc and Denis-Robichaud, (2017).

1.3.7 Reproductive diseases: cystic ovaries

The condition known as cystic ovaries is defined as the occurrence of persistent and enlarged smooth, round structures, larger than 25 mm, on one or both ovaries (Kelton et al., 1998). The lactation incidence can range from 1-16%, with median incidence of 8% (Kelton et al., 1998). Other studies have reported incidence of 11% (Gröhn et al., 1998), and described the incidence as having a bimodal peak, the first peak between 30-40 days postpartum and the second peak around 190-220 days postpartum (Bartlett et al., 1986). Lactation incidence has been found to increase with parity, from 9% in primiparous cows to 12-20% in multiparous cows (Bartlett et al., 1986). Chances of developing cystic ovaries were increased in the summer and fall months (Oltenacu et al., 1990) and the same seasons were reported to have high lactation prevalence of 15% and 13%, respectively (Bartlett et al., 1986).

Cystic ovaries have not been associated with milk loss; instead, several studies have linked this condition with increased milk production (reviewed by Fourichon et al. 1999) and as a predisposing factor for mastitis (Gröhn et al., 1990). Cystic ovaries also influence reproductive performance (reviewed by Fourichon et al., 2000). For example, cystic ovaries are associated with reducing fertility by 21% (Gröhn et al., 2003), extending days to first service by 6-11 d, and prolonging days to conception by 20-30 additional days (reviewed by Fourichon et al., 2000).

It is uncertain whether cystic ovaries affect the risk of culling in dairy cows (Beaudeau et al., 2000). On the one hand, Milian-Suazo et al. (1989) reported that cystic ovaries increase the relative risk (RR) of culling by 1.1, while Oltenacu et al. (1990) indicated that cows with cystic ovaries have 3 times higher chances to be culled. In contrast, other studies, after adjusting for the effect cystic ovaries have on fertility, reported that this condition was no longer associated with culling (Gröhn et al., 1998; Rajala-Schultz and Gröhn, 1999a, b, c). The findings from these last studies suggest that any effect of cystic ovaries on culling may occur through reduced fertility.

1.3.8 Metabolic diseases: hypocalcaemia

Failure of the homeostatic mechanisms to supply the increased amount of calcium (Ca) needed by dairy cows after calving is known as clinical hypocalcaemia, milk fever or periparturient paresis (reviewed by Goff, 2008). Based on the clinical signs, clinical hypocalcaemia can have 3 stages. Stage 1 is characterized by mild excitement, hypersensitivity, decreased appetite, and muscle weakness, stage 2 by sternal recumbency, depression, muscle tremors, and reduced gastrointestinal mobility, and in stage 3 cows may develop lateral recumbency, severe bloat and loss of consciousness (see Kelton et al., 1998). Cows with clinical hypocalcaemia usually are unable to stand and those that do not respond to treatment and remain lying for longer periods (6-12h) develop secondary recumbency which is considered a severe complication of clinical hypocalcaemia (see downer cow syndrome, above).

The lactation incidence of milk fever ranges from 0.03% to 22% with median incidence of 7% (Kelton et al., 1998). A recent study from Germany reported prevalence of clinical hypocalcaemia of 1.4% in second lactation cows, 6% in the third and 16% in cows in the fourth or later lactations (Venjakob et al., 2017). Based on data gathered from 480 US dairy farms, the prevalence of subclinical hypocalcaemia was reported to be 25% in primiparous and approximately 50% in multiparous cows (Reinhardt et al., 2011).

Maintaining normal blood Ca levels is important for nerve and muscle functioning and failure to do so could act as a predisposing factor for developing other metabolic and infectious disease (reviewed by Goff, 2008). For example, cows with hypocalcaemia have higher risk of developing displaced abomasum (Chapinal et al., 2011; Seifi et al., 2011) and metritis compared to norm-calcaemic cows (Martinez et al., 2012, 2014). Hypocalcaemia also influences the reproductive performance of cows by prolonging the period of ovarian inactivity after calving and reducing the likelihood of pregnancy at first artificial insemination (Chapinal et al., 2012; Caixeta et al., 2017).

Since high milk yield has been reported as a predisposing factor for hypocalcaemia, the effect of this condition on milk production is difficult to evaluate, especially when considering the entire lactation (Rajala-Schultz et al., 1999; Neves et al., 2017). However, when milk production was observed in the period of 4-6 weeks after calving, the milk loss ranged from 1-3 kg per day, varying by parity (Rajala-Schultz et al., 1999), and remained reduced by 3 kg of milk per day during the first 4 DHI milk tests following hypocalcaemia diagnosis (Chapinal et al., 2011).

Hypocalcaemia increases the chances of culling, first at the beginning of the lactation (within 30 DIM; RR 1.6) and again at the end of the lactation (after 240 DIM; RR 2.3; (Gröhn et al., 1998). Recent studies reported that cows with hypocalcaemia measured during the first week after calving had high odds of being removed in the first 60 days in milk, and these odds of being removed increased if hypocalcaemia was diagnosed during the second week after calving (Seifi et al., 2011; Roberts et al., 2012).

1.3.9 Metabolic diseases: displaced abomasum

The abomasum normally lies on the ventral side of the abdomen below the rumen. In some cases, the abomasum might be filled with gases and moved laterally toward the left (90% of the cases) or toward the right upper flank of the abdomen providing a characteristic ‘ping’ sound on percussion. Depending on the side where the abomasum is positioned, the condition is known as left (LDA) and right (RDA) displacement of the abomasum (Radositits et al., 2007; Berge and Vertenten, 2014). Lactation incidence of displaced abomasum (DA) reported by Gröhn et al. (1995) was around 6%, while for LDA this could range from 0.3% to 6%, with median incidence of 2% (Kelton et al., 1998). The lactation incidence varies by parity, with incidence reported at 4% in primiparous cows, 3% in second lactation and 6% in cows with 3 or more lactations (LeBlanc et al., 2005).

One week before diagnosis of displaced abomasum cows reduce the time spent ruminating by around 45 min/d, reduce their activity by around 45%, increase the time lying down by around 2 h/d and increase the lying bout duration by 11 min/bout (King et al., 2017). Cows with LDA lose on average 557 kg of milk from calving to 60 days after diagnosis with 30% of the milk loss occurring before the diagnosis of the condition (Detilleux et al., 1997). Primiparous cows were reported to have smaller milk losses (363 kg) compared with those in higher parities (Detilleux et al., 1997).

DA has not been associated with reduced reproductive performance (Chamberlin et al., 2013), but was reported as a risk factor for culling, especially at the beginning of the lactation (within 30 d) independent of any relationship with milk production and fertility (Gröhn et al., 1998). Rajala-Schultz and Gröhn (1999a) reported that cows diagnosed with DA in the first 30 d after calving had a 6.8 times greater chance of being culled in the first month and 3.8 times greater chance of being culled in the second month of lactation. More recent studies also indicated that DA increases the odds (OR 3.6) of culling in the first 60 DIM (Roberts et al., 2012).

1.3.10 Metabolic diseases: ketosis

Around calving there is an increased need for energy (glucose) which cannot be supported with feed intake; hence a lipid mobilization and lipolysis is initiated. In these conditions, the lipid metabolism involves partial oxidation of fatty acids (non-esterified fatty acid [NEFA]) that results in creation of ketone molecules (acetoacetate, β-hydroxybutyrate [BHB]) which are used by peripheral tissues as an energy source, while glucose is spared and used for lactogenesis (Goff and Horst, 1997). Failure to balance lipid metabolism is followed by hyperketonemia or ketosis – a condition associated with decreased appetite and increased synthesis of ketone molecules, which are present in the milk, urine and breath (Kelton et al., 1998). The lactation incidence of ketosis ranges from 1% to 18%, with median incidence of 5%, with the majority of cases occurring in the first 60 DIM (Kelton et al., 1998). The risk of developing ketosis is higher in cows with three or more lactations and in cows calved in the winter, spring and summer months compared to those calved in the fall (Vanholder et al., 2015).

Changes in cow behaviour have been reported before and after diagnosis of ketosis. For example, reduced visits and time spent at the feed bunk were observed in cows at risk for ketosis, while cows that developed this condition showed lower competitiveness at the feed bunk (Goldhawk et al., 2009). Similarly, cows that developed ketosis had fewer and longer standing bouts one week before and on the day of calving compared to healthy cows (Itle et al., 2015).

Hyperketonemia has a negative effect on milk production. For example, Duffield et al. (2009) reported reduced milk yield of 330 kg during the 305-day lactation in cows with hyperketonemia. Depending on the indicator and threshold used to identify ketosis, cows could reduce milk production from 393 to 674 kg of milk during the 305-day lactation (Ospina et al., 2010). On the contrary, milk production in primiparous cows with hyperketonemia remained unaffected (Ospina et al., 2010).

Ketosis has a negative effect on reproductive performance in dairy cows by reducing the probability of pregnancy after the first insemination by 20% in subclinical and by 50% in clinical cases (Walsh et al., 2007). Cows with ketosis needed around 16-22 days longer to become pregnant compared to healthy cows (Walsh et al., 2007). Similarly, cows with increased indicators of ketosis (high levels of BHB and NEFA) had 13-16% reduced chances of pregnancy within the first 70 days after the voluntary waiting period (i.e., the time from calving to first insemination; Ospina et al., 2010).

Ketosis also influences the likelihood of culling. In one study, cows with ketosis were 3.6 times more likely to be removed from the herd within 2 months of the disease occurrence (Seifi et al., 2011). Other studies reported that ketosis increases the risk for culling even after adjustment for milk production (Rajala-Schultz and Gröhn, 1999a, b). Interestingly, Gröhn et al. (1998) reported that cows with ketosis had higher risk of being culled either soon after the diagnosis or sometime later in the lactation, which could be related to delayed breeding or reduced fertility.

1.3.11 Other diseases: pneumonia

Respiratory diseases in cows commonly involve abnormality in the breathing rate, lung sounds, respiratory noises and posture, together with lethargy, coughing and nasal discharge (Radositits et al., 2007). Frequent terms used to describe such respiratory conditions in dairy cows are pneumonia or bronchopneumonia (McConnel et al., 2009). In the US respiratory diseases were reported by 61% of operations and affected around 3% of the dairy population. Of affected individuals, around 28% were sold and 11% died or were euthanized (USDA-NAHMS, 2018).

The negative effect of pneumonia on cow behaviour is observed through changes in feeding and activity in the sick cows. In one study, 4 days before diagnosis cows with pneumonia reduced the time spent ruminating by 50 min/d, and body weight was reported to be reduced by 14 kg/d. During the same time cows reduced milk production by 4 kg/d compared to healthy cows (King et al., 2017). Moreover, cows with pneumonia were also found to reduce their activity by 36% and showed a tendency to increase the duration of their lying bouts (King et al., 2017).

Cows with pneumonia have increased risk of being removed from the herd (reviewed by Monti et al., 1999), particularly in early lactation (Dohoo and Martin, 1984; reviewed by Beaudeau et al., 1993). In addition, mortality caused by pneumonia is relatively high, as one necropsy-based study classified pneumonia (both chronic and aspiration-caused) as the proximate cause of death in slightly over 8% of the observed cows (McConnel et al., 2009).

1.3.12 Other diseases: bovine leukosis

Bovine leukosis is an infection of dairy cattle caused by the bovine leukemia virus from the Retroviridae family (Radositits et al., 2007). Most infected cattle will not show clinical signs (subclinical); 70% will develop lymphocytosis (increased number of circulating lymphocytes), but only 1-5% will develop lymphosarcoma (Schwartz and Lévy, 1994). In Canada the percentage of infected herds (having at least one positive animal) ranged from 62% (Quebec) to 95% (Manitoba), with a mean of 78% infected herds (Nekouei et al., 2015). The median prevalence in infected herds ranges from 14% (Nova Scotia) to 63% (Manitoba), or 37% in Canada as a whole (Nekouei et al., 2015). In the US, according to NAHMS (2014) 0.1% of the dairy cows were affected by lymphoma; of them 4% remained in the herd, 85% were sold and 11% died or were euthanized. At the herd level, during 2013, 6% of small and 40% of large dairy operations confirmed at least one case of leucosis (USDA-NAHMS, 2018).

Studies involving dairy herds from Canada and the US confirmed the negative effect of leukosis at the herd level as observed through reduced milk production in infected herds (Sargeant et al., 1997; Ott et al., 2003; Erskine et al., 2012). A more recent study reported that positive cows with 2 and 3 lactations produced 2,554 kg and 1,171 kg less milk during their productive life, respectively, when compared to leukosis-negative cows with the same number of lactations (Nekouei et al., 2016). Similarly, leukosis-positive cows had consistently higher probability of being culled or dying compared to leukosis-negative cows (Nekouei et al., 2016), and this risk was estimated to be 40% higher compared to uninfected cows (Bartlett et al., 2013). Leucosis was recognized as the proximate cause of death in slightly over 4% of the cows that underwent necropsy in a Colorado dairy farm (McConnel et al., 2009).

1.3.13 Other diseases: paratuberculosis or Johne’s disease

Paratuberculosis is a contagious, chronic, progressive granulomatous infection, targeting primarily the small intestine and other organs including the liver, mesenteric and hepatic lymph nodes. The disease is caused by *Mycobacterium avium ssp. paratuberculosis* (MAP) and is also known as Johne’s disease (reviewed by Garcia and Shalloo, 2015). The animal-level prevalence of paratuberculosis in dairy cattle ranges from 1% (Belgium) to 41% (Germany), while the herd-level prevalence ranges from 7% (Belgium) to 83% (Switzerland), with large variation based on the methods used for disease detection (reviewed by Garcia and Shalloo, 2015). In Canada, the herd prevalence varies from 24% in Quebec, to 47% in the Atlantic provinces, 54% in Ontario and 66% in the western Canadian provinces (Corbett et al., 2018).

Paratuberculosis has an immense but highly variable economic impact on the dairy industry. Studies conducted to test the effect of paratuberculosis on fertility reported inconsistent findings ranging from negative, neutral to positive effects (reviewed by McAloon et al., 2016). Investigations on the effect of paratuberculosis on SCC and mastitis ranged from no significant effect to an increased SCC and mastitis in positive cows (McAloon et al., 2016). A review by Garcia and Shalloo (2015) concluded that positive cows have an increased chance of developing lameness, mastitis, digestive disease and respiratory disease. Milk production in sub-clinically and clinically infected cattle has been reduced by 15% and 20%, respectively (Chi et al., 2002), while a study that followed an Irish herd from 1997-2002 reported milk production reduced by 24% (Barrett et al., 2006). Changes caused by MAP include reduced feed conversion and reproductive performance, and a threefold increase in culling (Alonso-Hearn et al., 2009; Raizman et al., 2007). Cows with clinical signs of paratuberculosis were removed because of a positive MAP test in 50% of cases, because of reduced body weight in 33%, and because of reduced milk production in 17%. Infected cows without symptoms were removed due to poor milk yield (46%), mastitis (27%), positive MAP test (9%), and infertility (9%; reviewed by Garcia and Shalloo, 2015). Overall population mortality rate caused by paratuberculosis could range from 1% to 5% (Radositits et al., 2007), and compared to uninfected herds the mortality rate in MAP-positive herds is increased by around 3% (reviewed by Garcia and Shalloo, 2015).

The conditions reviewed in this section are the most cited health reasons for removing cows from dairy farms. Some of the conditions affect animal welfare directly, for example by causing pain or important changes in animal behaviour. Others, may not have a direct effect on cow welfare, but indirectly can increase the risk of other health conditions that may be painful condition themselves, change animal behaviour and/or increase the risk of culling. Management of these conditions at the herd level plays an important role in animal welfare, both on the farm and in the following stages which include transport and management at slaughter plants. A program of proactive culling can make an important contribution to animal welfare by removing cows from the herd before their condition deteriorates.

1.4 The effect of transport duration and feed and water deprivation during transport on cattle health and welfare

The transport process involves activities inside and outside the transport vehicle. These activities may involve loading and waiting for departure, driving, stationary periods such as stops and delays (e.g., at international borders), waiting to be unloaded and other activities that prolong transport and potentially amplify the adverse effects and reduce the welfare of transported animals (reviewed by Schwartzkopf-Genswein et al., 2016).

1.4.1 Comparison of transport regulations

Transport regulations in North America are less rigorous than in some other countries such as New Zealand and countries of the EU (see Table 1.1). For example, in Canada cattle and other ruminant species may be continuously transported for 48 h without feed and water and the travel time may be prolonged to 52 h if needed to reach the final destination. After reaching the maximum transport time cattle should be unloaded and rested with provision of feed and water for 5 h (CARC, 2001).

In the US, the 28-h transport law is practiced for cattle transport, but this time can be extended, if needed, to 36 h. After this maximum transport time 5 h rest with feed and water is required (28-h law, USDA-NAL, amended 1994). Cattle in Australia that are older than 6 months, not pregnant and not lactating can be transported for 48 h without access to feed and water; following the maximum transport time, 12-36 h of rest with feed and water is required depending on the species and conditions (AHA, 2012). New Zealand's regulation allows a maximum of 12 h transport without water and 24 h without food for adult cattle, but for lactating cows the transport time without water is limited to 8 h. After the maximum transport time is reached, 8 h rest is required (NAWAC, 2018). The transport regulations in the EU restrict the time cattle spend in transport to 8 h. However, longer trips can be allowed if the vehicles are designed to provide water to the animals at all times, have proper insulation, mechanical ventilation and have special partitions. Rest stops of 24 h, with provision of feed and water, are required after reaching the maximum transport time (Regulation Council (EC), 2005).

1.4.2 Transport duration

Actual transport duration may be under-reported particularly when cattle are sold through livestock markets where they change ownership. This practice prevents monitoring of the entire journey length from farm to processing, and results in studies that document and report only the last portion of the trip (Warren et al., 2010b). For example, even with the 48-hour transport restriction some cull cows removed from Newfoundland and processed in Ontario were transported for around 2,500 km, a journey that could take between 7 to 10 days before the animals are processed (NFAHWC, 2017).

Even with the limitations caused by under-reporting, a wide range of transport times and distances have been reported. For example, a study in Ontario observing the transport times of cattle arriving in federally inspected slaughter plants reported mean transport time of 4.6 h, with the majority (86%) of the trucks arriving at the plant within 8 h, while only about 2% took 24-48 h and only 2 trucks (0.2%) took more then 56 h to arrive at the plants (Warren et al., 2010b). The short transport duration typically seen might be explained partly by the origin of the cattle, the majority of which were from Ontario (84%) and Quebec (13%), while only a few loads originated from Western and Atlantic Canada. In the US, the National Beef Quality Audit-2016 (NBQA), conducted at 18 commercial packing facilities in 10 states, reported mean transport duration of 6.7 h (range 0.2-39.5 h) with mean distance traveled of 456 km (range 3-2,274 km; Harris et al., 2017). In Alberta, a study of the effects of long-distance transport using surveys gathered data for 6,152 trips that were ≥400 km which the industry considered as long-haul transport (González et al., 2012b). The authors reported a mean distance traveled of 1,081 km (range 400-2,560 km) and a mean duration of 16 h that cattle spent confined in the truck (range 3-45 h; González et al., 2012b). Transporters reported delays at the Canada-US border in 77% of the trips, lasting on average 1 h with a maximum of 15 h; the delays were a consequence of the additional administrative work and inspection by US veterinary inspectors which might involve unloading cattle that are not shipped directly to slaughter plants (González et al., 2012b).

In general, long-distance transport has a negative effect on the condition of the transported animals and increases the chances of their becoming compromised (González et al., 2012a). This latter study reported an increased likelihood of becoming lame, non-ambulatory and dead at unloading when the transport duration was between 20 and 30 h. Moreover, the proportion of compromised cattle drastically increased when the transport duration was over 30 h. However, long-distance transport did not affect all cattle categories equally. The most sensitive category was cull (dairy and beef) cattle, which were more likely to develop lameness, become non-ambulatory or die during transport compared to other categories (González et al., 2012a).

Physiological measures indicate that transport of cattle is associated with stress and dehydration (reviewed by Knowles, 1999). In one study transported cattle showed increased levels of plasma cortisol compared to the control group; cortisol peaked at 12 h of transport and was followed by a decline in cortisol with further increases in journey duration (Knowles et al., 1999). A similar increase in plasma cortisol concentration was reported in cattle transported for 24 h, but this increase was also associated with high stocking density (Tarrant et al., 1992). Moreover, based on several blood parameters, cattle transported for 24 h suffered from dehydration. The blood parameters included increased total protein and albumins (Knowles et al., 1999) and increased red blood cells and packed cell volume (Tarrant et al., 1992).

1.4.3 Feed and water deprivation (FWD)

Transport trailers in North America are not equipped to provide feed and water; thus while cattle are confined in the trucks during transport they are deprived of feed and water (reviewed by Schwartzkopf-Genswein et al., 2016). Moreover, an accepted industry practice before transport is a period of feed and water deprivation which has two goals: to reduce the digesta in the gastrointestinal tract of the transported animals and thus reduce hide and carcass contamination, and to allow for better carcass weight prediction in cases where animals are sold by weight (Hogan et al., 2007).

Cattle reduce their body weight depending on the length of transport and the associated feed and water deprivation (FWD). The largest weight loss has been reported during the first 12 h of FWD. After this initial reduction in body weight, in the next 36 h there is a slower but stable rate of loss (reviewed by Knowles, 1999). For example, cattle fasted for 12, 24, 48 and 96 h reduced their body weight by 6, 8, 12 and 14 %, respectively (reviewed by Schwartzkopf-Genswein et al., 2016).

A recent study used several outcome measures to evaluate the effect of feed and water deprivation by comparing 3 groups: (1) cattle transported for 24 h (1,200 km), (2) cattle fasted for 24 h and (3) a control group that had *ad libitum* access to feed and water (Marques et al., 2012). Both transported and fasted cattle showed reduced body weight compared to the control group. Transport and fasting initiated mobilization of the fat reserves which was observed through increased non-esterified fatty acid (NEFA) concentrations. In addition, the fasted group had higher cortisol concentrations than the transported group suggesting that FWD was the main cause of the animals' stress response (Marques et al., 2012).

The percentage of body weight loss during transport, also called “shrink”, includes the loss of gut fill and the loss of tissue mass (Coffey et al., 2001; Schwartzkopf-Genswein et al., 2016). Cull cattle (dairy and beef) were more sensitive to long-distance transport and showed faster shrink (percentage of body weight loss per hour) with increasing time spent on the truck, compared to other categories of cattle (González et al., 2012c). Cattle that showed shrink of more than 8% were more likely to die than those with less shrink; some (linear) models indicated increased risk for becoming non-ambulatory and a tendency for developing lameness at 8% shrink. Cattle with body weight loss over 10% had higher probability (0.1-0.2) of becoming compromised (lame, non-ambulatory or dead; González et al., 2012c).

1.4.4 Behaviour during and after transport

During transport cattle typically maintain a standing position, avoid diagonal and parallel orientation of the body and prefer to align their body perpendicular to the direction of movement (Tarrant et al., 1992). During long-distance trips, however, the animals may try to lie down and have been observed to reduce rumination. They may also use stationary periods to lie down, and require long periods (around 24 h) to recover after the journey (Knowles et al., 1999). After 16 h in transport cattle usually try to lie down, but this may be prevented if there is high stocking density (Tarrant et al., 1992), thus, contributing to elevated plasma creatine kinase which suggests physical exhaustion (Tarrant et al., 1992; Knowles, 1999). Fatigue after long transport has been observed at slaughter plant lairage where cattle after arrival were reported to spend more time lying and drinking and had high levels of free fatty acids and dehydration (Jarvis et al., 1996a, b).

In summary, all activities related to transport including loading and unloading, FWD, mixing and enclosing animals in close proximity for many hours is unnatural and likely to cause stress in these animals. Moreover, the lack of available infrastructure can sometimes contribute to longer transport times for some vulnerable animals (e.g., cull cows), during which their condition could deteriorate significantly. Regulators, instead of using a single maximum duration for all classes of cattle, should consider adjusting transport times based on the condition of the animals and their ability to withstand transport.

1.5 Health and welfare problems observed in cattle sold at livestock markets and arriving at slaughter plants

After being removed from the dairy herd, cull dairy cows enter the marketing system which in North America typically involves transport and sale at livestock auction markets followed by transport to slaughter plants for processing. Around 64% of cull dairy cows in the US (Glaze and Chahine, 2009) and 78% of all cull cattle experiencing long hauls in Alberta are marketed through livestock markets (González et al., 2012c) and may experience multiple handling events, mixing with unfamiliar animals and delays to slaughter (Warren et al., 2010a; Ferguson et al., 2007).

1.5.1 Condition of cattle at livestock (auction) markets

Livestock markets are often associated with many adverse effects (Knowles, 1999; Schwartzkopf-Genswein et al., 2012, 2016), yet only a few studies have observed and reported the condition of cattle at auction markets in North America (Ahola et al., 2011a; Moorman et al., 2018; see Table 1.2).

A recent study observed 4,460 cull dairy cows sold at 3 livestock markets in Ontario during 64 sales (Moorman et al., 2018). The authors reported that 41% of the animals were thin, with body condition score (BCS) of 2 or less. Around 73% of the cows had some abnormality of locomotion ranging from inability to track-up to severe limp. Slightly over a quarter (27%) had swelling (i.e. increased tissue thickness) on at least one of the hocks, and 13% had docked tails (Moorman et al., 2018). One limitation of this study was that the data collection period (May to August) was only during the summer months and thus could not detect seasonal effects. This study followed proAction Animal Care Guidelines (DFC-PLC, 2017) and evaluated cows using the Guideline's criteria for acceptable or not acceptable condition, thus providing only limited description of the condition of the animals.

A more comprehensive study of cattle sold at livestock markets was conducted in the US during 125 sales (64 in the spring and 61 in the fall) at 10 livestock markets located in 3 different states (Ahola et al., 2011a). During this study 23,479 animals were observed, of which 53% were market (cull) dairy cows, 3% market dairy bulls, 39% market beef cows and 5% market beef bulls. The body condition of the dairy cows was assessed using the BCS scale of Wildman et al. (1982) where score 1 indicated emaciated and 5 indicated obese cows. Around 13% of the dairy cows were emaciated (BCS $\leq$ 1.5) and 22% were thin (BCS=2). Lameness was scored based on the locomotion score (LS) described by Sprecher et al. (1997) where score of 1 indicated locomotion of sound cows and 5 indicated severely lame cows. Of the different categories of cattle, dairy cows had the highest percentage of lameness with 45% showing some sign of lameness, followed by dairy bulls (26%), beef cows (15%) and beef bulls (15%; Ahola et al., 2011a). Other quality defects reported in this study included mastitis, visibly sick animals, and cows with multiple defects that were declared as 'no sale' (Ahola et al., 2011b; see Table 1.2).

Both studies found that a large portion of cull dairy cows sold at livestock markets have one or more defects and a higher prevalence of these defects than other categories of cattle. More studies observing the condition of cattle sold at livestock auction markets throughout the entire year would provide a better overview of the industry, observe the animals' fitness for transport, identify weaknesses in the marketing system and serve as a guide for future improvements.

1.5.2 Condition of cattle at slaughter plants

Compared to the limited number of studies conducted at livestock markets, several studies in Canada and the US have systematically gathered information about the condition and defects of cattle arriving at slaughter plants. For example, Van Donkersgoed et al. (1997, 2001) conducted two Canadian Beef Quality Audits (CBQA), the first in 1995-96 and the second in 1998-99, while in the US four similar audits were completed (National Beef Quality Audit, NBQA-1994, 1999, 2007, 2016; Smith et al., 1994; Roeber et al., 2001; Nicholson et al., 2013; Harris et al., 2017).

The most recent audit (NBQA-2016), involved 18 commercial packing facilities in 10 states during March to December 2016 when about 5,500 live animals and carcasses were evaluated for quality defects (Harris et al., 2017). BCS of the cattle was assessed using a 5-point scale (1=thin and 5=over-conditioned). Of the 2,878 dairy cows observed, around 9% were emaciated, with BCS of 1.5 or less. Locomotion score (LS) was evaluated slightly differently from the previous NBQA audits and used a 4-point scale (1=sound and 4=severely lame) developed by the North American Meat Institute Animal Welfare Committee (2015; Edwards-Callaway et al., 2017). Based on this scale, 76% of the dairy cows were sound, 18% showed some signs of lameness (LS=2), 5% showed obvious limp, signs of discomfort, reluctance to walk and could not keep up with the herd (LS 3 and 4), and around 1% were non-ambulatory. Other defects, namely swollen joints, abscesses, and hide damage, were also observed in 2.4%, 0.7% and 1.1% of the dairy cows, respectively. Mastitis was reported in 10% of the dairy and 2% of the beef cows. Carcass evaluation indicated that 67% of the processed animals had at least one minor bruise (where less than 0.45 kg of trimming was needed to remove the bruise damage), while 41% of the dairy and 24% of the beef cows had multiple bruises (Harris et al., 2017; see Table 1.3).

In comparison to the previous NBQA-2007 audit, the 2016 audit reported improvement in cows' mobility and a reduced percentage of emaciated cows (Harris et al., 2017). However, the change in the locomotion scale (from a 5-point to a 4-point scale) might explain some of the discrepancies. The 2016 audit also showed an improvement in body condition; the percentage of emaciated cows fell from 22% in 2007 to 9% in 2016 (see Table 1.3). However, this change could have been influenced by differences in milk prices exerting influence on culling decisions. For example, in 2007 the milk price had an upward trend, increasing from $15/cwt to $22/cwt (1cwt=45.359 kg), possibly encouraging farmers to delay their culling decisions to profit from the increased price, while in 2016 milk price had a downward trend and was more stable, ranging from $16/cwt to $19/cwt (CLAL, 2018).

The Canadian Beef Quality Audit (1998-99) involved 5 processing plants in Alberta and Ontario which at that time processed over 80% of the cattle in Canada (Van Donkersgoed et al., 2001). Each plant was visited on 5 consecutive days in different months throughout the year to account for the seasonal effect on certain quality defects. With body condition assessed on a 5-point scale (1=thin and 5=over-conditioned), the study reported that 37% of the cows (both beef and dairy) were emaciated (BCS=1). Bruises were identified in 79% of the cows, with 12% of the cows having ≥ 4 bruises per carcass while 8% had critical bruises; these values were higher compared to other categories of cattle including heifers, bulls and steers (Van Donkersgoed et al., 2001). Whole carcass condemnations (0.2%) during the 1995-96 audit were related to emaciation, pneumonia, arthritis, bruising, abscesses, mastitis and other causes (Van Donkersgoed et al., 1997), reasons that are frequently observed in cull dairy cows. Unfortunately, only the audit in 1998-99 assessed the condition of live animals arriving at the slaughter plants, and this was limited to evaluating only the body condition and did not report beef and dairy cows separately.

1.5.3 Other findings at slaughter plants

Several studies have indicated adverse effects of the marketing system (i.e. livestock markets) by comparing the meat quality and condition of cows at slaughter plants after being loaded from auction markets versus those loaded directly from farms or feedlots (Warren et al., 2010a; González et al., 2012a). For example, lower meat quality was reported for cows bought and loaded from auction markets (Warren et al., 2010a), or if cattle were held overnight at the plants (Ferguson et al., 2007; Ferguson and Warner, 2008). In addition, cattle arriving from more distant livestock markets (>64 km) had greater bruising score than cattle coming from nearby markets (Jarvis et al., 1996b). In another study the extent of bruising was associated with distance travelled and the time cattle spent in lairage (McNally and Warriss, 1996). Cattle at auction markets experience multiple handling events such as loading, unloading and mixing with unfamiliar animals, all of which will likely increase social interactions. Consequently, when arriving at slaughter plants these animals tended to spend more time lying down and drinking and showed higher levels of free fatty acids and signs of dehydration (review by Knowles, 1999).

One study reported that livestock markets have negative effects on the condition of cattle because they extend the period without feed and water, thus depleting body reserves (González et al., 2012c). In another study cattle sold through livestock markets and transported to slaughter facilities for more than 400 km had increased chances of becoming non-ambulatory or dead during transport compared to cattle loaded at feedlots and farms (González et al., 2012a). However, the effect of the livestock markets as a single explanatory variable of these findings is uncertain as the authors did not include the condition of the animals at loading.

In summary, when observing the effect of the transport continuum multiple variables need to be considered. These include transport duration, FWD, and handling, as well as the baseline condition of the animals at the farm of origin, including the reason for culling and the condition of the animal at loading. Moreover, the events that cattle undergo while in livestock markets cause changes in cattle behaviour, and may increase hunger, thirst, stress and fatigue which affect meat quality and lead to reduced welfare (review by Knowles, 1999). Therefore, whether culling decisions are based on economic criteria or disease management, the decision should be complemented with an evaluation of the condition of the animals and their ability to withstand the negative consequences caused by the transport continuum.

1.6 Conclusions and future studies

The literature indicates that many conditions and diseases related to culling have negative effects on the health and welfare of dairy cattle. After removal from the herd, dairy cows enter the marketing system which is associated with numerous adverse effects on animal welfare and meat quality. Moreover, when arriving at the processing facilities many animals have one or multiple defects which reflects poor health and welfare, and numerous management issues along the transport continuum. However, the dairy industry devotes little attention to improving the management of cull dairy cows that enter the food chain, leaving that issue more to the beef industry. Future studies might cover this knowledge gap by observing on-farm culling decisions, evaluating the condition of cows when they are removed from the farm, following them at the auctions and slaughter plants, and cumulatively quantifying the effect of the marketing system on the condition and welfare of cull dairy cows.

Continuous genetic selection and improvements in cattle nutrition have helped to create high-producing breeds of dairy cattle. However, this increase in milk production is associated with increased risk of certain diseases such as mastitis and lameness which are painful and related to poor welfare. Nonetheless, cows with these conditions are often removed from the dairy farms and enter the marketing system even though their fitness for transport may be questionable. Therefore, future studies should shed light on conditions such as lameness and mastitis and provide improvements in assessing fitness for transport, guidelines for dealing with animals with these conditions before shipping (e.g., treatment before shipping) and alternatives if animals are not fit for transport.

Milk price and changes in the demand for milk products, either globally or within a country, can also influence farmers' management strategies and herd culling rates. Depending on the marketing system (free market or supply-management) increasing demand may lead to higher prices or other incentives to increase the supply of milk, thus influencing the management of the dairy herds. If these changes cause culling decisions to be delayed, cows are kept longer in the herd and their condition and welfare could deteriorate. Future studies might evaluate how different milk management systems influence farmers' culling decisions and the effect on the condition of the animals removed from dairy herds.

1.7 Thesis objectives

Given the low recovery rate of non-ambulatory cows, the first objective of this thesis was to test whether using an alternative treatment (flotation therapy) will improve recovery and to identify and quantify factors that may increase recovery such as recumbency duration and nursing care. The second objective was to describe the extent and diversity of cull dairy cow management in Canada and develop consensus recommendations that will guide future research and policy. Following these recommendations, the third objective was to describe the movement of cull dairy cows in British Columbia, evaluate cows' condition at farm, auction and at the abattoir, and quantify any changes of cows' condition while in the transport continuum.

Table 1.1 Comparison of recommended maximum transport time of cattle and minimum feed, water and rest time in different jurisdictions

Jurisdiction	Maximum transport time	Rest breaks before reloading
Canada[1]	48 hours, can be extended to 52 hours	5 hours
USA	28 hours, can be extended to 36 hours	5 hours
Australia	48 hours, excluding pregnant and lactating cattle	12-36 hours
New Zealand	12 hours without water and 24 hours without feed, lactating cattle maximum 8 hours without water	8 hours
European Union	8 hours and can be extended if the vehicles provide water, insulation, special partitions and mechanical ventilation	24 hours

[1]Amended transport regulations with lower maximum transport time (36 h) and longer rest breaks (8 h) and will come into force February, 2020.

Table 1.2 Conditions and quality defects observed in dairy and beef cattle at livestock markets in the US and Canada, based on two published studies

	Dairy		Beef	
Conditions and defects	Cows (%)	Bulls (%)	Cows (%)	Bulls (%)
Ahola et al. 2011a				
Lameness ≥ 2	45	26	15	15
Clinical lameness ≥ 3	18	11	3	4
Severe lameness ≥ 4	4	7	1	2
BCS ≤ 2	35	10	-	-
Udder size[1] >2	12	-	3	-
Mastitis	3	-	1	-
Visibly sick	3	1	1	0.1
No sale[2]	1.5	-	0.2	-
Moorman et al. 2018				
Lameness ≥ 3	73	-	-	-
BCS ≤ 2	41	-	-	-
Hock injuries[3]	27	-	-	-
Docked tails	13	-	-	-

[1]Udder size was scored on a 3-point scale (1=small, 3=extra large).
[2]No sale – cows were not bought or died at the livestock market.
[3]Hocks with medium or major swelling larger than 1 cm.

Table 1.3 Conditions and quality defects observed in dairy and beef cattle at slaughter plants in the US during the NBQA-2007 (Nicholson et al., 2013) and NBQA-2016 (Harris et al., 2017)

	Dairy		Beef	
Conditions and defects	Cows (%)	Bulls (%)	Cows (%)	Bulls (%)
Nicholson et al. 2013				
Lameness ≥ 2	49	22	16	31
Low BCS[1]	22	4	10	2
Mastitis	9	-	0.4	-
Failed suspensory ligament	4	-	2	-
Harris et al. 2017				
Lameness ≥ 2	24	23	13	17
Low BCS[1]	9	1	8	6
Mastitis	10	-	2	-
Failed suspensory ligament	15	-	4	-
Large udder size[2]	8	-	2	-
Multiple bruising	41	25	24	14
Swollen joints	2	3	1	5
Non-ambulatory[3]	0.9	0	0.2	0

[1]For low body condition score beef animals were scored 1.0 or 2.0 (emaciated) on a 9-point scale, and dairy animals were scored 1.0 and 1.5 (emaciated) on a 5-pt scale.
[2]Acute milk accumulation causing enlargement of the udder.
[3]Cows unable to rise.

Chapter 2: Non-ambulatory cows: Duration of recumbency and nursing care affect flotation therapy outcome

A version of this chapter has been published as Stojkov, J., Weary, D.M. and von Keyserlingk, M.A.G., 2016. Nonambulatory cows: Duration of recumbency and quality of nursing care affect outcome of flotation therapy. J. Dairy Sci. 99:2076-2085.

2.1 Introduction

Cows are at greatest risk of disease and death in the weeks just after calving. Risks include metabolic illnesses such as hypocalcaemia and ketosis, infectious diseases such as mastitis and metritis, and other maladies such as dystocia and hoof and leg injuries that cause lameness. Unfortunately, some cows become so compromised that they become non-ambulatory, others are at high risk for becoming non-ambulatory and in all cases experience poor welfare. The challenges described above as well as the potential risks associated with dairy cows having to interact with equipment, such as manure scrapers and the milking parlor on a daily basis, likely explains why dairy cows, compared to beef cattle, are at much higher risk of arriving at auction and slaughter facilities unable to stand or walk (Doonan et al 2003; Green et al., 2008). The National Animal Health Monitoring Survey (NAHMS) estimated that about 234,000 dairy cows of the approximately 9 million lactating cows in the United States became non-ambulatory in 2013, of which approximately 18% (42,000) died naturally on farm (i.e. were not euthanized; USDA-NAHMS, 2016).

Non-ambulatory cows are unable or unwilling to stand (Fenwick, 1969; Cox, 1988) and remain recumbent for ≥ 12 h (Burton et al., 2009). Regardless of cause, extended periods of recumbency initiates secondary pressure damage to the muscles and nerve tissue causing a condition described as secondary recumbency (Cox, 1982), which in turn increases the risk of compartmentalization and crushing syndrome (Cox, 1988). Non-ambulatory cows that struggle to stand are also susceptible to muscle and ligament damage resulting in permanent or terminal recumbency. The severity of non-ambulatory cow condition is affected by both the original cause and the duration of recumbency.

The care and handling of non-ambulatory cows is a major challenge for dairy producers and veterinarians (Stull et al., 2007), but to date has received little research. For example, there is currently no scientific basis for recommendations for when non-ambulatory cows should be euthanized versus treated. Current evidence suggests that cows that are recumbent for > 24 h can develop muscle and nerve tissue lesions greatly hindering their ability to recover (Green et al., 2008). Given the risks associated with extended periods of recumbency, standard industry practice on many farms is to force cows to stand using devices such as hip lifters, slings, air bags, and more recently, flotation therapy (Stull et al., 2007; Burton et al., 2009). These procedures likely expose the cow to distress, but there is little scientific guidance available to judge which cows are most likely to recover, and which procedures are most effective.

Flotation therapy has recently received some attention (Burton et al., 2009). Floating the cow in warm water reduce secondary pressure damage to muscles and nerves and positions the cow in a standing position for when the water is eventually drained. To our knowledge, no previous study has assessed the stress associated with the flotation treatment or determined the conditions under which cows are most likely to recover following this treatment. The objectives of the current study were 1) to assess the physiological responses to stress using heart rate variability (HRV) measures taken before, during and after the flotation treatment, and 2) to evaluate the effects of recumbency duration and nursing care provided to the non-ambulatory cow on the outcome of the flotation treatment. We hypothesized that the flotation would induce a stress response in cows, and that cows that had spent little time recumbent and received good nursing care during recumbency would have a greater chance for recovery.

2.2 Materials and methods

2.2.1 Animals, housing and management

Cases were recruited from 27 commercial dairy farms in the Fraser Valley region of British Columbia, Canada from February to August 2015. A total of 36 Holstein dairy cows having a mean (±SD) parity of 3.4 ± 1.4, identified by a veterinarian as non-ambulatory cow (see below for criteria), were enrolled in the study. All farms but one used free-stall housing; the exception used tie-stalls.

2.2.2 Data collection

Commercial farms that reported a non-ambulatory cow were visited by a veterinarian who performed a detailed physical examination to establish eligibility for flotation treatment (see Table 2.1 for inclusion and exclusion criteria). Eligible cows were subjected to flotation therapy on-farm. General information about the cow, and data regarding the medical history, recumbency duration, treatment and management of the recumbent cow were collected (see Table 2.2). The duration of recumbency was defined as the time (as identified by the farmer or farm worker) from when the cow was discovered down until the flotation treatment was initiated. Information from the 5 questions regarding the non-ambulatory cow management practices used on their farms was combined with the subjective on-site evaluation made by the veterinarian, and used to assign a cumulative ‘nursing care’ score (ranging from 0 to 5) before treatment was initiated. This information was then used to assign a binary variable (good care was assigned when the score was ≥ 3.0 versus poor care (score ≤ 2.0) describing the overall quality of nursing care provided to the non-ambulatory cow before the flotation therapy was initiated (see Table 2.2 for more details). Cows subjected to flotation therapy were diagnosed as having metabolic disorders (16), musculoskeletal injuries (4), or a combination of metabolic disorders and infectious disease (3), metabolic disorders and musculoskeletal injuries (7), and having experienced a difficult calving followed by a metabolic disorder (4). Recumbent cows were provided treatment based on the primary cause of recumbency before flotation was initiated. For instance, cows diagnosed with metabolic disorders received supplement therapy and nonsteroidal anti-inflammatory drugs (NSAID), cows with infectious diseases received antibiotic therapy and a NSAID, cows with musculoskeletal injuries and dystocia received a NSAID. Between flotation treatments 3 cows received additional antibiotics as part of their treatment plan, 5 cows received another dose of NSAID, and 4 cows received additional supplemental therapy.

Before any manipulation of the non-ambulatory cows was initiated, a heart rate monitor (HRM; Polar Equine RS800CX or V800, Polar Electro Oy, Kempele, Finland) was attached to cow’s chest. The HRM was set to record each inter-beat interval (R-R recording rate) during the baseline period and the entire flotation treatment. The Polar HRM was previously validated for use in cows (Hopster and Blokhuis, 1994). Each HRM consists of an elastic strap, Wearlink transmitter, and watch receiver. The elastic strap had 2 incorporated electrodes and removable Wearlink transmitter attached. The cow’s body was gently tilted towards one side and the strap placed underneath the cow’s sternum and pushed towards the opposite side. The cow was then tilted gently towards the opposite side until the strap was visible at which time it was pulled and then adjusted accordingly. Before fitting the HRM around cow's chest, the 2 incorporated electrodes on the strap were lubricated with gel (EcoGel 100, Eco-Med Pharmaceutical Inc., Ontario, Canada) to improve conductivity between the electrodes and the cow's body. The upper electrode was located behind the left shoulder blade and the lower electrode placed near the sternum. After placing the elastic strap around the cow's chest, the watch was started. Previous studies have reported a period of 5 to 10 min as sufficient for animals to acclimate to the HRM equipment (Mohr et al., 2002; von Borell et al., 2007; Stojkov et al., 2015). In this study, cows were allowed to habituate to the equipment for approximately 10 min before recording was initiated. The recording was continued throughout the flotation procedure. The researcher marked each phase of the flotation treatment by recording the time and duration of each phase.

2.2.3 Flotation treatment description

The flotation treatment consisted of 5 phases: baseline (before filling), manipulation (placing the cow into the tank), filling (the tank was filled with water), flotation (the cow was confined in the filled tank) and draining (water was removed from the tank). All cows were floated in the same flotation tank (length 2.4 m, height 1.37 m and width 1.32 m; Aqua Cow Rise System, Kirby Manufacturing Inc., Merced, CA) filled with 2400 L of water. During the first phase (baseline), the recumbent cow was fitted with a HRM and was left undisturbed for 20 min (10 min for adaptation to the equipment and 10 min for recording the baseline HRV values). The cow was then placed on a rubber mat that required the involvement of at least 3 individuals. The cow was transitioned from sternal recumbency to a lateral position. While the front and the hind legs were slightly elevated by 2 individuals, a third person slid the rubber mat under the cow. All cows were able to achieve sternal recumbency on their own or with minimal assistance. Using a manual winch or machinery, the mat was then pulled into the float tank. The duration of this phase was approximately 30 min, and finished when the doors of the tank were closed. The filling phase lasted for approximately 5 min and involved filling the flotation tank by pumping approximately 2400 L of previously heated water. Once the tank was filled and the cow was standing comfortably on 4 limbs, a water bowl and a feed bin were attached to the front of the tank. Cows that did not show any signs of struggling or distress while in the flotation tank, were standing on all four limbs and were seen to be eating from the feeding bucket, were floated for 8 ± 2 h (flotation phase). Cows that were unable to stand, or were standing only on thoracic or pelvic limbs, or were not standing on all 4 limbs, and did not show any initiative to eat were removed immediately from the tank and euthanasia was recommended. The draining phase required approximately 15 min. Cows were allowed to remain standing in the flotation tank without water support for an additional 15 min to adapt to carrying their full weight. The gate was then opened and cows exited voluntarily or were gently encouraged to exit the tank.

The temperature of the water was measured with a thermometer (T-5622 Pool Thermometer, Taylor Precision Products Inc., Oak Brook, IL, USA) at the beginning of the flotation phase and again immediately before the draining phase. The body temperature of a non-ambulatory cow was measured prior the flotation treatment using a rectal thermometer (Accuflex10, AMG Medical Inc., Montreal, QC, Canada), and again at the beginning of the floating phase and again before the water was drained.

2.2.4 HRV variable description

HRV data was downloaded from the Polar HRM with Polar Performance software (Polar Electro Oy, Kempele, Finland). Calculation of the HRV parameters was conducted using Kubios

HRV 2.2 software (University of Eastern Finland, Kuopio, Finland) (Niskanen et al., 2004). HRV data were graphically and visually inspected for presence of the 5 types of anomalies as described by Marchant-Forde and colleagues (2004). Files that contained more than 5% anomalies or 3 consecutive anomalies were excluded from the analysis (von Borell et al., 2007). The frequency bands were set to 0.00 to 0.04 Hz for the very low frequency (VLF), 0.04 to 0.20 Hz for the low frequency (LF), and 0.20 to 0.58 Hz for the high frequency (HF), adjusted for the respiratory rate in cattle (von Borell et al., 2007; Stojkov et al., 2015).

Nine different time periods were selected to analyze the HRV measures with each segment lasting 5 consecutive min (see Malik and Camm, 1995; Malik et al., 1996): baseline, filling, and at 1, 2, 3, 4, 5 and 6 h into the flotation period. If the first selected 5 min period contained more than 5% anomalies or 3 consecutive anomalies the next 5 min period in the same hour was selected. The HRV values from 1 – 6 h of flotation were averaged and used for the analysis. The final 5 min period was selected when the cow was standing in the tank without water support and was marked as draining.

Frequency domain measures including HF, LF, LF-to-HF ratio were extracted and used in the analysis. Both LF and HF were expressed in normalized units where the absolute power of each component was expressed as a portion of the total power minus the VLF component (e.g., LF/ (total power – VLF power); LF (nu) and HF (nu); von Borell et al., 2007). The total power incorporated the frequency range between 0 and 0.58 Hz. HRV data during the first flotation therapy was collected from 18 cows. Due to anomalies one cow was excluded leaving 17 cows in the final data set that was used for the analysis. HRV data for the second therapy was obtained from 11 cows.

2.2.5 Outcome evaluation, additional treatment recommendations

The outcome of the immediate flotation treatment was considered to be a success if the cow walked out of the tank and resumed normal standing and lying behavior. Cows were considered to fail if the cow was unable to stand on 4 feet when the tank was filled with water. Cows that were able to stand comfortably and showed initiative to eat during the flotation phase but became recumbent within the 12 h following flotation received a second flotation treatment (see Figure 2.1). The final outcome was based on the cow's ability to maintain normal standing and lying behavior within 7 consecutive days following the final flotation treatment.

After each flotation treatment and again after 12 h, the veterinarian assessed the cow's condition as having improved or deteriorated. In cases where the cow was observed to have improved but either became non-ambulatory immediately following the flotation, or within the next 12 hours, an additional treatment was conducted. In cases where subsequent flotation treatments took place the procedure described above was repeated. Additional treatments (third and occasionally fourth) were only recommended for cows that appeared to be in good condition, remained standing and walked at least few steps out of the tank. All other cases were classified as not successful and we recommended that the farmer euthanize the cow.

2.2.6 Statistical analyses

The manipulation required to place the cows into lateral recumbency resulted in numerous interruptions of the HRM and meant that the data during the manipulation period could not be used. The remaining four phases (baseline, filling, floating and draining) were analyzed. Missing data from both the HRV and the behavioral outcomes resulted in two cows being dropped from the analyses leaving 34 cows in the final dataset. Univariate logistic regression was conducted using the LOGISTIC procedure in SAS (version 9.3, SAS Institute Inc., Cary, NC). The model was set to assess the effect of recumbency duration (h) on the outcome (recover or failed to recover) of the flotation treatment (n=34). Because few cows (9) received poor nursing care, the effect of nursing care was tested only at the univariate level; specifically, Fisher Exact Test was used to assess the effect of nursing care (classified as good or poor) provided to the recumbent cows prior the flotation treatment on the outcome of the treatment (n=34). The frequency domain HRV parameters (HF, LF and LF-to-HF ratio) and recumbency duration were tested for normality and presence of outliers using the UNIVARIATE procedure. The HRV data collected from 17 cows had missing values in various phases of the flotation therapy. Complete HRV data for all 4 phases of the treatment was only captured from 8 cows. Using a paired t-test we tested the following: (1) baseline versus filling the tank, (2) baseline versus floating in the water, and (3) baseline versus draining the tank. In addition, we tested the differences in the HRV measures between the first and the second therapy. The HRV analysis of both data sets, n=17 (with missing values in some phases) and n=8 cows (complete values in all 4 phases) showed the same findings. We considered the latter as a subset of the larger data set and thus used the HRV data from 17 cows for the final analysis.

2.3 Results

The water temperature at the beginning of the flotation treatment and at the end of the treatment averaged (mean ± SD) 31 ± 3 °C and 27 ± 3 °C, respectively. The water was heated only at the beginning of the flotation therapy and maintained only from the cows' body temperature. The cows' body temperature prior the flotation treatment was (mean ± SD) 38.5 ±

0.4 °C; measured at the beginning and at the end of the treatment, cows' body temperature was (mean ± SD) 38.6 ± 0.4 °C and 38.5 ± 0.3 °C, respectively.

Distress responses to the flotation procedure were assessed by testing changes in the frequency domain HRV measures during the 4 phases of the flotation procedure (baseline, filling, floating and draining). The greatest change of the sympathovagal balance was noted during the filling and draining phases (see Table 2.3). During the filling phase the HF component of the HRV declined on average by 45% to 2.8 ± 0.2, compared to the baseline value ($P < 0.01$; see Table 2.3). However, the HF component of the HRV returned to baseline levels within the first hour of flotation. During the draining phase the HF component of the HRV once again declined to 3.1 ± 0.4 ($P < 0.01$; see Table 2.3), similar to that observed during the filling phase. The LF and LF-to-HF ratio, both increased during the filling and draining phase ($P < 0.01$ and $P < 0.05$, respectively; see Table 2.3). The HRV measures in the first and the second therapy indicated identical changes in the filling and draining phase during both treatments.

Of the 34 cows recommended for flotation, 17 cows recovered after receiving one or more flotation treatments (see Figure 2.1). Of the cows that recovered, 7 recovered after receiving only one flotation treatment, with the remaining cows needing 2 to 4 treatments (see Figure 2.1). In all but 3 cases, the animals walked into the tank for the subsequent (final) treatment. The cow that received 4 flotation treatments was placed on the mat and winched into the tank for the second and third flotation treatments but walked into the flotation tank on the fourth treatment. Three cows (n=3) that were recommended for flotation therapy were successful in their attempts to briefly stand before the treatment started. Given the high risk that these cows would return to the recumbent state they were included in the study. However, the exclusion of these 3 cows did not change the results and these cows were thus included in the study.

Of the 17 cows that failed, 9 were unable or unwilling to stand after the tank was filled with water. The condition of these cows was considered irreversible and euthanasia was recommended. An additional 8 cows were able to stand normally on all 4 limbs during the flotation phase and immediately following treatment but became recumbent again within 12 h. Of these 8 cows, 6 were recommended for euthanasia after the second treatment, and 2 cows received a third flotation treatment (see Figure 2.1). On average cows that failed to recover were subjected to 1.6 ± 0.7 flotation treatments (mean ± SD).

The duration of recumbency and the level of care provided before flotation affected recovery. Cows that recovered were recumbent for (mean ± SD) 36.4 ± 22.5 h, while those that failed to recover remained recumbent for 65.3 ± 33.5 h before flotation therapy began. Overall the odds that the flotation treatment resulted in recovery of the non-ambulatory cow declined with every additional hour that the animal was recumbent before treatment was initiated (OR = 0.96; CI = 0.93-0.99, for 1 h increase; $P < 0.05$; see Figure 2.2). Using the coefficient estimates from the logistic regression, the odds of recovery with 95% confidence intervals were calculated as follows: intercept 1.96 + coefficient estimate for every hour change in recumbency duration (-0.04) multiplied by the duration of recumbency in hours. The product of this equation was exponentiated to calculate the odds of recovery at different time points. For example, cows recumbent for 12 h before treatment [exponentiate (1.96 + (-0.04*12))] were likely to recover following flotation therapy (odds = 4.37; CI = 4.23-4.52). The odds dropped to 2.7 and 1.7 when cows had been recumbent for 24 h and 36 h, before flotation, respectively. Cows that had been recumbent for 48 h or more had low odds for recovery (odds = 1.03; CI = 0.99-1.06).

Cows identified as having good nursing care, based on survey questions and an on-site assessment by the veterinarian, were more likely to recover compared to cows that had received poor care (P < 0.05; Figure 2.3). During the study 74% of the non-ambulatory cows (n=25) received good nursing care (mean score ± SD) 4.2 ± 0.7, and 26% (n=9) were provided poor nursing care (mean score ± SD) 1.7 ± 0.5. Of those 25 cows that received good nursing care 64% recovered after undergoing on average 1.7 ± 0.9 (mean ± SD) flotation treatments. In contrast, 8 of the 9 cows provided poor nursing care failed to recover after receiving on average 1.7 ± 0.5 flotation treatments. In this study, 4 of the cows were reported to been dragged by the neck and 1 cow was reportedly moved using hip clamps; all 5 were categorized as having received 'Poor' nursing care. Necropsy findings for the cow moved using hip clamps showed laceration of the abdominal musculature with hemorrhage, edema and muscular necrosis.

2.4 Discussion

This is the first study that provides evidence about the stress associated with flotation therapy in dairy cows using HRV measures. The frequency domain measures and the sympathovagal balance observed during the different phases of the flotation procedure suggest that certain phases were more stressful than others. The greatest changes occurred during the filling and draining phases. The reduction in vagal tone during these two phases, compared with the baseline, may be explained in part by the novelty of the rapidly filling or draining of the tank. Changes in the HF component have been previously reported in cattle undergoing an invasive rectal palpation procedure (Kovacs et al., 2014), being introduced to novel milking systems (Hagen et al., 2005), and in calves subjected to external (ambient related stimuli) or internal (pathological stimulus) stress (Mohr et al., 2002). Similarly, horses subjected to novel exercises showed vagal tone reduction and a shift of the sympathovagal balance towards sympathetic domination (Rietmann et al., 2004).

Changes in the body posture and the effort involved to stand and remain standing during filling and emptying may have also contributed to the shift of the sympathovagal balance. As the tank filled cows changed their body posture from lying to standing which requires effort thus affecting the sympathovagal balance; strenuous exercise in horses subjected to various types of exercises showed similar changes (Physick-Sheard et al., 2000). Similarly, during the draining phase cows were required to exert increasing energy in order to remain standing, which likely contributed the observed changes in sympathovagal balance. In summary, cows showed a physiological response to the filling and draining phase.

During each hour of the flotation phase the frequency domain measures HF, LF and LF-to-HF ratio remained relatively constant and similar to that observed during the baseline period. During periods of rest there is a parasympathetic (vagal) dominance corresponding with an increase of HF component of the HRV (Porges, 1995; von Borell et al., 2007). Exercise and stress amplifies sympathetic activity resulting in changes in the sympathovagal balance and an increase of LF component and LF-to-HF ratio, while the parasympathetic tone is reduced (Porges, 1995; von Borell et al., 2007). Horses that were subjected to exercise and stress have shown similar responses (Physick-Sheard et al., 2000; Rietmann et al., 2004). Changes in the body posture (e.g. transitioning form lying to standing) have been shown to reduce HF component in cattle (Frondelius et al., 2015).

To our knowledge, ours is the first study to assess the effects of duration or recumbency and nursing care on the outcome of flotation treatment. The results show that both nursing care and recumbency duration affect the outcome of non-ambulatory cows subjected to flotation therapy. Duration of recumbency has been previously identified as prognostic for recovery of non-ambulatory cows, with cows recumbent for ≤ 24 h most likely to recover (Green et al., 2008). Duration of recumbency affects secondary compression damage, primarily in the large muscles of the pelvic limbs, which are usually non-functional or paretic in non-ambulatory cows (Cox, 1988; Radositis et al, 2007). Unlike the front limbs that are protected by the sternum that supports most of the weight during sternal recumbency, the pelvic limbs are always positioned under the cow's body and thus far more susceptible to compression damage (Cox, 1988). In one study, 50% of the cows subjected to anesthetic induced recumbency for durations of 6-12 h showed extensive compression damage to the muscles and nerves of the pelvic limbs (Cox et al., 1982). Necropsy findings revealed severe damage to the sciatic nerve i.e. discoloration and collagenous tissue proliferation and muscles of the pelvic limbs i.e. described as pale, necrotic and foul smelling (Cox et al., 1982). Based on these previous studies it follows that compression damage is likely closely related to recumbency duration or the duration of the pressure insult. The results in our study provide additional evidence that extended durations of recumbency are negatively associated with recovery.

Previous studies recommending good nursing care for recumbent cows have included criteria such as: (1) access to feed and water as it promotes health and biological functioning, (2) segregation to prevent additional injuries from other animals, and (3) relocation done in a humane manner to prevent additional injuries, pain and suffering (e.g. using a wooden pallet or loader bucket) (Cox, 1988; Stull et al., 2007). The quality of nursing care provided to the down cows in our study while recumbent had a profound effect on the outcome of the treatment. Relocation (1) of a non-ambulatory cow to a comfortable segregated (2) sick pen, access to feed and water (3), regular repositioning (4) of the non-ambulatory cow and a dry clean bedding (5) surface were the 5 criteria used to evaluate nursing care in this study. The use of poor practices for moving cows (e.g. dragging by the neck, hip clamps) may result in additional injuries such as tearing of abdominal muscles. During this study 5 cows were moved in these ways. Only one of these cows was sent for autopsy; the serious injuries identified in the report may have been due to the way the cow was moved or may have been sustained before the cow became recumbent.

Regularly repositioning of non-ambulatory cows is thought to help avoid prolonged pressure points on the pelvic limbs and thus minimize secondary muscle and nerve damage (Cox, 1988; Stull et al., 2007). However, the one study to date that has assessed repositioning found a negative association between repositioning and recovery (Green et al., 2008). This study should be viewed with some caution given that they included a number of cows that recovered within a few hours after treating the primary cause (e.g. hypocalcaemia), which likely did not benefit from repositioning (Green et al., 2008). Nursing care, particularly repositioning, and provision of a supportive lying surface and pain management are important components of human patient nursing care and are associated with reduced pressure damage (Arnold, 2003). Thus in our study repositioning was considered as part of the good nursing care.

Previous work has concentrated on defining the success rate and identifying promising candidates for the therapy (Burton et al., 2009). Studies on horses and cattle have reported improvements from flotation therapy following skeletal injuries and limb surgery (Smith, 1981; Hutchins et al., 1987). Flotation therapy, referred to as hydro- or aqua-therapy in human physiotherapy, promotes recovery in human patients with various conditions (reviewed by Becker, 2009). Improvements from hydrotherapy in human patients with musculoskeletal injuries have been related to increased cardiac output and redistribution of the blood flow towards the muscles. For example, an increase of 225% in muscle blood flow was reported in water immersed patients compared to the control (dry land; reviewed by Becker, 2009). In geriatric patients aquatic exercise decreased the risk of falling by improving balance and coordination (reviewed by Becker, 2009). In patients with fibromyalgia, a condition associated with pain and reduced quality of life, aquatic therapy has been reported to reduce pain, improve sleep quality, as well as physical and cognitive abilities (Munguía-Izquierdo and Legaz-Arrese, 2008). Aquatic therapy has also been reported as an effective tool to regain joint mobility in human athletes, described as a pain and discomfort free process with no risk for further injury (Prinse and Cutner, 1999). Athletes that suffered ligament injuries recovered sooner and were able to return to athletic activities earlier if subjected to aquatic exercise compared to land-based exercises (Kim et al., 2010). Interestingly, both studies recommended that aquatic therapy begin in the early phase of the rehabilitation process. Collectively these human studies show clear benefits of aqua therapy combined with exercise on recovery suggesting that cows may also benefit if they could be induced to exercise while in the flotation tank.

There is little data to inform decisions regarding for the number of times flotation therapy should be reapplied to a single patient. The non-ambulatory cows in this study received 1 to 4 treatments prior to recovery or euthanasia, but in other work cows have been re-treated as many as 13 times (Burton et al., 2009). The decision about whether additional therapy is warranted should depend upon both the likelihood of recovery, and the likelihood of suffering from both continued recumbency and the stress associated with repeated applications of this procedure. When the likelihood of recovery is low, and the welfare costs of continued treatment are high, treatment should be discontinued and the cow euthanized. In the current study cows were evaluated after each treatment and were only assigned to an additional session only if they met the pre-established criteria for improvement. We recommend the adoption of similar established criteria in practice, agreed upon in advance of treatment by the veterinarian and the producer, to avoid the potential for prolonged suffering in the hope that cows may recover after 'one more treatment.'

In conclusion, 50% of the down cows deemed eligible for the study (e.g. were alert and able to maintain sternal recumbency) recovered following flotation therapy. The likelihood of recovery was higher when treatment was begun soon after cows became recumbent; chances of recovery were much higher if treatment was begun with 24 h, and recovery was unlikely if treatment began after more than 48 h. Recovery was also more likely if cows received good nursing care while recumbent, including the use of a segregated sick pen with provision of adequate bedding, access to feed and water, and regular repositioning. We strongly advice that all farms have an up to date standard operating procedure outlining best practices of how to manage and care for non-ambulatory cows that also places focus on minimizing suffering by clearly identifying humane endpoints.

Table 2.1 Description of conditions that were used as exclusion and inclusion criteria when selecting non-ambulatory cows for flotation treatment

Inclusion criteria[1]
Metabolic disorders (e.g. hypocalcaemia, hypophosphatemia)
Infection diseases (e.g. endotoxic mastitis, septic metritis)
Difficult calving (e.g. malpresentation, fetal disproportion)
Minor musculoskeletal injuries (not detectible during physical exam)
Exclusion criteria[2]
Non-alert cows
Maintained lateral recumbency
Fracture on a limb or the spine
Arthritis on multiple joints
Major musculoskeletal injuries
Poor body condition (body condition score of 2.0 or less)[3]

[1]Alert cows with apparently normal mental state that maintained sternal recumbency, were willing to eat, showed initiative to stand up (reported by the farmer and assessed by the veterinarian), and had one or more conditions from the inclusion criteria were recommended for treatment.
[2]Cows that showed at least one of the symptoms described in the exclusion criteria were not recommended for treatment.
[3]Scoring was according the chart for body condition scoring of Holstein dairy cows (1-5), where 1 was severe under-conditioning (emaciated) and 5 was severe over-conditioning (Edmonson et al., 1989).

Table 2.2 Description and assessment of on-farm non-ambulatory cow management practices, based on survey questions and the on-site assessment by the attending veterinarian. A cumulative ‘nursing care’ score ranging from 0 to 5 was assigned: nursing care was defined as ‘Good’ when the score was ≥ 3 versus ‘Poor’ when the score was ≤ 2

Non-ambulatory cow management practices	**Assessment Criteria**
Bedding	Assessed lying surface and bedding type, depth, and cleanliness: scored as ‘+1’ if the bedding was clean and deep or cows were housed on pasture with shade provided; otherwise scored as ‘0’.
Access to feed and water	Frequency of monitoring of feed and water and proximity to cow: scored as ‘+1’ if feed and water were offered to the cow 3 or more times per day and placed within reach of the cow; otherwise scored as ‘0’.
Housing conditions	Housing of the non-ambulatory cow: scored as ‘+1’ if the cow was housed in a sick pen with no more than 2 other cows; otherwise scored as ‘0’.
Relocation the down cow	Relocation of the non-ambulatory cow from the pen: scored as ‘+1’ if relocated using a loader bucket or placing on a pallet and pulled to the desired location; otherwise scored as ‘0’.
Repositioning	Number of visits and repositioning frequency: scored as ‘+1’ if the cow was visited ≥ 3 times per day and repositioned at each visit; otherwise scored as ‘0’.

Table 2.3 Arithmetic mean (± SE) of high frequency (HF) and low frequency (LF) components of heart rate variability expressed in normalized units of total power (nu), and LF-to-HF ratio during the different phases of flotation treatment (n=17)

Phases of the flotation therapy					*P*-value		
Variable	Baseline	Filling	Floating	Draining	Baseline vs. filling	Baseline vs. floating	Baseline vs. draining
HF (nu)	5.1 ± 0.6	2.8 ± 0.2	4.9 ± 0.3	3.1 ± 0.4	0.006	0.814	0.002
LF (nu)	94.9 ± 0.6	97.2 ± 0.2	94.9 ± 0.3	96.8 ± 0.4	0.006	0.901	0.002
LF:HF ratio	21.8 ± 2.5	36.0 ± 2.7	22.3 ± 1.4	36.6 ± 6.5	0.016	0.470	0.047

Figure 2.1 Outcome of flotation treatments provided to non-ambulatory cows (n=34), including the number of cases that were reassessed and received additional flotation treatments

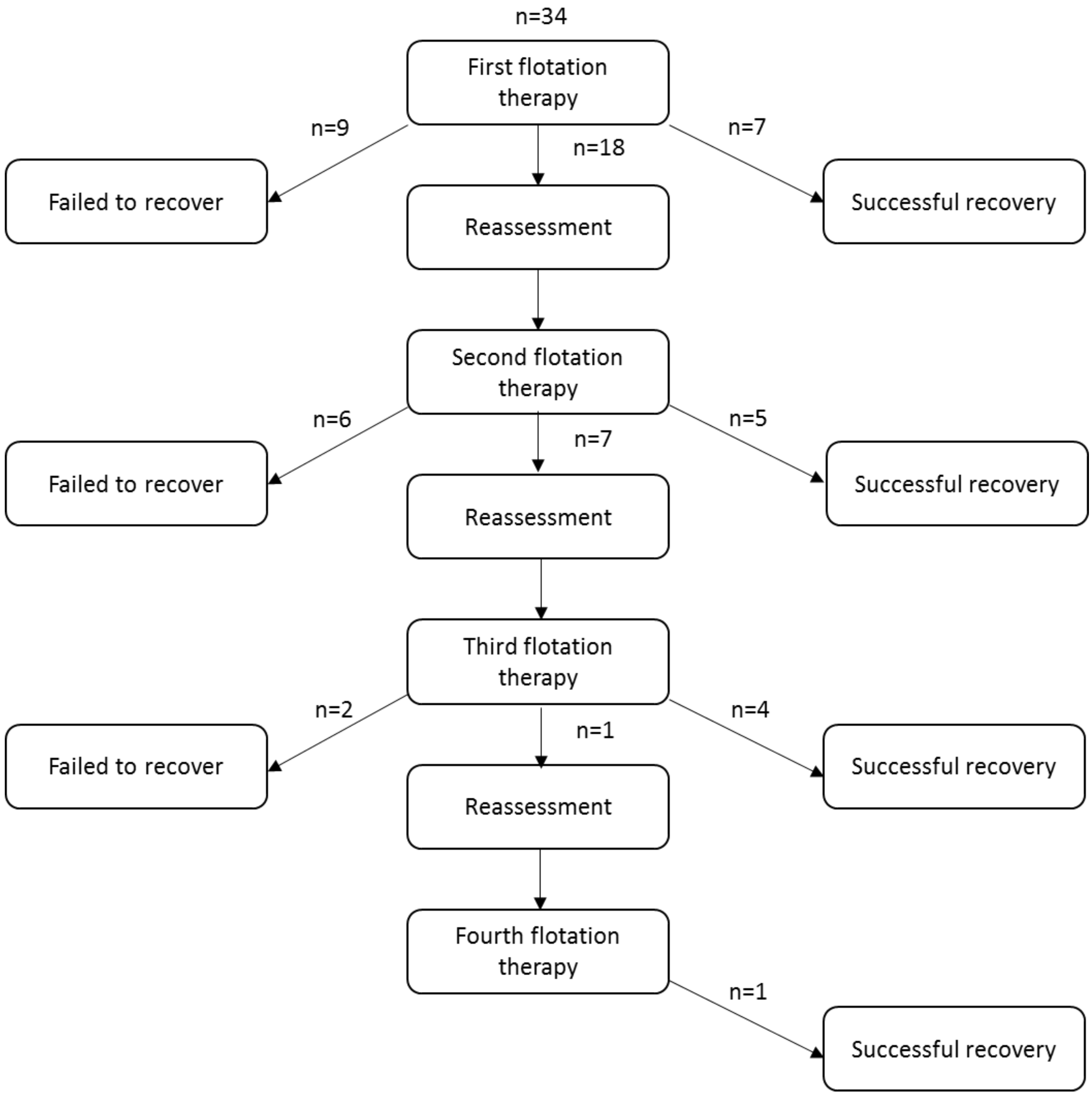


Figure 2.2 Probabilities of recovery (with 95% confidence intervals) of non-ambulatory cows (n=34) after treatment in the flotation tank, relative to the time that cows had been recorded as recumbent before treatment was initiated. Small circles on the lines for 0.00 and 1.00 probability indicate duration of recumbency before treatment for cows that did (1.00) or did not (0.00) recover

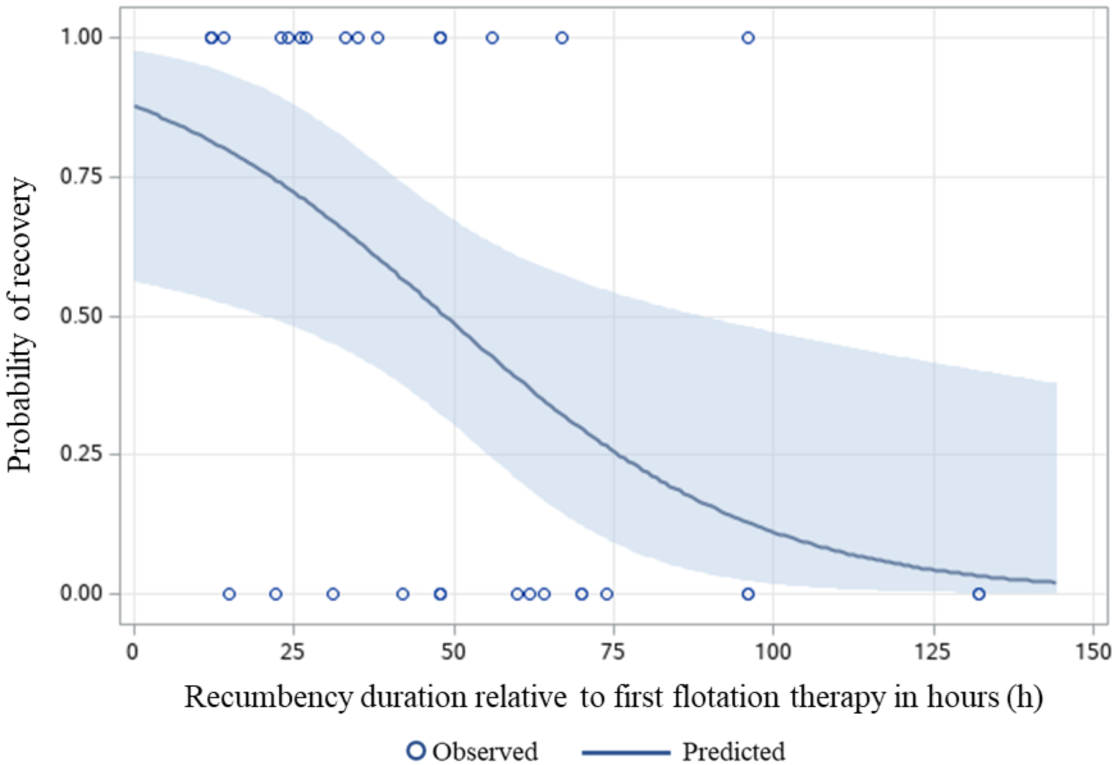
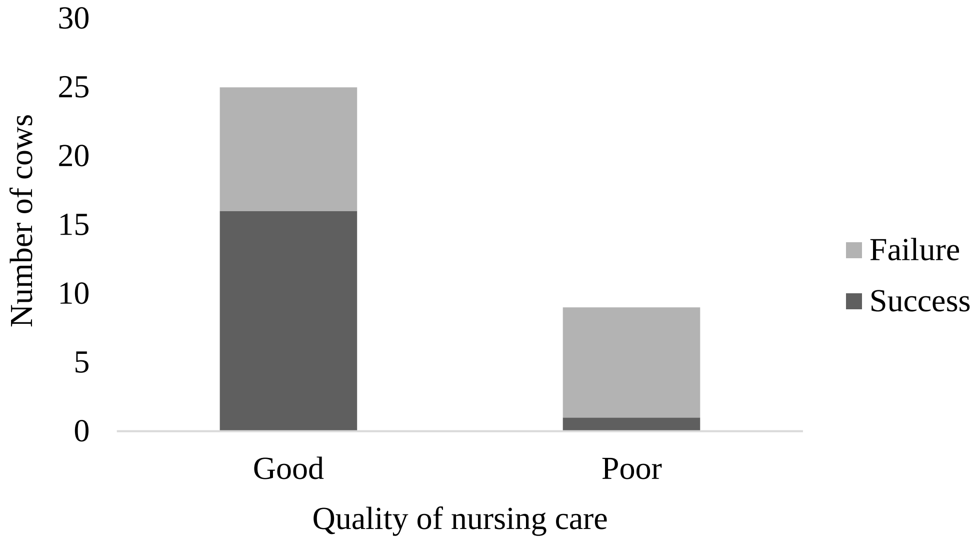


Figure 2.3 The effect the quality of nursing care provided to the non-ambulatory cows (n=34) before flotation treatment on the likelihood of recovery. Nursing care was rated on a 5-item scale and classified as ‘good’ for score ≥ 3 (versus poor for scores ≤ 2)



Chapter 3: Management of cull dairy cows: Consensus of an expert consultation in Canada

A version of this chapter has been published as Stojkov, J., G. Bowers, M. Draper, T. Duffield, P. Duivenvoorden, M. Groleau, D. Haupstein, R. Peters, J. Pritchard, C. Radom, N. Sillett, W. Skippon, H. Trépanier, and D. Fraser. 2018. Management of cull dairy cows: Consensus of an expert consultation in Canada. J. Dairy Sci. 101:11170–11174.

3.1 Introduction

The management of cull dairy cows (i.e., cows removed from the milking herd and sent for slaughter or salvage) is a significant animal welfare challenge that has received little systematic attention in policy and research. Currently, about 28-34% and 25-30% of dairy cows are removed from dairy herds each year in Canada and the United States, respectively (CDIC, 2017; Pinedo et al., 2010). Some of these are healthy animals that are culled because of low production, failure to breed or simply to rejuvenate the milking herd, but many are culled because of compromised health. For example, in a survey of cull cows arriving at auction yards in the United States, Ahola et al. (2011a) reported that 18% of cull dairy cows were lame (lameness score ≥ 3 on a 5-point scoring system), mastitis was diagnosed in 3%, and 13.3% had a body condition score (BCS) of < 2. In a similar study at slaughter plants in the United States, 18% of cull dairy cows had lameness score ≥ 3, 9% had mastitis, and 22% had a BCS of < 2 (Nicholson et al., 2013). Collectively these studies confirm that many cull dairy cows in North America arrive at auctions and slaughter plants with compromised health that could have developed at the farm of origin, during transport, or while in the marketing system.

Cull dairy cows present a range of challenges. Because cull cows are a somewhat specialized segment of the beef market, many slaughter plants do not accept them. Hence, animals with compromised health may be transported significant distances. Most cull dairy cows are marketed through auction yards (64%; Glaze and Chahine, 2009), and thus experience additional handling and transport. Moreover, as cull dairy cows are often shipped from farms in small numbers, delays and mixing of animals may occur before transporters have assembled a load ready for slaughter. The problems may be especially significant in large countries like Canada and the United States where dairy production is spread over large geographic areas and slaughter plants are scarce in some locations. Despite these challenges, management of cull dairy cows has received remarkably little research.

Expert consultation was chosen as the method for this study because it is often used as an initial research method for complex problems, especially where there may be significant geographic variation (e.g. Fraser et al., 2009). The goals were: to describe the extent and diversity of cull dairy cow management using Canada as a case study, to identify challenges and possible solutions, to identify additional needs for research, and to develop consensus recommendations on actions and policy.

3.2 Materials and methods

Experts with eight types of involvement in management of cull dairy cows were identified: dairy producers, veterinary practitioners, federal regulators, provincial regulators, researchers, and individuals with extensive experience in livestock transportation, auction and slaughter. Experts were drawn from the five main regions of the country with significant dairy production: British Columbia, the prairie provinces, Ontario, Quebec and Atlantic Canada.

Participants were identified and recruited using "key informants" (Hammersley and Atkinson, 2007) including members of the National Farmed Animal Health and Welfare Council (NFAHWC), Dairy Farmers of Canada (DFC), Canadian Food Inspection Agency, provincial and federal government officials, and the University of British Columbia (UBC) Animal Welfare Program. Of the 17 invited participants, 15 attended the consultation meeting and two provided their contributions and comments after the meeting while a consensus statement (described below) was being developed.

Experts met on March 23-24, 2016, in Ottawa, Canada and worked through a planned agenda that covered 1) the management and movement patterns of cull dairy cows in different regions, 2) potential animal welfare problems, 3) tools available for dealing with compromised cull dairy cows, 4) risk factors related to current management practices, and 5) recommendations for stakeholders. On each topic the experts reported personal observations, shared their experience and provided their opinions, related to their region and sector of involvement. The meeting was chaired by D. Fraser and coordinated by J. Stojkov and N. Sillett; all provided input in the discussion. The meeting was supported by the NFAHWC and approved by the UBC Behavioural Research Ethics Board.

Written notes were taken during the meeting by the chair and the two coordinators and the entire meeting was audio-recorded. Additional details from the discussion were later added to the written notes by listening to the audio recording. Content analysis (see Coffey and Atkinson, 1996) was used to identify certain themes that frequently occurred in the written notes. Themes that were widely supported by observations and reports from the experts were identified by two of the authors (D. Fraser and J. Stojkov) and became the basis for defining the eight points of agreement. These were summarized and sent to all participants as a draft "consensus statement" for further refinements and corrections. This process was repeated two additional times until no further changes (except editorial improvements) were proposed. The discussion centered on 9 main themes, and a consensus recommendation emerged for each one.

3.3 Results

3.3.1 The need for information and analysis

Experts noted that the management of cull dairy cows varies widely depending on the location. Where the option exists, some producers ship cows directly to a nearby slaughter plant and the animals are slaughtered promptly. More often, cows are sent to a livestock auction from where they may be shipped to a plant, possibly some distance away, or bought by dealers who may re-sell them one or more times in a process that may involve repeated handling and lengthy transportation. As examples from Canada, some cull dairy cows from Newfoundland are slaughtered in Ontario (a distance of ~2,500 km); some cull cows from Quebec have been identified in British Columbia (~4,500 km); and cows from several provinces are commonly slaughtered in the United States. Experts considered that the time from farm to slaughter could be as much as 7-10 days in some cases. Reasons for long delays and distances include lack of local slaughter plants willing to accept cull cows, temporary lack of slaughter capacity at busy times, the closure of one plant that formerly processed cull dairy cows from a large area, and the need for cattle dealers to assemble a full load before driving to a distant slaughter plant.

The consensus of the meeting was that research/investigation is needed, using available sources of information, to better characterize cull cow management and movement from farm to slaughter, and the factors that lead to long delays.

3.3.2 The need for awareness

In many cases, producers and herd veterinarians are not aware of the extent of the transport and delay that may occur when they make culling decisions. In particular, some may assume that cattle sent to a livestock auction will have relatively little delay until slaughter, whereas the reality may be very different.

The consensus was that communication is needed to make producers and herd veterinarians aware of the potential for long travel distances and delays so that this information can be taken into account when culling decisions are made.

3.3.3 Pro-active culling

In many cases, pro-active culling can prevent cattle from developing significant health and welfare problems (e.g., lameness, serious loss of body condition) that reduce both animal welfare and the commercial value of the animal. Pro-active culling might be promoted by providing training materials to both producers and herd veterinarians, by including the herd veterinarian in culling decisions, and by promoting greater recognition among dairy producers that they are producing a valuable meat product and hence the potential advantage of shipping cattle before they lose their value for slaughter.

The consensus was that training materials on the benefits of early culling decisions should be developed and provided to producers and veterinarians, that early culling criteria should be part of every herd health program, and that producers should consider including the herd veterinarian in culling decisions, so that pro-active culling of non-compromised animals becomes the norm.

3.3.4 Animal condition

Experts noted that cows culled for health reasons vary widely in their condition, with different degrees of lameness, body condition, mastitis, metritis, displaced abomasum, and pneumonia. The condition of the animal, together with the potential delays to slaughter, need to be considered when culling decisions are made. Compromised cows can deteriorate quickly when transported. As examples, displaced abomasum can severely affect animal welfare if several days elapse before slaughter, and cows may develop mastitis if they are not dried off before long-duration handling and transportation. Each animal's fitness for the longest potential journey should be assessed before loading.

The consensus was (1) that a fitness-for-transport decision-tree, which includes both the animal's condition and the potential delay to slaughter, be made widely available, (2) that the herd veterinarian play an active role in guiding producers on determining fitness for transport, and (3) that personnel involved in transport and auctions be trained to recognize and handle compromised cattle, including awareness of appropriate criteria for deciding to load animals for the potential journey.

3.3.5 Opportunities for local slaughter

Some long distances and lengthy delays occur because of a lack of opportunities for local slaughter, either because plants are not available or will not accept cull dairy cows.

The consensus was that efforts must be made to identify more local options for the slaughter of cull dairy cows, perhaps through agreements between producer organizations and slaughter plants, in order to make short transport distances and timely slaughter the norm for cull cows, especially those at high risk of animal welfare problems.

3.3.6 Options for management of compromised animals

Experts reported that different jurisdictions have different management options for cull dairy cows.

• In Ontario, authorized veterinarians are empowered to use a “direct-to-slaughter” tag so that compromised animals received at an auction must proceed directly to a nearby slaughter plant and not go through the normal (potentially lengthy) marketing process.

• On-farm emergency slaughter is allowed in some provinces. In this case, the animal receives ante-mortem veterinary inspection on the farm, is then killed and bled on the farm, and is transported to a nearby slaughter plant for post-mortem inspection before entering the food system.

• Mobile slaughter is permitted in some jurisdictions. This allows the entire slaughter process to occur without transporting the animal, and (pending inspection) possibly enter the food system.

The different options have potential advantages and disadvantages in terms of animal welfare, food safety, biosecurity and economics.

The consensus was that the various options for cull cow management need to be investigated thoroughly so that they can be considered for more widespread adoption.

3.3.7 Euthanasia

Experts noted that on-farm euthanasia is the only acceptable option if an animal cannot be shipped and would suffer if kept alive for other options such as emergency slaughter. Producers need training in making decisions about euthanasia, plus either suitable training and tools to perform euthanasia or ready access to euthanasia services including carcass disposal. Veterinarians need suitable training so that they can support humane on-farm practices.

The consensus was that all dairy farms and auctions should have the training and tools needed for prompt, effective euthanasia, or access to euthanasia services, and that a euthanasia protocol should be part of every herd health program.

3.3.8 Enforcement

Consistent enforcement of the relevant regulations could help to address animal welfare problems and create public confidence. In contrast, inconsistent enforcement could lead to animal welfare problems if it creates an incentive for compromised animals to be sent to locations where inspection is less frequent or less rigorous. Moreover, enforcement can be complicated if the animal changes ownership repeatedly between farm and slaughter so that different people are responsible for judging fitness for travel. At present, enforcement related to the management of cull dairy cows involves a number of agencies and is handled in somewhat different ways in different jurisdictions.

• The Canada Food Inspection Agency (CFIA) is responsible for enforcing federal animal transport regulations. CFIA staff are present at all federally inspected slaughter plants, and periodically at auctions, assembly yards and other locations, to determine compliance.

• Provincial officials enforce various provincial regulations at slaughter plants and elsewhere depending on the jurisdiction. Inspection is periodic or complaint-based in some provinces, whereas Ontario requires that inspectors are present at auctions on any day when auction is conducted.

• In some provinces, Society for the Prevention of Cruelty to Animals (SPCA) inspectors enforce animal welfare/cruelty laws and may attend auction or assembly yards, typically on a complaint basis.

• In some provinces, provincial inspectors are authorized to monitor compliance with federal animal transport regulations in order to achieve more efficient inspection and sharing of information between federal and provincial authorities.

• In some provinces, producer organizations are formally involved in certain corrective actions, for example, by visiting producers who are found to have shipped compromised animals.

The consensus was that the different models of enforcement should be examined with a view to recommending the widespread and harmonized adoption of practices deemed best for the protection of animal welfare, and that enforcement authorities consider formal cooperation to facilitate sharing of information.

3.3.9 Age verification for shipment to the United States

In addition to the normal handling of cattle at auction yards, cows intended for shipment from Canada to the United States have been subjected to additional handling to verify that they were born on or after March 1, 1999. The additional handling, normally done by running animals through a chute, imposes increased risk of stress and injury, while the probability of a dairy cow being aged more than 17 years is negligible.

The consensus was that Canadian and United States authorities should negotiate alternative means of age verification, for example from health records, and a date when additional age verification can be discontinued.

Note: In accordance with this recommendation, since November of 2017 the age of exported animals can be verified from producer records, and the requirement for individual ages of exported animals for immediate slaughter has been discontinued (CFIA, 2018).

3.4 Discussion

The welfare of cull dairy cows is a complex issue that depends on infrastructure (e.g., local slaughter options), on decisions made by producers and other actors, on economic factors such as the value of the carcass, and on regulatory environments and options which vary among jurisdictions. Moreover, cull dairy cows are not a uniform group; for instance, a degree of handling and transport that is suitable for a healthy animal culled because of low milk production may be completely unsuitable for an animal that is very thin or lame. In the absence of comprehensive research on the issue, pooling knowledge from actors from all relevant sectors and with broad geographic experience provides an alternative form of understanding.

The difficulty of following the movement and condition of cull dairy cows once they leave the farm creates an information vacuum. One study indicated that compared to feeders and fat cattle, cull cattle (beef and dairy) were more likely to be lame at loading and when arriving from auction markets (González et al., 2012a). When transported ≥ 400 km, culls (compared to other categories of cattle) were more likely to become lame, non-ambulatory or die during the journey (González et al., 2012a). Similarly, higher mortality rates in cull dairy cattle during transport were reported by European studies (Večerek et al., 2006; Malena et al., 2007). These findings indicate inadequate fitness for transport of some cull cows and/or negative effects of long distance transport on the condition of cull cattle.

Previous work in Canada and the United States has shown considerable carcass losses because of problems during transport and handling, and has emphasized the need to improve the management and handling of dairy cattle (Van Donkersgoed et al., 2001; Nicholson et al., 2013). For example, Canadian beef quality audits indicated losses of $190 million and $274 million annually because of quality unconformities in all classes of cattle in 1995-96 and 1998-99, respectively (Van Donkersgoed et al., 1997, 2001). Both bruising and low body condition score were more present in dairy cows compared to beef animals (Van Donkersgoed et al., 2001). Moreover, conditions leading to entire carcass condemnation included emaciation, bruising and mastitis are common among dairy cows (Van Donkersgoed et al., 1997). Similarly, audits at livestock markets and slaughter plants in the United States identified several quality defects, including emaciation, lameness and bruising, that lowered the market value of cull dairy cows; this led to recommended actions to improve on-farm management, particularly timely culling decisions (Ahola et al., 2011a, b; Nicholson et al., 2013).

A variety of insights arose from this exercise. These include the wide range of transport distances and times that cull dairy cows experience, some of the factors that influence delay and handling, and the variety of regulatory arrangements and options. In addition, the consultation gave rise to numerous recommendations for action by producers, producer organizations, veterinarians, regulators and other players. Recommended areas for research include better documentation of transport distances and times, and the advantages and disadvantages of different options such as direct-to-slaughter and emergency slaughter. Such research could guide industry policy, actions, Codes of Practice, and inform revisions to the Transportation of Animals Regulations which currently do not make explicit provision for cull dairy cows.

Chapter 4: Fitness for transport of cull dairy cows at livestock markets in British Columbia

4.1 Introduction

To maintain continuous and profitable milk production, dairy producers from Canada and the United States remove around 25-34% of milking cows from their herds annually (Pinedo et al., 2010; CDIC, 2019). Decisions to remove cows are driven by a combination of individual cow factors, herd factors and the farmer's management style (Beaudeau et al., 1996, 2000; Hadley et al., 2006). Multiple cow factors, including various health conditions, may lead to culling, and many cows are removed because of health conditions such as mastitis and lameness that can affect their fitness for transport.

Economic factors also influence culling decisions. Because milk is the main product of the dairy industry, the demand for milk can influence herd management and culling decisions. In a free market system (as in the United States), both domestic supply and consumer demand influence milk price which in turn influences herd management and culling decisions (Rogers et al., 1988a; Hadley et al., 2006). In contrast, the supply-management system used in Canada provides a stable milk price (Muirhead, 2014), but increased consumer demand leads to an increase in the production quota (set for each farm) which can influence herd management and culling decisions.

Cows removed from dairy herds are transported to and commonly sold through livestock markets. The condition of cows at livestock markets varies widely, with some cows showing severe lameness, emaciation, mastitis, visible signs of sickness and other quality defects (Ahola et al., 2011a; Moorman et al., 2018). These conditions affect the price paid for cows (Moorman et al., 2018), and dairy cows in very poor condition are not sold at all (Ahola et al., 2011b). While at livestock markets, cows are commonly exposed to novel environments, mixed with unfamiliar animals, segregated in a sales ring, exposed to people, and may experience significant delays to slaughter (Knowles, 1999; Ferguson and Warner, 2008). These circumstances can be stressful, and the multiple social interactions can cause exhaustion and injuries (Ferguson et al., 2001) resulting in lower meat quality (Knowles, 1999; Warren et al., 2010a). Because of such issues, the use of livestock markets is declining in the European Union (Knowles, 1999), but it remains common in the United States (Glaze and Chahine, 2009).

The objectives of this study were to better understand the animal health and welfare status of cows moving through the marketing system, and the factors that influence these outcomes. Specifically, this study (1) evaluated the condition of cull dairy cows sold at livestock markets in British Columbia, (2) tested how changing demand for milk influenced the cows' fitness for transport, and (3) quantified how the condition of the animals influenced the price paid.

4.2 Materials and methods

During 1 year (May 2017 to April 2018), two livestock auction markets in the Fraser Valley, British Columbia, Canada were visited every week, on the 1 or 2 days per week when cull dairy cows were sold. The markets were selected based on their willingness to participate in the study and because most cull cows originating in the region were sold at these markets. Livestock market owners provided verbal agreement to the collection of data before the study started. This study was completed under protocol number A16-0336, approved by the University of British Columbia Animal Care Committee.

4.2.1 Description of livestock markets

Livestock markets are designed to house and market hundreds of animals per day. The animal holding area, which varies in size depending on market capacity, is arranged to house large numbers of animals in multiple holding pens separated by metal rails. These pens are not equipped with feed and water troughs and the flooring is usually soil, dirt or sawdust. From here, cattle are brought to the sales area which includes a platform for the auctioneer, a sales ring for the cattle (and for 1 or 2 employees), and an audience seating area.

Cattle arriving from farms in the lower Fraser Valley region of BC were usually transported in gooseneck trailers, while cattle originating from more distant regions (e.g., Vancouver Island or the BC interior) were trucked in tri-axle trailers. On arrival cattle were off-loaded via ramp from tri-axle trailers, or directly from gooseneck trailers. Once off-loaded, cattle were placed in the holding pens and mixed with other cattle from multiple farms. The stocking density was relatively high and it was uncommon to see cows resting in a lying position.

Most cattle arrived in the morning and spent several hours in these holding pens. Other cattle arrived the day before the auction and spent the night in the holding pens. These animals were usually marketed as “overnight stay” or “empty” animals, suggesting they were not fed during the night and had low gut content.

On the day of the sales, animals were moved from the holding pens by market employees who used metal rails to guide the animals to the sales ring. When a cow entered the sales ring the entrance door was closed and the animal was thus confined to the ring which had sawdust flooring and enough space for the animal to walk several strides. Cattle in the sales ring were accompanied by 1-2 employees who maintained close proximity to the animals and used plastic or wooden sticks to move the animals around the sales ring so buyers in the audience could observe the animal and bid. While in the sales ring cows were in close proximity to the audience and subjected to a noisy environment caused in part by the auctioneer who used a loudspeaker while marketing the cattle (range 63-93 dB; measured using a phone app, Decibel X, Sound Spectrum Analyzer & FFT, SkyPaw Co. Ltd, Hanoi, Vietnam). Once a cow was sold, the exit door was opened and the cow usually ran from the sales ring while the market employees used metal rails to guide the animal to the buyer's holding pen where it was mixed with unfamiliar animals. Cattle were then loaded via ramps to tri-axle trailers and transported either (1) to assembly yards where they were kept until full loads were assembled and the designated slaughter plant was ready to process the load, or (2) to another livestock market to be re-marketed. After the sale, cattle intended for export to the United States were also locked individually in a chute so a CFIA accredited veterinarian could read their unique identification tag and prepare an export certificate.

4.2.2 Data collection

One primary observer (a veterinarian) and two auxiliary observers (one veterinarian and one provincial dairy inspector) were trained and involved in the data collection. The primary observer was present at most sales (>90%) and the other two observers were present periodically, either individually or accompanying the primary observer. After initial training, intra- and inter-observer reliability was assessed through live observations, photos and videos. Inter-observer reliability of the primary observer and the provincial dairy inspector was tested every 3 months. Intra-observer reliability was tested every 3 months for the primary observer and on 2 occasions for the provincial dairy inspector (midway and end of the study). The other auxiliary observer joined the study later and the inter-observer reliability was tested twice (midway and end of the study) while intra-observer reliability was tested at the end of the study. In total, the observers were present at 137 sales (spring 28, summer 37, fall 39, winter 33) and observed 6,263 cull dairy cows in the auction ring.

Animals were assessed only if marketed as a single cow in the sales ring, not in a group of cows. The assessment included: locomotion, body condition, udder condition and certain quality defects that could affect the cow's suitability for transport. Locomotion was assessed using a 5-point locomotion score (LS), where 1 = sound and 5 = severely lame (Flower and Weary, 2006). A body condition score (BCS) was assigned using a scoring system for Holstein dairy cows (1-5 scale, 0.5 increments), where 1 was severe under-conditioning (emaciated) and 5 was severe over-conditioning (Ferguson et al., 1994). Udder condition was scored using a 3-point scale, where 1 = normal milked (loose) udder, 2 = tight/engorged udder, and 3 = swollen/inflamed udder. Any apparent quality defects were recorded as notes and later coded as 1 = signs of disease/weakness including signs of pneumonia, gastrointestinal conditions (severe diarrhea), severe ocular dysplasia or cancer eye, lump jaw or retained placenta, 2 = body injuries such as bleeding, open wounds, and hobbles, 3 = abscesses, and 4 = no defects. The observers also noted the animal's breed, whether the tail had been docked, whether animals were marketed as dry cows, and the cows' weight and price (expressed in Canadian dollars - CAD, as dollars per kilogram; $/kg). Assessments included only cull dairy cows sold for immediate slaughter, not heifers and cows sold for herd replacement.

Fitness for transport of each cow was evaluated using an aggregated measure based on industry standards (NFACC, 2009; DFC-PLC, 2017; CFIA, 2019). Cows were scored as '1' (poor fitness for transport) if they had one or more of the following conditions: BCS ≤ 2, LS ≥ 4, udder condition ≥ 2, or had one or more quality defects (e.g., abscess, hobbles); all others were scored as ‘0’ (good fitness for transport).

Finally, a categorical variable labelled “milk demand” was created for each month to indicate any changes in milk production set by the Milk Marketing Board (MMB). In the supply management system in Canada, each dairy farmer holds a production ‘quota’ expressed as the daily quantity of butterfat in kilograms that the farmer is required to produce and is allowed to market. For example, 150 kg of butterfat could be a daily quota for a 100-cow dairy farm; this converts to 4,500 kg of butterfat in a 30-day month. The MMB sometimes demands increased production in either of two ways. “Additional quota allocation” is a permanent increase in the daily butterfat production of the farm. An “incentive day” requires the farm to increase its monthly butterfat production by the equivalent of one additional day of production in the month when the incentive day was assigned. Incentive days apply only to the assigned month. Milk demand was recorded as ‘1’ when the MMB increased the demand for butterfat production using 1 incentive day (as occurred in May and June 2017); ‘2’ when demand was increased by more than 1 incentive day and/or additional quota allocation (as occurred in July to December 2017) or ‘0’ if demand did not change (January to April 2018).

4.2.3 Statistical analyses

The FREQ procedure in SAS (version 9.3, SAS Institute Inc., Cary, NC) was used to compute the prevalence of different conditions in cull dairy cows sold at the markets.

The intra- and inter-observer reliability for BCS, LS and udder condition was tested by calculating linear weighted kappa coefficients (K_w) and interpreted as follows: 0.0–0.20 = slight;

0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = substantial; and 0.81–1 = excellent agreement (Landis and Koch, 1977).

Logistic regression was used to test the effects of each month of the year and the monthly milk demand score on cows' fitness for transport. Because the milk demand was highly correlated with month, the final model included only the month of the year when cows were sold, and the month of January 2018 (the first month with demand of '0') was used as a reference month for comparison. Contrasts were set to further test the differences of cows' fitness for transport between months with and without additional demand (i.e., comparing milk demand of '1' versus '0' and '2' versus '0').

The effect of the animals' condition (BCS, LS, udder condition, quality defects and weight) on sale price was tested using linear mixed-effect model that included all animal-based measures as explanatory variables. To account for the effect that the day when sales were held might have on the price, 'day of sale' was included as a random effect. To avoid having a small number of observations in some categories and retain good resolution of the outcome measures, BCS scores were reduced to 5 categories, where BCS ≤ 2 included the scores 1, 1.5 and 2, and BCS ≥ 4.5 combined 4.5 and 5. Similarly for locomotion scores, LS of 4 and 5 were merged into one category LS ≥ 4. Before fitting the model, correlations among the explanatory variables were calculated. Two variables, 'BCS' and 'weight' showed high correlation ($r=0.65$); consequently 'weight' was excluded from the final model. BCS remained in the final model because it is better than weight as an indicator of fat reserves in dairy cows (Wright and Russel, 1984), is a more useful on-farm tool to evaluate body condition, and showed higher correlation with the dependent variable (sale price). The effect of fitness for transport (poor or good) on price was tested with an additional linear mixed-effect model that included 'day of sale' as a random effect.

For a subset of 549 cows, DIM (days in milk) and parity were known and were included in a separate linear mixed-effect model, but this analysis is not reported because DIM and parity did not influence sale price.

4.3 Results

Intra-observer weighted kappa coefficients (K_w) for the primary observer ranged from K_w 0.79-0.89 for BCS, from 0.77-0.87 for lameness, and 0.92-1.00 for udder condition. The intra-observer agreement for the 2 auxiliary observers ranged from K_w 0.82-0.93 for BCS, from 0.74-0.89 for lameness, and from 0.92-1.00 for udder condition. Inter-observer weighted kappa coefficients (K_w) for the 3 assessors ranged from K_w 0.69 – 0.82, respectively for BCS, from 0.67 – 0.89 for lameness, and from 0.74 – 0.96 for udder condition.

4.3.1 Condition of cull dairy cows at livestock markets

Of the 6,263 cows observed, most (97.7%) were of the Holstein breed with a few Jerseys (1.9%) and Ayrshires (0.4%). Mean (±SD) body weight (BW) was 654 ± 110 kg. Most cows had BCS of 2.5 (35.6%), 3 (27.6%) or 3.5 (14.6%), but 10.3% were very thin (BCS ≤ 2) and 11.9% were scored with BCS of 4 or higher. The cows had a mean (±SD) BCS of 2.9 ± 0.6. Slight to severe locomotion abnormalities were observed in 59.5% of the cows; of these, 6.8% had severe lameness (locomotion score ≥ 4). Recently milked (loose) udder was observed in most animals (87.2%), but 9.7% had an engorged udder and 3.0% had a swollen/inflamed udder. Quality defects were observed in 6.2% of the cows; these included abscesses (2.1% of cows), signs of disease/weakness (2.0%), hobbles (0.9%), signs of pneumonia (0.3%), eye injury (0.2%), and lump jaw (0.1%). In addition, docked tails were observed in 5.0% of the cows (see Table 4.1).

In total, 29.2% of the cows had one or more conditions that could affect fitness for transport; that is, they were thin (BCS ≤ 2), lame (LS ≥ 4), had engorged or inflamed udder (udder condition ≥ 2), or had quality defects. Of those, 23.2% had only one of these conditions, 5.1% had two, 0.9% had 3 and one cow had 4 conditions.

Among the 6,263 cows, 615 had been marked as part of a different study, and hence were easy to recognize at the livestock markets. Of these, 12 animals (2%) were observed being sold at both livestock markets, but on different days.

4.3.2 Factors affecting fitness for transport

Cows removed from the dairy farms in certain months (notably during summer and fall) were more likely to have poor fitness for transport (χ^2 =93.6; P<0.0001; see Figure 4.1). Specifically, cows removed from farms in August and September 2017, had higher odds of poor fitness for transport [odds ratio (OR) 1.8, 95% CI 1.38-2.28, and OR 2.5, 95% CI 1.93-3.19, respectively; P<0.0001; see Figure 4.1] than those removed in the reference month (January, 2018). Similarly, cows removed from farms during October and November had higher odds of poor fitness for transport (OR 1.3, 95% CI 1.04-1.67, and OR 1.3, 95% CI 1.05-1.66, respectively; P=0.02) compared to the reference month. Cows removed in December 2017 tended to have higher odds of poor fitness for transport (OR 1.3, 95% CI 0.97-1.65; P=0.08).

Fitness for transport of the cows removed in the months when the milk demand was increased by only 1 incentive day (demand=1) did not differ from fitness for transport of cows removed in the months without increased demand (demand=0). However, when demand was increased by more than 1 incentive day and/or by additional quota allocation (demand=2) cows had higher odds of poor fitness for transport compared to cows removed in months without increased demand (demand=0; OR 8.6, 95% CI 4.02-18.22; P<0.0001).

4.3.3 The effect of cows' condition on price

The price paid for the cows varied greatly depending on body condition ($F_{5,5918}$=562.9; P<0.0001). As a base comparison, cows with BCS of 3 were sold for a mean (±SE) of 1.33 ± 0.02 \$/kg. Cows with lower body condition, BCS of 2.5 and ≤ 2 had prices reduced by 0.27 ± 0.01 \$/kg and 0.63 ± 0.01 \$/kg, respectively (P<0.0001). In contrast, cows with BCS of 3.5 and 4 were sold for slightly higher prices of +0.07 ± 0.01 \$/kg (P<0.0001), while over-conditioned cows (BCS ≥ 4.5) sold at prices that were slightly reduced (-0.05 ± 0.02 \$/kg, P=0.04; see Table 4.2).

Quality defects had the second largest influence on price ($F_{3,5918}$=243.6; P<0.0001). Cows without quality defects were sold for (mean ± SE) 1.45 ± 0.01 \$/kg (comparison base price), whereas the price was reduced by 0.55 ± 0.02 \$/kg for cows with visible signs of sickness, by 0.20 ± 0.04 \$/kg for those with injuries, and by 0.27 ± 0.03 \$/kg for those with abscesses (P<0.0001; see Table 4.2).

Prices were associated with locomotion score (LS) ($F_{3,5918}$=179.4; P<0.0001). Sound cows (LS=1) were sold for mean price of 1.35 ± 0.02 \$/kg; whereas, cows with LS of 2 and 3 were discounted by 0.11 ± 0.01 \$/kg and by 0.16 ± 0.01 \$/kg, respectively, and cows with LS ≥ 4 had highest reduction in the sales price of (0.35 ± 0.02 \$/kg; P<0.0001; see Table 4.2)

Udder condition (UC) also influenced price ($F_{3,5918}$=66.3; P<0.0001). Cows with UC score of 1 were sold for 1.27 ± 0.02 \$/kg. In comparison, cows with UC score of 2 and 3 were sold for discounted prices of -0.06 ± 0.01 \$/kg and -0.30 ± 0.02 \$/kg, respectively (P<0.0001).

Dry cows were sold slightly above the price of the cows with UC of 1 (+0.02 ± 0.02 \$/kg; P=0.4; see Table 4.2).

Fitness for transport influenced sale price ($F_{1,5978}$=2473.6; P<0.0001). Compared to cows with good fitness for transport (sold for mean price of 1.70 ± 0.01 \$/kg), cows with poor fitness for transport were sold for 1.19 ± 0.01 \$/kg (reduction of 0.51 ± 0.01 \$/kg; P<0.0001; see Table 4.3).

4.4 Discussion

4.4.1 Condition of cull dairy cows at livestock markets

Around 11% of cull dairy cows sold at the livestock markets were very thin (BCS ≤2). Low body condition has not been cited as a direct reason for removing cows from the dairy herds (Bascom and Young, 1998; CDIC, 2019), but BCS is highly correlated with the cow's energy (fat) reserves and BCS ≤ 2 has been linked to reduced productivity and reproductive performance (reviewed by Roche et al., 2009). Because body condition mirrors cows' feed intake and nutritional status (Burkholder, 2000), low BCS can be associated with certain health problems or with reduced feed intake due to illness, or it can indicate reduced care (reviewed by Roche et al., 2009). In all such cases, thin cows can be expected to have reduced welfare and reduced ability to withstand transport. Moreover, according to the Canadian proAction animal care standards, thin cows (BCS ≤ 2) should be given prompt attention and appropriate health care and should not be transported (DFC-PLC, 2017); however, other programs are more tolerant of BCS and focus their concern on emaciated cows (BCS <2; FARM, 2017).

Around 7% of the cows had severe lameness (locomotion score ≥4). This corresponds to the percentage of cows that are removed from the dairy farms in Canada because of feet and leg problems as reported by farmers (CDIC, 2019), and with the prevalence of severe lameness recorded for herds in BC (7%; von Keyserlingk et al., 2012). However, because lameness can be a reason for culling, we might expect severe lameness to be more common among culled cows at livestock markets than those on farms. The scores recorded in this study may have underestimated the true prevalence of severe lameness at livestock markets because of the softer (sawdust) flooring versus concrete that is common on farms. In addition, the novelty of the environment combined with unfamiliar animals and handlers could distract animals and reduce limping as observed in other cases (Gentle, 2001; reviewed by Cook and Nordlund, 2009).

Lameness is a painful condition (Whay et al., 1998, Rushen et al., 2007) as is recognized by farmers and veterinarians (Leach et al., 2010; Fajt et al., 2011), and it is considered a major animal welfare problem in the dairy industry (von Keyserlingk et al., 2009). Severe lameness influences the general mobility of cows and reduces their ability to walk through the corridors in the livestock markets and climb loading ramps. Moreover, lameness leads to prolonged lying bouts and increased lying time (Chapinal et al., 2009; Ito et al., 2010; Solano et al., 2016), but livestock markets do not always provide an opportunity for cows to lie comfortably in the holding pens. Thus, there are good reasons why cows with severe lameness should not be shipped to livestock markets. According to industry guidelines, managers should provide these cows with proper care (DFC-PLC, 2017) and consider alternatives including euthanasia and shipping directly to slaughter (Stojkov et al., 2018).

Some cows sold at the livestock markets showed signs of udder inflammation (3%) or acute milk accumulation and engorgement (10%). Some of these cows may have had mastitis, as mastitis is often reported as a reason for culling (CDIC, 2019). Moreover, both mild and severe mastitis is considered painful (Fitzpatrick et al., 2013; Leslie and Petersson-Wolfe, 2012). For other cows, poor udder score may reflect simple milk accumulation due to cessation of milking; this has been associated with increased udder pressure and fecal cortisol, even in cows with low milk production (around 10 kg/d; Odensten et al., 2007; Bertulat et al., 2013). Cessation of milking is experienced by all cows that enter the marketing system. Since many cows remain in the system for several days before processing (Stojkov et al., 2018), they are at increased risk for udder engorgement and edema. Specific guidelines regarding udder health are needed that will underline the importance of drying-off cows before shipping.

The journeys of cull dairy cows from farm to abattoir often include change of ownership and shared responsibility about animals' health and welfare. Farmers are aware of cows' pre-existing condition and are required to transfer this information to others involved in this process. However, when different stakeholders evaluated fitness for transport of cull dairy cows, farmers showed the largest inconsistencies (Dahl-Pedersen et. al., 2018a). Therefore, specific guidelines and training for evaluating fitness for transport should be available to all stakeholders, so they can consistently identify and manage compromised animals.

4.4.2 Factors affecting fitness for transport

The condition of the cows at livestock markets showed a seasonal pattern, possibly related with seasonal occurrence of some diseases. In particular, cows with severe lameness were more frequently observed during summer and fall months (July to November) when the incidence of claw horn lesions is greatly increased (Sanders et al., 2009). The frequency of udder problems, emaciation and other quality defects did not indicate seasonality.

Cull dairy cows with poor fitness for transport were more frequently observed during some summer and fall months coinciding with the increased demand for milk in the province.

During the months of high demand (demand=2), cows removed from the dairy herds were more likely to be compromised. Increased demand for milk production can be met most easily by increasing the number of milking cows in the herd by delaying culling.

Data from recent years in Canada show that changes in milk production levels are closely related to culling and herd turnover rates. From 2010 to 2014 milk production in Canada was relatively constant, increasing by about 2 million hectolitres. During this time, culling rate was around 31% and herd turnover rate was 38%. In the following 3 years (2015-2017), milk production increased by around 11 million hectolitres, indicating increased demand. During this period the culling and herd turnover rates declined steadily and in 2017 reached 26% and 33%, respectively (CDIC, 2019). This suggests that a substantial increase in demand, even in the Canadian supply-management system where the milk production is relatively stable, can influence and delay on-farm culling decisions and reduce culling and herd removal rate. In the free market system, herds expand by retaining less desirable and low-producing cows and culling only the more severe cases (Weigel et al., 2003; Fetrow et al., 2006; Hadley et al., 2006). The MMB should consider developing a process that would allow an increase in milk production without causing farmers to delay culling decisions and thus retain animals until their welfare is compromised.

4.4.3 The effect of cows' condition on price

Low body condition of cull dairy cows reduced their sale price at livestock markets, with thin cows (BCS of ≤ 2) selling for a mean price of only 0.70 ± 0.02 \$/kg, averaging \$385 per cow. The extremely low prices for thin cows could be associated with health problems (e.g., pneumonia) that a buyer might take into account because they reduce the ability of cows to withstand transport and increase the risk of condemnation at the abattoir. Nonetheless, buyers were willing to buy thin cows because some slaughter plants specialize in processing Holstein cows whose lean carcasses can supplement products such as ground beef, and also achieve better cut-out and price value (CanFax, 2003).

The price difference between sound cows and cows with some abnormal locomotion was relatively small, whereas a larger difference was observed between sound and severely lame cows (1.35 $/kg versus 1.00 $/kg, respectively). This suggests that severe lameness was probably associated with certain negative outcomes such as reduced mobility, increased lying time or increased risk of condemnation, and hence had a larger effect on price. The willingness to purchase lame cows may reflect their resilience, as very few become non-ambulatory during transport (González et al., 2012a), and the fact that cows are required to walk only short distances in a slaughter facility. However, even short transport duration (e.g., 3 hours and <130 km), can negatively affect locomotion of cull dairy cows (Dahl-Pedersen et al., 2018b). Moreover, the *Code of Practice for the Care and Handling of Dairy Cattle* recommends that cows with severe lameness should be treated and not shipped (NFACC, 2009).

Udder engorgement had a slight effect on the price whereas udder inflammation reduced the sale price by around 0.30 $/kg (see Table 4.2). Buyers purchased cows with engorged udders presumably because this condition does not imply systemic illness that could cause carcass condemnation, while the opposite may be true for cows with udder inflammation.

Other quality defects had a negative effect on sale price. Buyers were visibly hesitant to purchase cows with pneumonia and watery diarrhea probably because they were thin and had reduced ability to withstand transport. Abscesses (2%) reduced the price (-0.27 $/kg) likely because of the partial condemnation associated with abscesses.

4.5 Conclusion

Around 30% of the cows sold at livestock markets in British Columbia had poor fitness for transport because they were thin, severely lame, had udder engorgement or inflammation, or other quality defects. These animals were sold for lower prices, particularly if they were thin or showed visible signs of sickness. In months when demand for milk increased, cows arriving at livestock markets were more likely to be compromised, likely because culling was delayed in an effort to meet higher production. We recommend the use of specific fitness-for-transport guidelines that will improve on-farm culling decisions, the training of all stakeholders to consistently evaluate fitness for transport, and greater use of alternative options such as direct-to-slaughter, emergency slaughter and euthanasia for compromised animals.

Table 4.1 The distribution of animal-based measures (Body Condition Score, Lameness Score, Udder Condition Score, quality defects, fitness for transport and tail condition) for cull dairy cows (n=6,263) sold at 2 livestock markets in British Columbia

Measure	Frequency	Percent (%)
Body condition score[1]		
BCS ≤ 2	645	10.3
BCS 2.5	2,226	35.6
BCS 3	1,724	27.6
BCS 3.5	910	14.6
BCS 4	578	9.3
BCS ≥4.5	165	2.6
Locomotion score[2]		
LS 1	2,514	40.5
LS 2	2,121	34.2
LS 3	1,150	18.5
LS ≥4	423	6.8
Udder condition score		
UC 1	5,270	84.1
UC 2	609	9.7
UC 3	190	3.0
Udder dry	194	3.1
Quality defects		
Disease	189	3.0
Body injuries	70	1.1
Abscesses	129	2.1
Absence of defects	5,875	93.8
Fitness for transport		
Good fitness for transport	4,436	70.8
Poor fitness for transport	1,827	29.2
Tail		
Full tail	5,952	95.0
Docked tail	311	5.0

[1]Body condition was not assessed for 15 cows (missing values n=15)
[2]Locomotion was not assessed for 55 cows (missing values n=55)

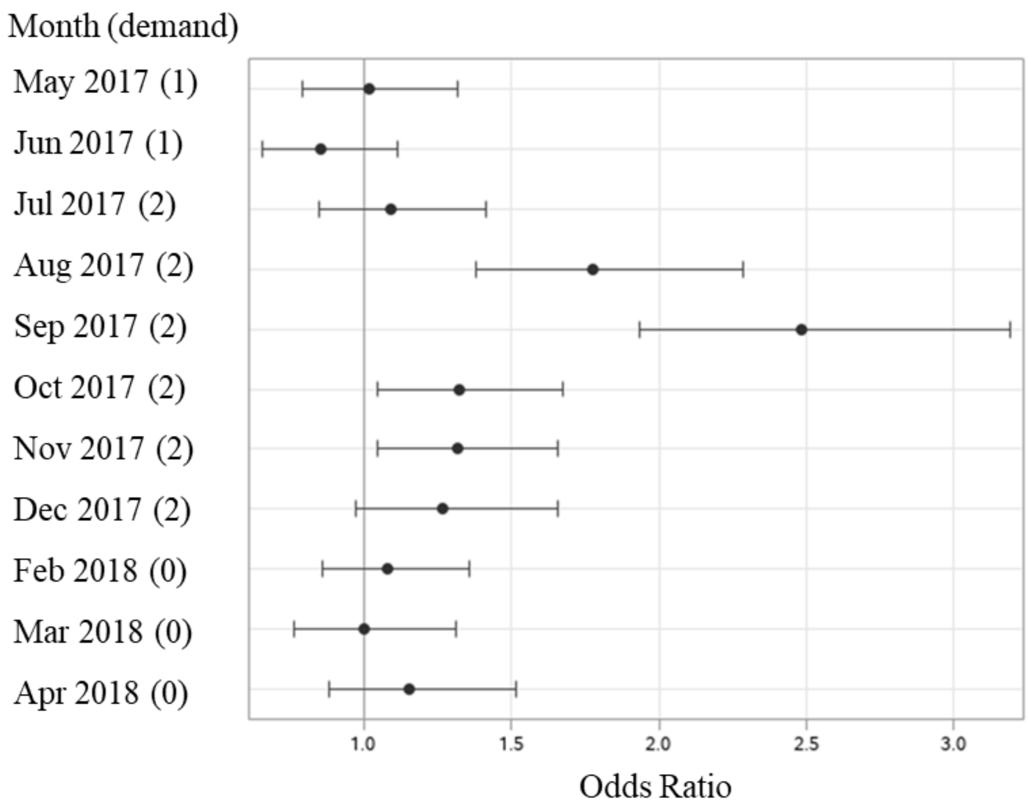
Table 4.2 Least square means (LSM±SE) from the final linear mixed-effect model indicating all factors that influenced the price of cull dairy cows (n=6,263) sold at 2 livestock markets in British Columbia

Variable	Estimated price $/kg	SE	95% Confidence limits Lower	Upper
Body condition score				
BCS 2	0.70	0.02	0.66	0.73
BCS 2.5	1.05	0.02	1.02	1.08
BCS 3	1.33	0.02	1.29	1.36
BCS 3.5	1.39	0.02	1.35	1.43
BCS 4	1.40	0.02	1.36	1.44
BCS ≥4.5	1.28	0.03	1.22	1.33
Locomotion score				
LS 1	1.35	0.02	1.31	1.38
LS 2	1.23	0.02	1.20	1.27
LS 3	1.18	0.02	1.15	1.22
LS ≥4	1.00	0.02	0.96	1.04
Quality defects				
Disease	0.89	0.02	0.84	0.94
Body injuries	1.24	0.04	1.17	1.32
Abscesses	1.18	0.03	1.12	1.23
Absence of defects	1.45	0.01	1.42	1.47
Udder condition score				
UC 1	1.27	0.02	1.24	1.31
UC 2	1.22	0.02	1.18	1.26
UC 3	0.98	0.03	0.93	1.03
Udder dry	1.29	0.03	1.24	1.34

Table 4.3 Least square means (LSM±SE) from the linear mixed-effect model indicating the effect of fitness for transport (poor or good) on the price of cull dairy cows (n=6,263) sold at 2 livestock markets in British Columbia

Variable	Estimated price $/kg	SE	95% Confidence limits Lower	Upper
Good fitness for transport	1.70	0.01	1.67	1.72
Poor fitness for transport	1.19	0.01	1.16	1.21

Figure 4.1 Odds ratios (with 95% confidence limits) of poor fitness for transport of cows sold at livestock markets in British Columbia in each month from May 2017 to April 2018. Demand for milk in each month was scored as unchanged (demand=0), minor increase (1) or major increase (2). January 2018 was used as a reference value because it was the first month with no additional demand



Chapter 5: Management of cull dairy cows in British Columbia: culling decisions, duration of transport, and effect on cow condition

5.1 Introduction

Managing dairy herds requires continuous replacement of less productive cows with young, more productive and genetically superior replacement heifers. In this dynamic herd management process, farm managers gather and process diverse information and make regular culling decisions. Farm managers have different management styles, perceive risks and benefits of factors differently, and handle information differently; some consider longevity and genetic selection as a priority while others seek mostly to maintain milk production (Beaudeau et al., 1996). Regardless of management style, farmers consider many individual cow factors such as milk production, fertility, somatic cell count, feet problems and other factors before reaching a culling decision (reviewed by Beaudeau et al., 2000). Moreover, external factors such as demand for milk, milk price, feed price, and the cost and availability of replacement heifers can also influence culling decisions (Hadley et al., 2006).

When culled, many cows have developed one or more health conditions that are often cited as the specific reasons for removal. In 2018, the five most cited reasons for removing cows from Canadian dairy farms included: reproductive problems (17%), mastitis (11%), feet and leg problems (7%), low milk production (8%), and sickness (4%; CDIC, 2019). Thus, although some cows are removed because of low fertility or low milk production, many are ill and some likely experience pain, for example from lameness or mastitis (Whay et al., 1998; Fitzpatrick et al., 2013; Evans et al., 2016) and these conditions reduce their ability to withstand transport.

The marketing system for culled cows commonly includes considerable handling and transport to livestock markets and then to abattoirs. This final leg of the journey has been reported as relatively short; for example, mean transport duration was 4.6 h in Ontario (Warren et al., 2010b) and 6.7 h in the United States (Harris et al., 2017). However, long-distance journeys of more than 1,000 km and lasting for 16 h are not uncommon (González et al., 2012b). Regardless of transport duration, many compromised cows have been observed at livestock markets (Ahola et al., 2011a; Moorman et al., 2018) and at abattoirs in Canada and the United States (Van Donkersgoed et al., 2001; Harris et al., 2017).

Cull dairy cows are a vulnerable category of animals that can become lame, non-ambulatory or die when subjected to long-duration transport (González et al., 2012a). Even with shorter transport (~3 h) they can develop wounds, an engorged udder and experience increased lameness (Dahl-Pedersen et al., 2018b). In countries such as Canada and United States where abattoirs are widely dispersed and tend to be selective about the type of cattle they process, long duration transport (>400 km) and delays to processing (7-10 d) occur regularly (González et al., 2012b; Stojkov et al., 2018; Edwards-Callaway et al., 2019).

Collectively, these studies suggest that some cows removed from dairy farms have a variety of health problems and a portion of cull dairy cows arrive at auctions and abattoirs with compromised health. However, whether cows developed these negative welfare states at the farm of origin, during transport, or in the marketing system remains unknown. Moreover, many farmers and veterinarians are not aware of the delays that commonly occur from farm to slaughter (Stojkov et al., 2018) and hence do not take the likely delays into account when deciding to ship animals. This study was designed to gather information about the duration of travel from farm to abattoir and evaluate any changes in the condition of cull dairy cows. The study also tested whether providing information to farmers about common delays to slaughter would influence their subsequent decisions to ship cull dairy cows.

5.2 Materials and methods

This study was approved by the University of British Columbia Animal Care Committee (#A16-0336) and the Behavioral Research Ethics Board (#H17-00009). Participating farms provided written consent, while the livestock markets and abattoirs provided verbal agreement. Participation of all parties was entirely voluntary.

5.2.1 Participants and data collection

The study monitored the condition of cull dairy cows (1) on 20 commercial dairy farms in the Fraser Valley, British Columbia (BC), Canada (the largest dairy region in BC), (2) at 2 livestock markets in BC where many of the cows were sold, and (3) at abattoirs in BC, Alberta, and Washington State (USA) where many were processed.

Participating dairy farms were recruited by invitations facilitated through local veterinary practices and two producer associations. Livestock markets and abattoirs were invited to participate through their associations. Farms and livestock markets participated throughout the study, while abattoirs entered the study at different times depending on the managers' decision to participate. One local abattoir stopped processing cattle during the study.

During data collection (May 2017 to March 2018) the primary observer was in regular (weekly) communication with participating farms via phone messages and visited on the days when farmers made their culling decisions. Cows included in the study were assessed for locomotion, body condition, and udder condition. Locomotion was assessed using a 5-point locomotion score (LS) (Flower and Weary, 2006), where 1 = sound and 5 = severely lame. Body condition was evaluated using a chart of body condition scores (BCS) for Holstein dairy cows (1-5 scale, 0.5 increments), where 1 was severe under-conditioning (emaciated) and 5 was severe over-conditioning (Edmonson et al., 1989; Ferguson et al., 1994). Udder condition was scored using a 3-point scale, where 1 = normal milked (loose) udder, 2 = tight/engorged udder, and 3 = swollen/inflamed udder. Records also included the cows' parity (lactation number) recorded as parity 1, 2, 3 or ≥4, and days in milk (DIM) recorded as 1-100, 101-200, 201-305 and >305 DIM.

A composite measure of fitness for transport was created for each cow following industry standards (NFACC, 2009; DFC-PLC, 2017; CFIA, 2019). Specifically, cows were scored as '1' (poor fitness for transport) if they had one or more of the following conditions: BCS ≤ 2, LS ≥ 4, or udder condition ≥ 2; all others were scored as '0' (good fitness for transport).

At the participating farms, two groups of cows were identified: those designated to be removed from the breeding herd (placed on the "culling list"), and those designated for immediate shipping to auction or slaughter ("shipping list"). Cows already on the culling list when the study began were assessed immediately. All new cows added to the culling list were assessed when the decision was made; this was weekly, biweekly or monthly, based on the farm dynamic. Cows were assessed again when placed on the shipping list, 1-3 d before they were shipped from the farm. These cows were marked with a distinct mark using cattle spray (Tell Tail Aerosol, FIL Industries, New Zealand) to make them easy to recognize at auctions and abattoirs. Assessors at the abattoirs were informed about the impending arrival of study cows and were asked to watch for the cows on arrival.

Cows at the farms and livestock markets were assessed by one primary observer (a veterinarian) and 2 trained auxiliary observers (one government dairy inspector and one veterinarian). The primary observer assessed >90% of the cows at the farms and livestock markets, while the auxiliary observers were involved periodically. After initial training, the inter-observer reliability of the primary observer and the dairy inspector was tested regularly. The intra-observer reliability was tested every 3 mo for the primary observer and on 2 occasions (midway and at the end of the study) for the dairy inspector. Because the other auxiliary observer joined later, inter-observer reliability was tested twice (midway and at the end of the study) while intra-observer reliability was tested at the end of the study.

Cows arriving at the participating abattoirs were assessed on arrival, or in the holding pen, or when walking to the slaughter line, by abattoir inspectors (3 veterinarians and 3 meat inspectors) who had been trained to use the same scoring systems. The initial training was scheduled after each abattoir agreed to participate in the study and based on the inspectors' availability. Continuous evaluation of the observers' scoring skills was scheduled to occur approximately every 3 mo, based on the observers' availability and work schedule. Because each observer's length of involvement in the study varied, observers had 1-3 inter-observer reliability tests and one (4 observers) or none (2 observers) intra-observer reliability tests midway or at the end of the study. Testing involved a combination of live observations, photos and videos. To estimate the total duration of transport, the inspectors also recorded the time and date when the cows arrived and were slaughtered; delays at international borders were not recorded during this study. Inspectors' involvement in the study was voluntary; one inspector dropped out during the study because of work-related restrictions.

Because excellent agreement between observers ($K_w > 0.80$) was not always achieved, each outcome measure (BCS, LS, udder condition) was expressed as a binary variable: '1' when cows were thin (BCS ≤ 2), severely lame (LS ≥ 4), or if the udder showed engorgement or inflammation (udder condition ≥ 2), or ‘0’ otherwise. This approach was taken under the assumption that consistent detection of extreme conditions could be achieved more easily.

5.2.2 Testing the effect of providing information

Based on data gathered from May to September 2017, informational materials were provided to half of the participating farms (Informed treatment) during November 2017 while the other farms constituted the Control treatment. To allocate farms to treatment, farms were first match paired by similar herd size and served by the same veterinary clinic where possible; then one farm in each pair was randomly assigned to each treatment. Owners and/or farm managers in the Informed treatment were provided with information on the findings of the first months of the study including duration of transport, the condition of cull cows at auction and at the abattoir, and prices paid at the auction markets, plus a simplified decision-tree tool for deciding whether to load a cow for transport. These producers were also given the contact number of a veterinarian for free telephone consultation, and the contact number of a local abattoir manager if they wished to ship cows directly to the abattoir (direct-to-slaughter). These information meetings lasted about 30 min and were delivered by a veterinarian (the auxiliary observer). Producers in the Control treatment were not provided with this information. The researcher who carried out the regular on-farm assessments remained blinded to the treatment assignment. The goal was to test whether providing such information would influence farmers’ culling decisions.

The effect of the treatment was tested by comparing the condition of animals at the time of shipping and the frequency of using alternative options (euthanasia, direct-to-slaughter, emergency slaughter) for removing compromised cows. These measures were gathered for each farm before (baseline period) and after the intervention (treatment period), and included the number of cows scored as thin (BCS $\leq$ 2), severely lame (LS $\geq$ 4), with udder condition $\geq$ 2, and cows with poor fitness for transport, expressed as count data or as a proportion of the total cows shipped. Because few cows were removed from the farms using alternative options, these variables were not used in the analysis. In addition, data were gathered on the number of cows that died or were euthanized and the total number removed from the herd.

5.2.3 Statistical analyses

Microsoft Access Database (Microsoft Office 2016) was used to calculate the time cows spent in the marketing system. All statistical analysis was completed in SAS (version 9.4, SAS Institute Inc., Cary, NC).

Intra- and inter-observer reliability for BCS, LS and udder condition was evaluated using unweighted kappa coefficients (K). Prevalence index (PI) and bias index (BI) were calculated to measure the effect that prevalence of the observed conditions and the observers' bias had on the reliability coefficients (Sim and Wright, 2005).

Generalized linear mixed-effects models (Proc Glimmix) were used to determine any deterioration in the condition of the cows at the 4 points of assessment: (1) when placed on the culling list, (2) when placed on the shipping list, (3) at auction, and (4) at the abattoir. The distribution was set as binary to fit the binary outcome variables, with logit link and residual pseudo-likelihood estimation. To account for the variation due to individual cows and the farm of origin, cow within farm was set as a random effect. Parity and days in milk (DIM) were included as covariates. A separate model was used to evaluate deterioration of each outcome variable: BCS, LS, udder condition and fitness for transport. In each model, a reference value for each explanatory variable was selected. Specifically, category 1-100 DIM was used as reference value for DIM, parity ≥4 for parity, and the scores when cows were placed on the "shipping list" was chosen as a reference value for point of assessment. Udder condition at the first point of assessment (i.e., culling list) was not included in the analysis because cows at this stage were regularly milked and treated for mastitis if necessary. Because there were missing observations at different points of assessment, two data sets were created and tested with these models. The first included all observations while the second excluded all animals with missing observations. The analyses showed the same findings and thus we used the larger data set for the final analysis. The similarity of the results from the two data sets likely reflects the robustness of the mixed-effect models even when used with unbalanced and missing data.

The effect of the intervention on the outcome measures (the count of thin, severely lame, cows with engorged and/or inflamed udder and cows with poor fitness for transport) was tested using negative binomial regression, where the baseline period was used as a covariate and the number of cows shipped to auction (observed by the researcher) as an offset variable. The same model was used to test the effect of the intervention on the number of cows that died or were euthanized on the farm, using the total number of cows removed as an offset variable. The models were constructed using the Genmod procedure in SAS, with the response distribution set as negative binomial with log link function. To test whether the veterinary clinic influenced the outcome measures of the intervention, the veterinary clinic that served the farms was also included as a covariate in the model. Because the models for the outcome variables BCS, fitness for transport, died and euthanized did not converge, the outcome measures from count data were transformed to percentages. For example, the number of thin cows sent to auction was expressed as a percentage of total cows sent to auction, and cows that died or were euthanized was expressed as a percentage of total cows removed from the herd. A general linear model (Proc

GLM) was applied to these percentages to test the effect of the intervention, using separate models for each outcome measure and including veterinary clinic and the baseline period as covariates.

Exploratory analysis, using the same outcome measures as were used to test the intervention, was performed to test the differences between the baseline and treatment periods. This analysis was done because demand for milk (a requirement for each farm to increase production as set by the provincial Milk Marketing Board) increased during all months of the baseline period (May-Nov), but not during the treatment period (Dec-Mar) except for the month of December. Time (baseline period or treatment period), treatment (Informed or Control) and the interaction between time and treatment were used as explanatory variables, and the veterinary clinic was added as a covariate. Because the interaction was not significant, it was removed from all final models. Initially all models were fitted with negative binomial regression with farm as a random effect, but the models did not converge except for the number that died or were euthanized. To fit linear mixed-effects models, the outcome variables were transformed from count data to percentage of thin, severely lame, cows with engorged and/or inflamed udder, cows with poor fitness for transport, and cows that died or were euthanized (as described above). After this transformation, all models converged except the model for the udder condition. After running diagnostic tests for this model, it was confirmed that the random effect was interfering with the model, hence the random effect was removed and a linear model without random effect was fitted. Results from the exploratory analysis that had $P > 0.05$ were also reported in the result section.

5.3 Results

During the study, 815 cows were assessed when placed on the culling list and 1,171 cows were assessed when removed from the participating farms; these 1,171 animals include cows from the culling list and those that were removed directly from the herd without being placed on the culling list. Of the cows removed, 615 were re-assessed at the livestock markets and 12 of these (2%) were observed at two different livestock markets, apparently because they were re-sold. Observers recorded 731 of the cows at participating abattoirs, of which 518 were assessed (see Figure 5.1). For 538 cows, the observers recorded the time when the animal was processed and this time was used to calculate the time elapsed from farm to processing (see Figure 5.2). One cow arrived at the abattoir dead; two were non-ambulatory at arrival and had to be euthanized.

Herd size (mean ± SD) of participating farms at the beginning of the study, including milking and dry cows was 311 ± 255 cows. Most of the study cows were Holstein (99.3%) with a few Jersey or Jersey x Holstein cross (0.7%). Mean (±SD) parity when removed from the herd was 2.9 ± 1.6, with cows at 209 ± 126 DIM when placed on the culling list and 273 ± 184 DIM when removed from the farm (see Table 5.1). About 80% were processed at abattoirs in the United States and were transported (±SD) 286 ± 220 km. Cows processed at plants in Alberta (11%) were transported 1,105 ± 190 km, and those processed in the local plants in British Columbia (9%) were transported 62 ± 4 km (see Figure 5.1). After leaving the farms, cows spent (mean ± SD) 82 ± 46 h in the marketing system until being processed. Including delays at auctions or assembly yards, 27 cows (5%) were processed within 1 day after being removed from the farm, 43% within 2-3 days, 41% in 4-5 days, 8% in 5-7 days and 16 cows (3%) spent 8-16 days in the marketing system (see Figure 5.2).

Unweighted kappa coefficients for intra- and inter-observer agreement for the 9 assessors who contributed to the final dataset indicated moderate to excellent agreement which ranged from 0.48 to 1.00 and 0.45 to 1.00, respectively for BCS, 0.69 to 1.00 and 0.52 to 1.00 for lameness score, and 0.79 to 1.00 and 0.49 to 1.00 for udder condition. The prevalence index ranged from 0.03-0.95 and the bias index ranged from 0.00 to 0.18 (see Table 5.2).

5.3.1 Changes in condition from farm to abattoir

Compared to the time of shipping (used as a reference value), when cows were first placed on the culling list had lower odds of being thin, but the odds of being thin increased when arriving at the abattoir ($F_{(3,1316)}$=48.12, P<0.0001; see Table 5.3). Cows in early lactation (0-305 DIM) had higher odds of losing body condition than those in late lactation (DIM>305; $F_{(3,1316)}$=21.42, P<0.0001). Older cows (≥3rd parity) had higher odds of having reduced body condition at abattoirs than those of parity 1 or 2 ($F_{(3,1316)}$=3.31, P=0.02; see Table 5.3).

Severe lameness (see Table 5.4) did not change while cows were on the culling list, at shipping or when arrived at abattoir, but cows at auction showed reduced odds of being scored as severely lame ($F_{(3,1188)}$=6.91, P<0.001). Stage of lactation did not influence locomotion score, but higher parity (≥2nd parity) was associated with increased odds for developing severe lameness ($F_{(3,1188)}$=8.56, P<0.0001; see Table 5.4).

Udder condition (see Table 5.5) did not deteriorate from the time of shipping until cows were scored at auction, but cows arriving at abattoirs had greater odds of acute milk accumulation or inflammation ($F_{(2,1025)}$=169.76, P<0.0001). Cows in the earlier stages of lactation (DIM≤305) and older cows (≥3rd parity) had higher odds of developing signs of udder engorgement and inflammation ($F_{(3,1025)}$=19.54, P<0.0001 and $F_{(3,1025)}$=5.19, P<0.01, respectively; see Table 5.5).

When placed on the culling list, cows had lower odds of poor fitness for transport than at the time of shipping (see Table 5.6). Similarly, cows at auction had lower odds of poor fitness for transport, mostly because of lower lameness scores as discussed below. However, cows arriving at the abattoir had much greater odds of poor fitness for transport ($F_{(3,1318)}$=106.38, P<0.0001). High odds of having poor fitness for transport was observed in cows in every stage of lactation, particularly cows in the first 100 DIM ($F_{(3,1318)}$=25.86, P<0.0001). Multiparous cows had higher chances of having poor fitness for transport; this was especially true of cows of ≥4th parity ($F_{(3,1318)}$=12.93, P<0.0001; see Table 5.6).

5.3.2 The effect of providing information

The experimental intervention (i.e., provision of information to half of the participants) did not improve the condition of cows removed. However, the exploratory analysis indicated improved outcomes during the treatment period compared to the baseline period regardless of treatment. Specifically the percentage of thin cows (BCS≤2) sent to auction declined from 9.0 ± 1.5% in the baseline period (May-Nov) to 4.9 ± 1.5% in the treatment period (Dec-Mar; $F_{(1,19)}$=7.13, P=0.02; see Figure 5.3), and farms in the Informed treatment shipped fewer thin cows (5.4 ± 1.5%) compared to the farms in the Control treatment (8.6 ± 1.8%; $F_{(1,19)}$=2.48, P=0.13). Moreover, farms that received services from certain veterinary clinics sent a lower percentage of thin cows to auction ($F_{(1,19)}$=7.06, P=0.05; see Figure 5.4)

The percentage of severely lame cows sent to auction was lower in the treatment period (7.8 ± 2.1%) than the baseline (10.8 ± 2.1%; $F_{(1,19)}$=1.92, P=0.18), and lower on the farms that were serviced by a certain veterinary clinic ($F_{(3,19)}$=1.94, P=0.16), but the percentage of severely lame cows removed from the farms was not influenced by treatment.

The percentage of cows with udder edema sent to auction declined from 9.4 ± 2.3% in the baseline period to 4.9 ± 2.3% in the treatment period ($F_{(1,19)}$=2.69, P=0.11), but neither the treatment or veterinary clinic showed any influence on this outcome variable.

The percentage of cows with poor fitness for transport declined from 25.8 ± 3.1% in the baseline period to 15.7 ± 3.1% during the treatment period ($F_{(1,19)}$=9.92, P<0.01). Treatment did not influence fitness for transport, but again clients of certain veterinary clinics shipped fewer cows with poor fitness for transport ($F_{(3,19)}$=1.89, P=0.17).

The percentage of cows that died (expressed as a percentage of total cows removed from the herd) declined from 11.9 ± 2.4% in the baseline period to 5.4 ± 2.4% during the treatment period ($F_{(1,19)}$=12.41, P<0.01). The percentage of euthanized cows also declined from 20.5 ± 3.0% in the baseline period to 13.3 ± 3.0% in the treatment period ($F_{(1,19)}$=5.06, P=0.04). Treatment and veterinary clinic did not influence the percentage of cows that died or were euthanized.

5.4 Discussion

Even though the prevalence index of reliability tests often had high values, most of the observers reached substantial or excellent agreement (see Table 5.2). This indicates that severe conditions (e.g., severe lameness) were easily recognized by the observers and the kappa values were only occasionally reduced. The bias index was used to detect observers' "drift" which was not observed in this study (Sim and Wright, 2005).

In this study, just over half the cows were in the marketing system for more than 3 d, even though most (80%) were processed in an abattoir located less than 300 km from most of the farms and from the large livestock markets in the lower Fraser Valley region of British Columbia (see Figure 5.1). Primary reasons for delays to slaughter, as reported by others, are lack of infrastructure and low slaughter capacity of available plants (Stojkov et al., 2018; Edwards-Callaway et al., 2019). The abattoir located in Washington State in the United States that processed the majority of cows in the current study also processed many cull dairy cows from nearby states, and this likely contributed to delays. In contrast, cows sent to the local abattoirs were processed faster, but these plants processed only a very small percentage of the cows and one plant discontinued processing cattle during the study. More local facilities for processing cull dairy cows are needed to service areas with large concentration of dairy farms; the local dairy industry is encouraged to identify the steps needed to build the necessary infrastructure.

5.4.1 Changes in condition from farm to abattoir

While dairy cows were on the culling list (i.e., from the decision to cull until the decision to ship) and in the marketing system (i.e., from farm to abattoir) their BCS declined. Compared to body weight, which can vary due to frame size and gut content, BCS is more representative of body fat reserves (Wright and Russel, 1984) and is a useful indicator of the animals' nutritional status (Burkholder, 2000). Extremely low body condition is usually linked with poor health (e.g., milk fever, lameness) or malnutrition (reviewed by Roche et al., 2009). In this study, cull dairy cows were exposed to multiple factors (e.g., transport, stress, handling) that likely contributed to a reduction in body condition probably reflecting poor welfare. In particular, the higher odds of being thin (BCS $\leq$2) on arrival at abattoirs likely reflected feed and water deprivation during some or all of the time in the marketing system. Moreover, the transport, repeated loading and off-loading and mixing with unfamiliar animals likely reduced feed intake and caused stress that can initiate mobilization of body reserves (Warren et al., 2010a; Ferguson and Warner, 2008; Marques et al., 2012).

Surprisingly, cows observed at livestock markets had lower (i.e., better) locomotion scores than when observed at the farm of origin. This may reflect a reduction in gait abnormality caused by distraction (Gentle, 2001). The novel environment of livestock markets, where cows are held individually in a noisy sales ring close to unfamiliar handlers, could shift the animals' attention away from the pain of lameness (Gentle, 2001). In addition, the sawdust flooring of the sales ring is softer than the concrete floors where the on-farm scoring was conducted; this may have improved the stride length and symmetry of the gait (reviewed by Cook and Nordlund, 2009).

In this study, severe lameness did not increase in cows followed from farm to abattoir, although short-duration transport has been reported to increase lameness scores in cull dairy cows (Dahl-Pedersen et al., 2018b). The lack of effect in our study might be due to the use of the merged locomotion scale that distinguished only severe lameness. In addition, the infrastructure at the abattoirs often prevented observers from evaluating 4 full strides, some plants had rubber flooring on the unloading track which could improve locomotion (reviewed by Cook and Nordlund, 2009), and here again the distraction caused by the new surroundings could have distracted the animals' attention from pain (Gentle, 2001).

The occurrence of acute milk accumulation and udder inflammation had increased dramatically by the time cows reached the abattoirs, presumably because most cows were in the marketing system for more than 3 d without being milked – a serious animal welfare problem.

Udder inflammation, regardless of severity, is considered painful (Leslie and Petersson-Wolfe, 2012; Fitzpatrick et al., 2013), and even subclinical mastitis has been reported to increase pain sensitivity in cows (Peters et al., 2015). Acute milk accumulation increases intra-mammary pressure resulting in tissue damage, discomfort, pain and stress as indicated by increased levels of fecal cortisol metabolites (Bertulat et al., 2013; reviewed by Zobel et al., 2015). Even cows with low milk production (around 10-15 kg/d), have increased udder pressure and fecal cortisol metabolites that peak at day 2 after cessation of milking (Tucker et al., 2009; Bertulat et al., 2013).

The cows' overall fitness for transport, as assessed by a combination of body condition, lameness and udder condition, declined while cows were on the culling list (i.e., until farmers reached the decision to ship). Reaching this decision is influenced by multiple factors and in this study increased milk demand in BC during 2017 may have resulted in delayed culling decisions, as described in expanding herds (Weigel et al., 2003; Hadley et al., 2006).

Fitness for transport also declined with increasing parity and was lower for cows culled during early stages of lactation (see Table 5.6). For example, cows in the first stage of lactation had higher odds of being thin, likely because many recently calved cows experience metabolic or infectious diseases that can reduce feed intake and body condition (LeBlanc et al., 2010). Compared to primiparous cows, older cows ($\geq 3^{rd}$ parity) had higher odds of losing body condition. Similarly, Gallo et al. (1996) found that multiparous cows experience more intense body condition loss and slower recovery. Cows with higher parity also had higher odds of developing severe lameness by the time they arrived at abattoirs; other studies have also reported that high-parity cows had greater risk of lameness and lower chances of recovery (Reader et al., 2011; Solano et al., 2015). The odds of developing udder edema were highest at the first stage of lactation but was maintained throughout the other stages of lactation and increased with parity, as described in other on-farm studies of mastitis (Barkema et al., 1998; Olde Riekerink et al., 2008).

5.4.2 The effect of providing information

Culling decisions did not appear to be influenced by providing information to farmers, but seem affected by other factors. The temporal analysis suggested that one likely factor was the increased demand for milk in BC during 2017. Specifically, the demand for milk increased during the first months of the study (May to Nov; the baseline period), but not during most of the treatment period (Dec-Mar). In the Canadian supply-management system, farmers are required to achieve any increases in production set by the provincial Milk Marketing Board to avoid penalties. This may well have influenced farmers to retain cows in the herd during the baseline period in order to increase milk production such that shipping was delayed until some animals were in poor condition ("involuntary culling"; Weigel et al., 2003; Fetrow et al., 2006; Hadley et al., 2006). Hence, when shipped under these market conditions a higher percentage of cows were thin (perhaps due to health problems) or had poor fitness for transport when removed from farms. Moreover, the health condition of some cows that remained on farms might have deteriorated to a degree that cows became unfit for transport and had to be euthanized or some might have died on-farm. This suggests that increased milk demand, as occurred in BC during 2017, can have a profound, albeit arguably unintended, effect on animal welfare.

The literature gives little evidence of how increased demand for milk influences culling decisions and the welfare of dairy cows. However, some studies from the United States have described the effect of herd expansion on culling (Weigel et al., 2003; Fetrow et al., 2006; Hadley et al., 2006). For example, fewer animals may be culled in the first few years after herd expansion (Hadley et al., 2006), and expanding herds practice more involuntary culling of high-producing cows compared to the pre-expansion period (Weigel et al., 2003). This trend was also more obvious in larger herds (>150 cows) and herds with higher average milk production (>11,340 kg; Weigel et al., 2003). As noted by Fetrow et al. (2006) management to achieve the short-term goal of expanding the herd involves retaining less favorable cows and reducing the culling rate. Once herd expansion is complete and the cash flow is stabilized, farmers replace undesirable cows with better cows and normal culling resumes (Fetrow et al., 2006).

We noted an effect of veterinary practice with the clients of one veterinary clinic making better culling decisions than clients of other veterinary clinics in this study. This may indicate that some farm managers use different criteria when making culling decisions (Beaudeau et al., 1996), or that some veterinary clinics give advice on culling or are more involved in culling decisions. Future studies should explore the scope for greater veterinary involvement in on-farm culling decisions.

5.5 Conclusion

In this study, many cows removed from dairy farms were in the marketing system for more than 3 d before being processed. During this time the cows' body condition deteriorated and the animals developed signs of udder engorgement/inflammation and reduced fitness for transport. Unfortunately, providing such information to producers had no clear effect on subsequent culling decisions. However, an increased demand for milk appeared to lead to delayed culling that resulted in a higher percentage of cows shipped with poor fitness for transport, and in more on-farm deaths and euthanasia. Fitness for transport guidelines for cull dairy cows need to consider body condition and udder health (i.e., drying-off) in light of the long delays that can occur. Moreover, the Canadian supply-management system needs procedures that would allow increasing milk demand without causing undue delays in culling.

Table 5.1 Frequency and percentage distribution of parity of cull dairy cows (n=1,110) removed from participating farms (n=20); information about parity was missing for 61 cows

Parity	Frequency	Percent	Cumulative Frequency
1	258	23.24	258
2	268	24.14	526
3	242	21.8	768
4	173	15.59	941
5	99	8.92	1040
6	47	4.23	1087
7	13	1.17	1100
8	6	0.54	1106
9	3	0.27	1109
10	1	0.09	1110

Table 5.2 Intra- and inter-observer agreement of observers (n=9; one primary, 2 auxiliary and 6 observers at the abattoirs), including range of kappa coefficients, prevalence index (PI) and bias index (BI)

Observers/agreement	Measure	Kappa	PI	BI
Intra-observer agreement				
Primary assessor	BCS	0.54-1.00	0.76-0.84	0.00-0.08
	Lameness	0.90-1.00	0.15-0.76	0.00-0.05
	Udder condition	0.93-1.00	0.23-0.76	0.00-0.03
Auxiliary assessors	BCS	0.48-1.00	0.89-0.95	0.00-0.05
	Lameness	0.69-1.00	0.58-0.91	0.00-0.10
	Udder condition	0.92-1.00	0.23-0.78	0.00-0.03
Abattoir assessors	BCS	0.55-1.00	0.37-0.87	0.00-0.11
	Lameness	0.80-1.00	0.10-0.76	0.00-0.10
	Udder condition	0.79-1.00	0.07-0.59	0.00-0.06
Inter-observer agreement				
Primary versus Auxiliary assessors	BCS	0.47-1.00	0.82-0.94	0.00-0.07
	Lameness	0.64-0.89	0.25-0.82	0.03-0.15
	Udder condition	0.69-1.00	0.03-0.50	0.00-0.07
Primary versus Abattoir assessors	BCS	0.45-0.84	0.68-0.83	0.03-0.18
	Lameness	0.52-1.00	0.35-0.85	0.00-0.16
	Udder condition	0.49-1.00	0.15-0.71	0.00-0.12

Table 5.3 Results of logistic mixed-effects regression indicating how low body condition score (BCS≤2) varied depending on different assessment points, days in milk and parity. Data were gathered from 20 participating dairy farms by assessing all removed cull dairy cows[1]

Effect (Body condition)	Estimate	Standard Error	t	Pr > |t|	Odds Ratio (95% Confidence limits)
Intercept	-4.062	0.260	-15.65	<0.0001	.
<u>Assessment point</u>					
Placed on culling list	-0.702	0.349	-2.01	0.0444	0.50 (0.25-0.98)
Placed on shipping list (reference)	.	.	.	.	.
At auction	-0.026	0.210	-0.12	0.901	0.97 (0.65-1.47)
At abattoir	1.760	0.170	10.34	<0.0001	5.81 (4.16-8.12)
<u>Days in milk</u>					
0-100 d	1.638	0.237	6.91	<0.0001	5.14 (3.23-8.18)
101-200 d	1.679	0.237	7.1	<0.0001	5.36 (3.37-8.53)
201-305 d	0.904	0.246	3.67	0.0003	2.47 (1.52-4.01)
>305 d (reference)	.	.	.	.	.
<u>Parity</u>					
First (reference)	.	.	.	.	.
Second	0.128	0.267	0.48	0.6314	1.14 (0.67-1.92)
Third	0.511	0.256	1.99	0.0463	1.67 (1.01-2.75)
≥ Fourth	0.641	0.238	2.69	0.0071	1.90 (1.19-3.03)

[1]Number of cows reported in result section.

Table 5.4 Results of logistic mixed-effects regression indicating how severe lameness (LS≥4) varied depending on different assessment points, days in milk and parity. Data were gathered from 20 participating dairy farms by assessing all removed cull dairy cows[1]

Effect (Locomotion)	Estimate	Standard Error	t	Pr > |t|	Odds Ratio (95% Confidence Limits)
Intercept	-3.217	0.271	-11.88	<0.0001	.
Assessment point					
Placed on culling list	0.191	0.246	0.78	0.4384	1.21 (0.75-1.96)
Placed on shipping list (reference)	.	.	.	.	.
At auction	-0.999	0.234	-4.26	<0.0001	0.37 (0.23-0.58)
At abattoir	-0.074	0.212	-0.35	0.7281	0.93 (0.61-1.41)
Days in milk					
0-100 d	0.163	0.235	0.69	0.4878	1.18 (0.74-1.87)
101-200 d	0.071	0.233	0.3	0.7622	1.07 (0.68-1.70)
201-305 d	-0.190	0.236	-0.8	0.4213	0.83 (0.52-1.31)
>305 d (reference)	.	.	.	.	.
Parity					
First (reference)	.	.	.	.	.
Second	0.856	0.305	2.81	0.0051	2.35 (1.29-4.28)
Third	0.980	0.306	3.2	0.0014	2.67 (1.46-4.86)
≥ Fourth	1.409	0.284	4.96	<0.0001	4.09 (2.35-7.14)

[1]Number of cows reported in result section.

Table 5.5 Results of logistic mixed-effects regression indicating how udder engorgement and inflammation (udder condition ≥2) varied depending on different assessment points, days in milk and parity. Data were gathered from 20 participating dairy farms by assessing all removed cull dairy cows[2]

Effect (Udder condition)	Estimate	Standard Error	t	Pr > |t|	Odds Ratio (95% Confidence Limits)
Intercept	-3.633	0.221	-16.44	<0.0001	.
Assessment point[1]					
Placed on shipping list (reference)	.	.	.	.	.
At auction	-0.086	0.208	-0.42	0.6776	0.92 (0.61-1.38)
At abattoir	2.687	0.163	16.51	<0.0001	14.69 (10.68-20.22)
Days in milk					
0-100 d	1.499	0.198	7.58	<0.0001	4.48 (3.04-6.60)
101-200 d	0.507	0.217	2.34	0.0196	1.66 (1.09-2.54)
201-305 d	0.557	0.206	2.7	0.007	1.75 (1.16-2.61)
>305 d (reference)	.	.	.	.	.
Parity					
First (reference)	.	.	.	.	.
Second	0.140	0.232	0.6	0.5457	1.15 (0.73-1.81)
Third	0.673	0.223	3.02	0.0026	1.96 (1.27-3.04)
≥ Fourth	0.661	0.210	3.14	0.0017	1.94 (1.28-2.93)

[1]The assessment point ‘culling list’ was omitted in this analysis; for more details see statistical analysis section.

[2] Number of cows reported in result section.

Table 5.6 Results of logistic mixed-effects regression indicating how poor fitness for transport (fitness score of 1) varied depending on different assessment points, days in milk and parity. Data were gathered from 20 participating dairy farms by assessing all removed cull dairy cows[2]

Effect (Fitness for transport[1])	Estimate	Standard Error	t	Pr > |t|	Odds Ratio (95% Confidence Limits)
Intercept	-2.622	0.169	-15.48	<0.0001	.
<u>Assessment point</u>					
Placed on culling list	-0.714	0.219	-3.26	0.0011	0.49 (0.32-0.75)
Placed on shipping list (reference)	.	.	.	.	.
At auction	-0.383	0.143	-2.68	0.0075	0.68 (0.52-0.90)
At abattoir	1.989	0.131	15.17	<0.0001	7.31 (5.65-9.45)
<u>Days in milk</u>					
0-100 d	1.343	0.163	8.26	<0.0001	3.83 (2.79-5.27)
101-200 d	1.034	0.165	6.27	<0.0001	2.81 (2.04-3.89)
201-305 d	0.548	0.163	3.36	0.0008	1.73 (1.26-2.38)
>305 d (reference)	.	.	.	.	.
<u>Parity</u>					
First (reference)	.	.	.	.	.
Second	0.442	0.184	2.4	0.0164	1.56 (1.09-2.23)
Third	0.763	0.184	4.16	<0.0001	2.15 (1.50-3.08)
≥ Fourth	1.018	0.171	5.95	<0.0001	2.77 (1.98-3.87)

[1]Poor fitness for transport was considered when a cow had one or more of the following conditions: BCS ≤ 2, LS ≥ 4, or udder condition ≥ 2.

[2] Number of cows reported in result section.

Figure 5.1 Movement of cull dairy cows (with number of animals) from 20 participating farms located in the lower Fraser Valley region of British Columbia to livestock markets and abattoirs

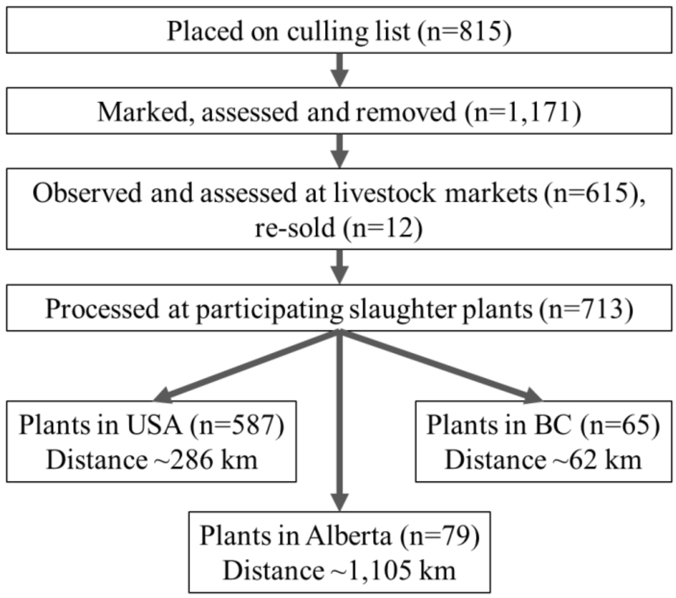


Figure 5.2 Percentage of cows that underwent different delays from the 20 farms of origin until processing at an abattoir, including the time cows spent at livestock markets, assembly and abattoir yards, expressed in days; data were gathered for 538 cull dairy cows

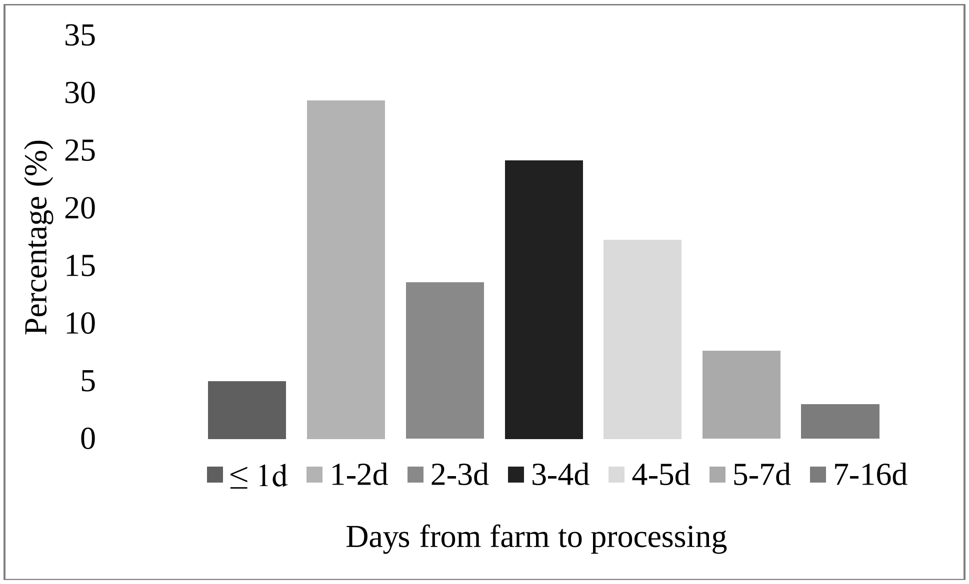


Figure 5.3 Percentage of thin cows and cows with poor fitness for transport sent to auction, and cows that died or were euthanasia on farm, during the baseline and treatment period. Data were gathered from 20 participating dairy farms by assessing all removed cull dairy cows

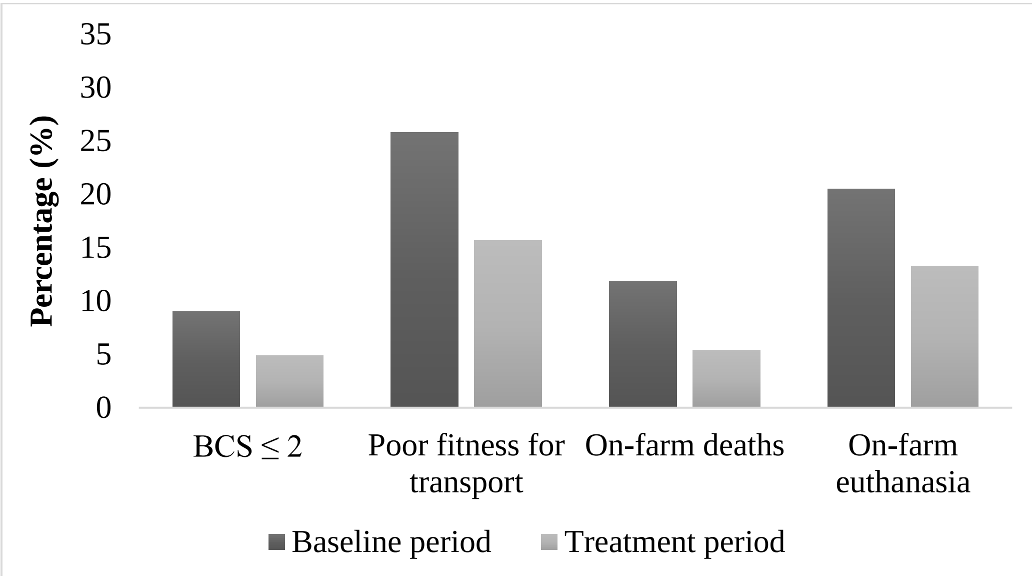
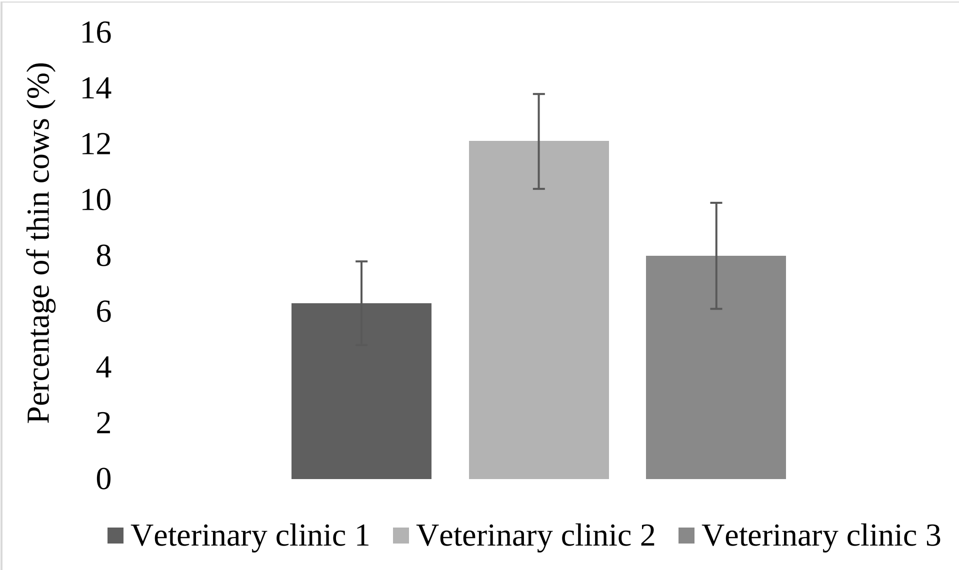


Figure 5.4 Percentage of thin cows sent to auction from 20 farms that received services from different veterinary clinics



Chapter 6: General discussion and conclusions

The research described in this thesis focused on understanding the management of vulnerable dairy cows. One aspect was improvement of recovery rates of non-ambulatory dairy cows by applying flotation therapy and identifying factors that could improve recovery. Second, the research described the diverse management of cull dairy cows in Canada using input from diverse group of stakeholders. Third, it provided a better understanding of the movement of cull dairy cows in British Columbia, farmers' culling decisions, and the condition of cows at the farm when culling decisions were reached, at livestock markets, and when they arrived at the slaughter plants. Factors that may affect farmers' culling decisions were also explored. This chapter provides an overview of the findings, discusses the limitations and proposes future studies that could clarify some unanswered questions.

6.1 Thesis findings

The literature review provided an overview of three topics that are interconnected and contribute to understanding the management of cull dairy cows. The first topic provided insight into the multiple factors that influence on-farm culling decisions such as short- and long-term factors and the farmers' management style. The second topic revealed that many health-related conditions directly or indirectly reduce the productive performance of dairy cows, influence culling and sometimes are associated with low recovery and extremely poor welfare (e.g., non-ambulatory cows). The third topic offered description of the marketing system in North America which includes transport and sale at livestock markets and transport to abattoirs for slaughter. Although some previous work provides a description of the adverse effects of the marketing system, only a few studies have reported the condition of cull dairy cows at these venues and none have quantified the overall effect of the marketing system (from farm to slaughter) on the condition of cull dairy cows (considering the condition of the cows before removal form the farm).

A large concern in the dairy industry is management and treatment of non-ambulatory cows. Therefore, Chapter 2 tested the effect of flotation therapy on recovery of non-ambulatory cows and quantified how recumbency duration and nursing care influenced recovery. The findings indicated that when flotation therapy was applied, recovery rate improved (50%). Moreover, cows that were treated sooner (within 24 h) and those that received good nursing care while recumbent, including provision of a segregated sick pen with adequate bedding, feed and water access, and regular repositioning, were more likely to recover. These findings are similar to other studies that confirmed a negative association of prolonged recumbency duration with chances of recovery (Green et al., 2008), and positive association of good nursing care with recovery of non-ambulatory cows (Poulton et al., 2016).

Chapter 3 responds to the need to describe the diverse management of cull dairy cows in a large country such as Canada and the many factors that influence the process. With this aim, a consultation meeting was convened that involved participation of experts from different sectors that are involved in management of cull dairy cows, representing several geographical regions of Canada. This meeting resulted in 9 consensus recommendations that will serve as a guide for future research and policy development. The recommendations from the expert consultation were then used to guide the methodology for the next two studies described in Chapter 4 and 5.

Chapter 4 evaluated the condition of cull dairy cows sold at livestock markets, identified the effect of changing milk demand on cows' fitness for transport, and quantified the effect of cows' condition on the price paid. About 30% of the cows sold at the markets were compromised, meaning they were thin, severely lame, had engorged or inflamed udder, or other quality defects. These conditions also reduced the price paid for these cows, particularly when the cows were thin or showed signs of sickness. During the months with increased milk demand (i.e., months with increased quota allocation or incentive days) cows arriving at livestock markets had higher odds of being compromised. The results from this study are similar to the findings from the other two studies at livestock markets in Canada (Moorman et al., 2018) and the United States (Ahola et al., 2011a, b). However, this work is the first to show an association between increased milk demand and reduced fitness for transport of removed (culled) dairy cows.

In Chapter 5, information about the duration of travel from farm to abattoir were gathered and changes in the condition of cull dairy cows were evaluated. This study also tested whether providing information to farmers about common delays to slaughter would influence their subsequent decisions to ship cull dairy cows. The study showed that most cows spent more than 3 days in the marketing system before being slaughtered. While in the marketing system cows developed reduced body condition and signs of udder engorgement and inflammation. Providing information about delays to slaughter did not influence farmer' culling decisions, but increased milk demand was associated with an increased percent of compromised cows removed from the farms; this included an increased percent of cows that were thin, severely lame, had an engorged or inflamed udder, and cows that were euthanized or died on-farm. This is the first study that measured the duration that cull dairy cows spent in the marketing system (from farm to slaughter) and quantified changes in cows' condition. In addition, the results of this study support the findings from Chapter 4 that increased milk demand influences culling decisions and fitness for transport.

6.2 Study limitations and future research directions

6.2.1 Animal-based measures and reliability

Continuous evaluation and maintenance of adequate intra- and inter-observer reliability is an important part of every study that uses subjective animal-based measures (Weary et al., 2006; Gibbons et al., 2012), particularly when studies use multiple observers over a long time and use several different locations that vary in accessibility and visibility of the animals (Gibbons et al., 2012; Vasseur et al., 2013). Studies reporting animal-based measures such as injuries, BCS and locomotion score have reported different values as thresholds indicative of high level of agreement (e.g., weighted kappa >0.60 or >0.80; Gibbons et al., 2012; Vasseur et al., 2013; Schlageter-Tello et al., 2014). Other studies have indicated unweighted kappa >0.40 as a minimum threshold and argued that kappa values should be accompanied by prevalence and bias index that would provide further explanation of kappa coefficients (Sim and Wright, 2005).

Because excellent agreement between observers was not always achieved (Chapter 5), locomotion, body condition and udder condition scores were converted into dichotomous scores that separated extreme conditions (e.g., severe lameness) from all others. This approach was adopted on the assumption that extreme conditions are so distinct that they can be identified more easily. Moreover, one previous study has reported that merging a 5-point scale to a 2-point scale (as done in Chapter 5) increased intra- and inter-observer reliability and assisted in achieving acceptable kappa values (Schlageter-Tello et al., 2014).

Merging the scales for BCS, locomotion and udder condition (as described in Chapter 5), caused large differences between the two observed categories. For example, thin cows (BCS ≤2) were relatively uncommon compared to cows with BCS >2 which made up most of the population. This prevalence discrepancy between the observed categories after merging the scales for animal-based measures can increase the prevalence index which in turn can reduce the kappa values (Sim and Wright, 2005). In addition, this approach of merging the scales reduced the resolution provided by the initial multiple-point scales and limited the ability of the study to detect changes over the entire length of the scales. This may have influenced the results of this study, particularly evaluating changes in the locomotion score.

Negative findings of lameness changes were also confounded by obstacles at the abattoirs. Specifically, the infrastructure at some abattoirs did not provide sufficient space for cows to move freely and often prevented the observers from evaluating four full strides. In other cases, large portions of the unloading track, where cows' locomotion was assessed, had rubber flooring which could improve cows' locomotion (reviewed by Cook and Nordlund, 2009).

Similar limitations were observed at livestock markets where cows received lower locomotion score compared to the score given at the farms of origin. This improved locomotion score was likely driven mainly because the livestock markets had softer (sawdust) flooring compared to the concrete floors at the farms, and involved multiple distractions (e.g., close proximity of unfamiliar handlers, novel and noisy environment) that could distract the animals' attention away from pain caused by lameness (Gentle, 2001). Because of these limitations, the data may have underestimated the number of lame cows at the livestock markets in both Chapter 4 and 5, but at the same time these results provide evidence that the prevalence of lameness in cows sold at livestock markets may be underestimated in other studies conducted in similar environments, for example studies conducted at livestock markets in Canada (Moorman et al., 2018) and the United States (Ahola et al., 2011a).

6.2.2 Milk demand and seasonal effect

The results from Chapter 4 indicated that during the months when demand for milk increased, cows sold at livestock markets had higher odds of being compromised probably because on-farm culling was delayed in order to increase milk production. Similar findings were reported in Chapter 5 where increased demand for milk probably delayed on-farm culling which resulted in removing more thin cows and cows with poor fitness for transport and increased on-farm deaths and euthanasia. However, one limitation with these findings is the inability to distinguish the effect of season versus increased demand.

Several studies have reported the effect of season on occurrence of certain diseases (Hogan et al., 1989; Sanders et al., 2009), but culling did not always follow this pattern (Pinedo et al., 2010). In some cases, disease occurrence and culling overlapped, for example lameness caused by claw horn lesions had higher incidence during the summer and fall months (Sanders et al., 2009) which corresponded with increased culling due to feet and leg problems during the same seasons (Pinedo et al., 2010). In contrast, the occurrence of clinical mastitis, which was reported to be more frequent in the summer months (Hogan et al., 1989), was not associated with increased culling in those months; instead mastitis and udder problems as causes for culling have been reported to be constant throughout the year (Pinedo et al., 2010). Moreover, culling because of diseases was reported to be constant during the entire year, while on-farm deaths were more frequent during spring and summer months (Pinedo et al., 2010).

Seasons with high temperatures tend to reduce milk production and reproductive performance in dairy cows (Ray et al., 1992; reviewed by Polsky and von Keyserlingk, 2017). To maintain milk production, dairy herds typically reduce the overall culling (Hadley et al., 2006; Pinedo et al., 2010). In Canada, to maintain constant milk production the MMB may use tools such as incentive days to increase milk production during the summer and fall months, while in the United States higher prices often stimulate increased milk production in the autumn (Hadley et al., 2006). During the studies described in Chapter 4 and 5, the Milk Marketing Board (MMB) did increase milk demand in the summer and fall months, and this, in combination with the seasonal effect, may have influenced culling decisions, as evidenced by delayed culling and increased involuntary culling. This may explain why more compromised cows were removed from participating farms and sold at livestock markets.

6.2.3 Future research directions

Reaching timely euthanasia decisions could prevent prolonged suffering of cattle that have certain health conditions (e.g., non-ambulatory cows) that are associated with poor animal welfare and low chances of recovery. Chapter 2 and other studies have indicated that prolonged recumbency and delayed treatment reduce recovery (Green et al., 2008), but in practice farmers rarely make prompt euthanasia decisions and around 40% of farms take more than 2 days to reach these decisions (USDA-NAHMS, 2016). Research is needed to understand the barriers that farmers and veterinarians face when reaching end-of-life decisions and to understand their aversion to promptly euthanize animals that would likely have poor welfare outcomes.

Cull dairy cows might develop multiple conditions before farmers reach a culling decision. However, the current dairy recording system allows recording of only a single pre-defined reason for culling, hence creating an inadequate dataset, frequently used for culling-related research (see Hadley et al., 2006; Dechow and Goodling, 2008; Pinedo et al., 2010). A limited number of studies have described the combined effect of various conditions on culling and indicated that farmers commonly report more than one culling reason if provided with this opportunity (Bascom and Young, 1998). Future research should investigate what combination of reasons/conditions contribute to culling and how these conditions influence the animals' ability to withstand transport.

Animals that are removed from farms should have good fitness for transport in order to endure the stresses caused by the marketing system. Moreover, consistent evaluation of fitness for transport among parties involved in transport is necessary to recognize compromised animals and adequately manage these animals. However, different stakeholders, particularly farmers, show large discrepancies when assessing fitness for transport (Dahl-Pedersen et al., 2018a). This indicates that research is needed to clarify ambiguities related to fitness for transport and, possibly through consultations with industry stakeholders, develop a user-friendly tool that will assist producers and industry stakeholders to consistently and accurately identify cows that are fit for transport.

6.3 General conclusion

The results from this research indicate that management of vulnerable dairy cows (i.e., non-ambulatory and cull dairy cows) is associated with reduced welfare and needs to be improved. Results in Chapter 2 provide evidence that flotation therapy is not stressful and can increase recovery of non-ambulatory cows if recumbency duration is short and if cows are provided with good nursing care while recumbent. The expert consultation meeting brought diverse experts into the discussion about management of cull dairy cows in Canada and through consensus reached 9 recommendations that will guide future research and policy on this topic (Chapter 3). Findings from the livestock markets suggest that large portion of cull dairy cows sold at the markets are compromised and sold for lower prices, particularly if they were thin or show signs of sickness. Moreover, this is the first study that showed an association between increased milk demand and reduced fitness for transport of cows sold at livestock markets (Chapter 4). By following cows from farm to slaughter I was able to map the movement of cull dairy cows in British Columbia, quantified the time they spent in the marketing system and the effect this process had on the cows' condition. Although providing information about delays to slaughter did not change farmers' culling decisions, I was able to quantify how increased milk demand in the province was correlated with the condition of cows that were removed from the farms (Chapter 5).

The findings from this research, together with the ongoing work in this area, indicate that management of non-ambulatory and cull dairy cows is a significant animal welfare concern, and underlines the importance of providing good nursing care and reaching timely and informed decisions to treat or remove cows from the herd. Considering the increased industry awareness and interest in the welfare of this vulnerable category of cattle, the results from this research should be useful for developing future practices and policies regarding management of vulnerable dairy cows.

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