The epidemiology of culling and mortality of New Zealand dairy cows

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Christopher William Raymond Compton

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Abstract

Culling of dairy cattle for non-production causes and on-farm mortality have adverse consequences for farm profitability and animal welfare. Farmers face increasing pressures to improve farm profit and to answer concerns from the public and consumers about the welfare of their animals and ethics of their management systems. Farmers in New Zealand need new information to both develop control programs to reduce losses that arise from non-production culling and mortality, and to promote and defend their farming system. Our main aims were to define the current and past trends in the incidence of culling and mortality in New Zealand dairy cows, and investigate their associated risk factors. Our secondary aims were to review the incidence of culling and mortality in dairy cattle in other modern dairy industries against which the findings from New Zealand studies could be compared, to evaluate any limitations for analysis of electronic database records of culling and mortality of New Zealand cows, and, to estimate the financial consequences for herd owners of reduced incidence of non-production culling and mortality. We found no trend over the last two decades in the incidence of culling of dairy cows, either internationally or nationally, whereas, over the same period, the incidence of mortality in cows has increased internationally, but not in New Zealand. Additionally, we identified several disorders especially common in the period immediately following calving associated with increased rates of culling and mortality; that electronic database records of cows that had been culled or died were suitable for analysis when they came from a large population, but could be biased from individual herds; and that farm profits were increased when the incidence of culling and mortality was reduced. These findings provide new information to support New Zealand dairy farmers to develop their own performance targets and control programs to reduce the incidence of mortality and non-production culling of cows.

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Preface and Acknowledgements

The background to this Thesis is a research partnership project between the New Zealand dairy industry, represented by DairyNZ, and the Ministry of Business, Innovation and Employment, named "Pillars of a Competitive and Responsible Dairy System: Improved Longevity and Reproductive Performance" [Anonymous, 2017a,b]. One aim of this project is to investigate " The prevalence of, and reasons for, premature mortality and health-related productivity losses in NZ dairy systems and how these are affected by farm management and nutrition, thereby improving the life of farmed animals and both the efficiency and sustainability of the industry." This partnership has two major components or 'pillars', namely cow fertility, and cow lifetime productivity, and it is the second of these that the work described in this Thesis contributes to. The PhD which this Thesis represents has been funded by this partnership, and is one of more than 10 programs to train emerging scientists and post-graduate students.

This Thesis is based on publications. The structure of the Thesis is centered around six chapters which describe separate studies, and these are surrounded by two chapters that firstly introduce, and then finally discuss the gathered findings. Each of these six study chapters were written originally in the style and format of a manuscript required for submission for publication in a peer-reviewed journal. An abstract and section for acknowledgements are included in each chapter as they would be submitted in a manuscript. The differences between a submitted manuscript and the format of each study chapter in this Thesis are that the tables and figures are placed within the body of the text rather than at the end, an interpretive summary has not be included as required by some publishers, a single bibliography is placed at the end of the Thesis rather than accompanying each chapter, and the spelling has been maintained as US English.

My first and deepest thanks go to my wife and greatest supporter, Jane. Jane has encouraged me daily, chided me when I have become distracted, and reminded me of why we set out on this path together. I have taken much time and energy out of our marriage and applied it to my PhD, and now look forward to redirecting that back to ourselves. I also thank my family and my friends who have shown interest in my work, and provided balance and welcome alternative activities. If you have caught some of my passion for lifelong-learning, and I know some have, then I am also encouraged.

While my family and friends have supported my life away from my workplace, my supervisors have initiated, encouraged, and enabled this Thesis to be completed, and each have contributed to the main chapters of this thesis. Professor Cord Heuer (Massey University), my Main Supervisor, has been my strongest supporter. Cord has contributed technical advice and wise counsel towards each chapter of the Thesis, and additionally assisted in reviewing articles for Chapter Two. I have especially appreciated Cord's broad and higher-level perspectives which have helped me keep my direction. Adjunct Professor, Tim Carpenter, Massey University (retired) also contributed his technical and writing skills into each chapter. I valued Tim's sage advice and keen sense of humor. Dr Scott McDougall (Cognosco, Anexa-FVC, Morrinsville), has played a part in this PhD from even before I became involved. Scott supervised Tom Brownlie, who collected the data for his PhD in 2009 and 2010, that I have now used in Chapters Three and Five of this Thesis, and provided input into the wider dairy industry partnership project that this PhD is a part of. Scott was also my previous manager at Cognosco in Morrinsville, and stirred my interest in veterinary epidemiology and encouraged me to apply for the PhD studentship for this project. I am grateful to Scott for his enduring influence on my career. Finally, Dr Claire Phyn (DairyNZ) has not only overseen my relationship with my study funders and championed our achievements, but also helped me appreciate the broad range of work contributing to the Pillars project and has tried to train my scientific writing style (will this task ever be complete?).

Several other university academics have made important technical and writing contributions to specific chapters in this Thesis, and will be co-authors on the published manuscripts. Dr Peter Thomsen, Aarhus University, Denmark, co-reviewed scientific articles for the Literature Review (Chapter Two) and contributed to writing the manuscript. His expertise in the subject area and in authoring reviews was greatly appreciated. Professors Henk Hogeveen, Wageningen University, and Mirjam Nielen, Utrecht University, both in the Netherlands, hosted me for three months and provided their expertise in animal health economics to enable me to complete Chapter Seven. Professor Mark Stevenson, University of Melbourne, assisted in preparation of Chapter Four, and in particular, the section on spatial analysis. I have also collaborated with Massey University academics on two chapters of this Thesis: Dr Carolyn Gates who wrote a software routine to efficiently create a data set to analyse trends of culling and mortality in the New Zealand dairy herds over two decades for Chapter Four, and Professor Nicolas Lopez-Villalobos, who advised on the mathematical modeling used in Chapter Seven.

Much of the data on which this Thesis is based was collected because of the work of dairy farmers and veterinary technicians. I owe a debt of gratitude to the farmers who gave of their time in to provide data for two field studies because they supported the study goals and wanted to give back to the dairy industry. I also greatly appreciate the efforts of the technicians who gathered and managed the data which I have analyzed. I also want to specifically thank Dr Tom Brownlie (LIC, New Zealand), who gathered and managed the data I analyzed in Chapters Three and Five, for his own PhD thesis.

I have also received assistance from several database software experts who helped me wrangle large data sets into a form that could be analysed. Andy Taylor (AE Software, Tauranga) worked on the data sets I used in Chapters Three, Five and Six; and Simon Verschaffelt and Richard Gilbert (Massey University) helped prepare the large data set in Chapter Four to be analysed. I am very grateful for their help.

I have relied heavily on Open Source software to complete the analyses and prepare this Thesis. My first thanks go to those who have developed and maintain the statistical software ‘R’ (R Foundation, Vienna, Austria), and the many add-on packages that I have used. The more significant software package contributors are acknowledged in the Bibliography. In particular, I have done all my work using the ‘R’ interface ‘R Studio’ (Boston, MA), and produced reports, manuscripts and this Thesis using the add-on package ‘knitr’, ‘rmarkdown’ and ‘bookdown’. This has been a ‘learning process’ for me, often challenging, but ultimately rewarding. My further thanks go to those who have developed and maintained the LaTex typographic software 'MikTex', which I used to print this Thesis.

Finally, I acknowledge and thank my PhD examiners, Ian Dohoo, John Morton, and Richard Laven, for the time and effort given by each to reviewing this Thesis and attending my examination. I appreciate their valuable insights, suggestions, and the discussions we had (and will hopefully continue to have in the future). I believe this Thesis is stronger for their input.

Chapter 1

Introduction

1.1 Background

Farmers in modern dairy industries strive to improve herd performance and production efficiency to meet their own personal goals and to be financially successful. In New Zealand new programs have been developed in recent decades for dairy farmers to achieve these goals through management of the nutritional, reproductive, replacement and udder health needs of their herds [Anonymous, 2017d]. Farmers also have many options for genetic improvement of their herds through selection of high genetic merit sires from breeding companies. Additionally, new technologies for milk harvesting, animal management and other labor-intensive tasks have reduced the demands on farmer time, thereby increasing the number of cows each labor unit can manage.

Improvements in herd culling policies provide yet further opportunities for herd improvement by removal of cows that are less productive or that have undesirable traits, or both. However, the options for improvement through breeding and culling policies are reliant on the success of the herd's programs for animal health, reproduction, and heifer-rearing to reduce on-farm mortalities and culling for non-production related reasons (i.e. due to disorders or disease), and to provide sufficient healthy and productive replacement animals. This is because when the farmer's goal is to maintain herd size, the number of cows that can be removed each year is equal to the number of replacements available, and when most or all of the cows are removed (culled or died) for non-production related disorders, little or no discretionary culling is possible that will directly improve herd quality. Therefore, animal health, replacement, and culling policies are interdependent, and their combined successes are necessary to help farmers achieve their farming goals.

Culling policies are interrelated with several other farming practices and the decisions made by farmers to cull cows are influenced by various factors. Cow-related factors are important, such as health and reproductive status, and the potential return from milk production or slaughter, but herd-related factors, such as any planned change in herd size, availability and cost of replacements and feed, and even farmer attitudes to risk, also influence culling policies [Beaudeau et al., 2000]. Hence, the incidence of culling in a herd is not just a reflection of the incidence of health and reproductive disorders. Rather, the interpretation of culling data needs to consider the management systems and other previously-mentioned factors.

1.2 Definitions

The definitions used in this chapter and elsewhere are outlined in Table 1.1.

1.3 New Zealand Dairy Industry

The New Zealand dairy industry is a key contributor to the economy and development of the nation. It contributes $7.8 billion (3.5%) to the national gross domestic product, and is the largest goods exporter ($13.6 billion in the year to March 2016) accounting for 29% of goods export earnings [Ballingall and Pambudi, 2017]. The most recent statistics for the dairy season that began in 2015 estimate that 5.0 million cows were farmed in 11,918 herds [Anonymous, 2017e]. The mean herd size was 419 cows, which equates to an approximately 30% increase over the past 10 yr. The national herd produced 20.9 billion liters of milk or 1.86 billion kg of milksolids (milk fat plus milk protein), which equates to a 47% increase in the total milk compared with that produced 10 yr previously. In the 2015 to 2016 season, mean per cow milk production was 4,185 liters or 372 kg of milksolids per lactation, which was a 17% increase on the per cow production in the season 10 yr previously.

On a typical New Zealand dairy farm, most of the cows' diets are comprised of grazed pasture and cows

Table 1.1: Definitions of common terms

Term	Definition
Culled	Animals transported from farm for immediate slaughter for human consumption. Does not include cows that either die on-farm or are sold for further dairy purposes. For some analyses cows that are sold for further dairy purposes are included among culled cows, but these instances are separately defined.
Incidence risk (IR)	The proportion (or percentage) of animals in a defined group initially free of the event of interest that experienced at least one case of the event in that defined time period. The main events of interest in this Thesis (culling, sale and mortality) could occur only once in the life of an animal in a herd, and therefore, IR was calculated as the number of cows that experienced that event divided by the number of cows at the start of the time period observed
Incidence density (ID)	The number of events of interest in a defined time period in a defined group of animals. The main events of interest in this Thesis (culling, sale and mortality) could occur only once in the life of an animal in a herd, and therefore, ID was calculated as the number of cows that experienced that event divided by the animal-time, for example, cow-years, in the time period observed
Mortality	Death of a cow on-farm. These cows may die unassisted, or be euthanized to prevent further suffering or because they are not suitable for human consumption. In some countries, but not New Zealand, separate categories are available for these two possible types of on-farm mortality
Non-production culling	Culling of an animal for any reason other than poor production i.e. almost always (apart from unsuitable temperament) due to a disorder or disease
Sold	Animals whose ownership is transferred to another farmer where they will be used for dairy production
Season	A dairy season spans the interval between the start and end of the seasonal production cycle in seasonal-calving herds, approximately from 1 June to 31 May in the following year

calve once a year in a seasonal pattern during the late-winter and early spring period [FAO et al., 2014]. This seasonally-concentrated calving pattern most closely matches the dietary requirements of dairy cattle in each stage of lactation with the seasonal pasture growth patterns, and therefore maximizes efficiency of feed production and harvesting. A small percentage of herds have other calving patterns, for example: continuous- or both spring and autumn-calving, to meet the requirements of the local liquid milk market or of specialist processors.

1.4 Specific Issues Associated with Culling and Mortality

Non-production culling (culling for reasons other than poor milk production) and mortality of cows result in reduced farm income and increased expenditure. The rate of non-production related culling is well known to be negatively associated with annual per cow revenue [Allaire and Cunningham, 1980, Van Arendonk, 1985, Meadows et al., 2005], and more current research has confirmed those findings. Moreover, the few reports from research in pasture-grazing, seasonal-calving systems [Evans et al., 2006, Lopez-Villalobos and Holmes, 2010] support those findings from work in housed, continuous-calving systems. Therefore, farmers require information on the way they can manage their herd to reduce non-production culling and on-farm mortality, as well as the financial consequences arising from any changes.

In addition, animal agriculture, including dairy farming, is coming under increasing public scrutiny of its animal welfare standards [de Vries et al., 2011], and New Zealand is not exempt from this interest [Webster et al., 2015]. This inquiry has pressured animal agriculture industries to provide evidence of high welfare standards to both promote their performance to consumers and to defend their management systems in the face of criticism from lobby groups. Both standardised individual animal-based measures, such as udder and flank hygiene, and, aggregated measures of routinely-collected data, for example, the incidence of common disorders such as lameness and mastitis, and the incidence of both culling and on-farm mortality, have been used to describe animal welfare conditions on dairy farms [de Vries et al., 2011, Laven and Fabian, 2016]. However, in the current absence of agreed animal-based measures of animal welfare in New Zealand, these aggregated herd measures become important indicators of welfare for both the dairy industry and those scrutinizing it.

1.5 Previous Steps to Address Issues with Culling and Mortality

One of the strategic goals of the New Zealand dairy industry is to "farm to high standards of animal health, welfare and well-being" [Anonymous, 2013a]. Accordingly, the New Zealand dairy industry has directed efforts to achieve this goal through research into animal health disorders and the development and extension of practical management strategies to prevent and control various diseases and disorders, and enhance animal welfare.

A considerable body of research has been undertaken in New Zealand dairy systems to increase understanding of animal disorders that adversely affect farm profitability. Much of this research has concentrated on understanding management factors and disorders that contribute to reproductive failure, and its prevention and treatment [Macmillan, 2002], particularly prolonged post-partum anestrus [Rhodes et al., 2003]. Mastitis has also attracted research attention, which built on the "Five-Point Plan" developed in the UK [Neave et al., 1969] by adding diagnostic testing criteria using milk somatic cell counts [Holdaway et al., 1996b]. While this work has recognized that increased culling is an important undesirable outcome and cost of these disorders, we could not find any published studies that investigated risk factors for mortality and non-production culling in New Zealand dairy herds, and few have specifically set out to describe these outcomes [Harris, 1989, Anderson, 1985].

Most scientific studies in the peer-reviewed literature on mortality and non-production culling were from housed, continuous-calving systems, which might not always be relevant to pasture-grazed, seasonal-calving herds in New Zealand. Housing, feeding, calving patterns and cow genetics are key components of dairy management systems that interact with animal health and production, and, therefore, also with culling and mortality. Considerable differences in these components exist between pasture-grazed, seasonal-calving dairy systems typical in New Zealand, Ireland, and some regions of Australia, and housed, continuous-calving systems, which are common elsewhere in Europe and North

America. Moreover, and perhaps because of uncertainty about the importance of these differences between farming systems, there is little evidence that findings from international research on culling and mortality have changed farm practice in New Zealand.

Notwithstanding these differences between systems, the New Zealand dairy industry has integrated knowledge from national and international sources to develop several control programs for specific disorders, with secondary goals of reducing the incidence of associated culling rates. Prominent programs include "InCalf" and "SmartSAMM" for reproductive and udder health management, respectively [Anonymous, 2017d]. No specific programs have been developed in New Zealand to control mortality, and farmers rely on best-practice animal husbandry methods to minimize mortality incidence in their herds. The development of culling policies for New Zealand farmers has been informed largely by the potential to improve genetic gain and milk production in the herd, with additional consideration of culling on history of animal health disorders. Farmers can prepare customized lists of cows, ranked on culling priority, using computer software tools offered by their animal data management company (LIC, Hamilton; CRV-Ambreed, Hamilton) to aid their decision-making.

1.6 Problems Addressed in Thesis

In this Thesis, we aimed to address an information deficit on three important themes concerned with culling and mortality of New Zealand dairy cows.

The **first theme** we identified were insufficient current New Zealand data to provide benchmarks for farmer performance, and an international context for our findings on culling and mortality of NZ dairy cows. Our first aim was to describe the subject of the Thesis. We aimed to address this in two parts: first, to define the incidence and reported causes of culling and mortality of dairy cows, both internationally and in New Zealand, and second, to evaluate the data and methods used to calculate those measures. For these purposes, we undertook four studies:

1. A systematic literature review and meta-analysis of culling and mortality in dairy cattle on

studies published in the last two decades. This work provided an international perspective on the results of analysis of New Zealand data, particularly on any trends over time, and helped to inform our own use of the terminology and measures used to describe culling and mortality. We explain how this aim was achieved in *Chapter Two*.

2. An analysis of recently-collected and historic data to describe current patterns, farmer-reported causes, and long-term trends in culling, mortality and length of life of cows in New Zealand dairy herds. For this purpose we had two data sets available: first, data previously collected in a prospective study on reproductive management in dairy seasons starting in 2009 and 2010 from herds in four regions of New Zealand, and second, data extracted from the New Zealand Dairy Industry Database of registered cows in herds in dairy seasons between 1990 and 2013. We detail how this aim was achieved in *Chapter Three* and *Chapter Four*

3. An investigation of different methods to measure culling and mortality, and to recommend methods that would meet the needs of dairy farmers to measure culling and mortality. To achieve this aim, we analyzed data collected from the previously-mentioned study in 2009 and 2010 to investigate possible biases in different methods to calculate incidence. This work is explained in *Chapter Three*.

4. An evaluation of the suitability of farmer-reported electronic records extracted from the New Zealand Dairy Industry Database for our analyses. To achieve this, we undertook a prospective field study to describe, and if possible, validate electronic records of culling and mortality against permanent on-farm records. This work is described in *Chapter Six*.

The **second theme** we addressed was inadequate information on the relative importance of different risk factors for mortality and non-production culling to develop and prioritize animal health management programs. To achieve this we undertook two studies:

1. An analysis of manageable cow-level risk factors for culling and mortality of New Zealand dairy

cows using data from the study in 2009 to 2010, which also included individual animal treatment records. This analysis is described in *Chapter Five*.

2. An analysis of herd-related factors from the New Zealand Dairy Industry Database associated with the incidence of culling and mortality and their spatial distribution, as described in *Chapter Four*.

The **final theme** we addressed was the lack of information on the financial consequences to farmers from changes in animal health management that would reduce the incidence of mortality and non-production culling. To achieve this, we used a mathematical simulation model to estimate the change in dairy operating profit that would result from realistic reductions in the incidence of culling and mortality for a typical New Zealand dairy farm. This information can provide a basis for financial justification to farmers of animal health management programs. This study is described in *Chapter Seven*.

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STATEMENT OF CONTRIBUTION
TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: C.W.R Compton

Name/Title of Principal Supervisor: Professor C. Heuer, Massey University

Name of Published Research Output and full reference:
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In which Chapter is the Published Work: Chapter 2

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate: 90%

  and / or

- Describe the contribution that the candidate has made to the Published Work:

CWR Compton

Candidate's Signature

22 Sep 2017

Date

Principal Supervisor's signature

22 Sep 2017

Date

GRS Version 3– 16 September 2011

Chapter 2

A systematic literature review and meta-analysis of mortality and culling in dairy cattle

ABSTRACT

Dairy industries and individual farmers are concerned about mortality and culling of dairy animals. This is because the timing and fates of animals that exit dairy farms have important animal welfare and economic consequences that reflects the conditions under which they are farmed, and the efficiency of their production systems. Reports from a few countries have indicated increased incidence of mortality, and occasionally culling, of dairy animals in recent decades, and these changes have been associated with intensification of productions systems. Dairy industries and farmers need benchmarks for culling and mortality against which they can compare themselves, as well as improved understanding of the extent of any change over time, and of any associated factors associated with a change. We reasoned that a systematic literature review and meta-analysis of scientific articles published between 1989 and 2014 would allow us to determine whether these reports were universal, to quantify any change over time, and to investigate whether production system or study factors were associated with culling and mortality. From a total of 3,275 articles retrieved from database and manual searching of cited articles, 118 articles were appraised independently by 2 reviewers and 51 articles representing 54 studies were assessed as eligible for review and meta-analysis. We estimated that both the annual incidence risk (**IR**) and incidence density of mortality of cows had increased significantly from 0.02 per cow and 2.32

per 100 cow-yr, to 0.04 per cow and 3.75 per 100 cow-yr, an increase per decade of 0.02 per cow and 1.42 per 100 cow years, respectively. We also estimated that the annual IR of culling attributed to low production had declined significantly from 0.07 to 0.05 and, that the IR of perinatal mortality of calves had increased significantly from 0.04 to 0.06, per decade. We found no evidence of change in overall annual IR of culling of cows over time, or any association between study design factors and the IR or incidence density of culling or mortality. These findings provide benchmarks for describing culling and mortality, and should encourage farmers and researchers in countries with modern dairy industries to discover and implement management strategies to reduce the animal welfare and economic costs associated with these changes.

Key words: dairy cow, dairy replacement, culling, mortality

2.1 INTRODUCTION

Culling or mortality is inevitable for all dairy animals, as they must, ultimately, either exit the herd for slaughter or sale, or die on-farm. Thus, while these events are inevitable and common, understanding their extent and causes at the herd or industry level is challenging. This is because culling and mortality are influenced by economic, social, management, and, animal disease factors. In turn, non-production culling and mortality have important adverse economic and animal welfare consequences. Net farm revenue is affected by costs incurred from rearing and purchase of replacements, and milk income is affected by replacement rate, because, on average, replacements produce less milk than the animals they replace [Renkema and Stelwagen, 1979, Rogers et al., 1988]. High and sustained rates of culling, and in particular, mortality, are also indicators of poor welfare status [de Vries et al., 2011]. For these reasons, an accurate quantitative description of culling and mortality within and across different dairy production systems, provides a foundation for understanding, extension, and further research.

Several authors have reported an increased incidence of mortality, and occasionally, of culling, over the last two to three decades, in dairy production systems in North America and Europe. For example, Thomsen et al. [2004] concluded that the lactational incidence risk (**IR**) of mortality of dairy cows in Denmark had increased between 1990 and 2001, and de Vries et al. [2010] reported increased culling rates in large dairy herds in the Eastern United States between 2001 and 2006. Furthermore, an increase in the incidence density (**ID**, sometimes known as the incidence rate) of mortality in Swedish cows was associated with intensification of that industry, as measured by increased herd size and average per cow milk production [Alvasen et al., 2014b]. However, it is unknown whether these reports are representative of other regions or countries, but we reasoned that these reported changes would also be reflected in other countries which have increased milk production and herd size in recent decades.

Development of control programs to mitigate against any such changes will require that they are quantified, and where it is valid to do so, knowledge of contributing causes of culling or mortality transferred between production systems. Systematic reviews (**SR**) and meta-analyses (**MA**) are methods suited to provide this information. They aim to review and summarise primary (original) literature on a topic [Sargeant and O'Connor, 2014, O'Connor and Sargeant, 2015], so as to provide a readily-available source of information on which to base actions in the practice of evidence-based medicine, or to direct policy decisions [O'Connor and Sargeant, 2014]. Systematic reviews and MA of observational studies are less common than those for randomized clinical trials, in part because of the inherent biases and differences in study methods used by epidemiological researchers [Egger et al., 1998]. However, MA can not only provide summary measures of, for example, prevalence of a disorder, but also investigate through the use of meta-regression (**MR**), the effect of moderator variables, such as study population characteristics or design features, on the results. We reasoned that we might identify by the use of MR, a positive association between the incidence of culling and mortality, and both the year of data collection in reviewed studies, and, measures of intensification of production systems, such as mean per cow milk production and herd size.

The main aim of this SR-MA was to investigate any change in the incidence of mortality or culling of dairy animals, reported in population-based studies from modern production systems, and published between 1989 and 2014. We also aimed to determine if the incidence has been modified by changes in their production systems, and, if study design features had affected the results reported.

2.2 MATERIALS AND METHODS

2.2.1 Scope of Review

Only articles from countries with modern dairy production systems were considered, because results of a preliminary database search of scientific articles were mainly from these countries, and other systems were considered so dissimilar, that results from others could not be reasonably compared. For this review, countries with modern production systems were defined as those that typically farmed Holstein-Friesian, Norwegian Red, Brown Swiss, Ayrshire, or Jersey dairy breeds [pages 130 to 131 in FAO et al., 2014], and included mainly countries in the European Union, North and South America, and Australasia. The publication time period was chosen to allow sufficient duration to allow us to identify any change over time. The outcome measures we considered were the IR and ID of mortality and culling, and length of productive life (**LPL**). Sale of animals was not specifically considered, except where it was combined with either culling or mortality, or both, and the categories could not be separated. This was because sale of animals for further productive purposes was considered an economically favorable choice made by the owner, and sale has few, or very few, adverse effects on the welfare of animals. Only female dairy animals were considered in this review, except for the results of perinatal mortality, where data from these studies usually reported both male and female calves combined.

2.2.2 Definitions

The main outcomes and definitions were: culling (removal of a live cow from the farm for immediate slaughter), sale (movement to another farm for future dairy purposes, and assumed to exclude temporary ownership by traders who subsequently send animals for slaughter), and, mortality (death of an animal on the farm, whether euthanized or unassisted). The use of these terms varied among articles in this review, but, where possible, their findings were categorized according to these definitions so they were comparable.

The definitions of the outcome measures used to quantify culling and mortality also varied among articles. The definitions we used for IR and ID were those commonly applied in epidemiological studies [Dohoo et al., 2009, pg 77]: $IR = \frac{X}{N}$, where X is the number of newly affected individuals in a defined period of time, and N is the number of animals in the population at risk of the condition; and $ID = \frac{X}{T}$, where X is the same as defined for IR, and T is the number of animal-time units at risk during the observed period. The definition of LPL was the interval between first calving and culling or death.

The age categories for animals used for description of articles in the SR were: calves (pre-weaned), heifers (weaning to age at first calving), and cows (calved at least once). Calves were further categorized for MA-MR as perinatal (full term birth to day 2 of life) or neonatal (day 1 of life to weaning). Sufficient data were available on causes attributed to culling of cows to be grouped into the three most frequent categories: udder-related (mastitis, high SCC, teat injuries), reproduction (not pregnant, reproductive disease causing infertility), and production (low milk production).

2.2.3 Identification of Literature for Review

Literature search. The electronic literature databases searched were: Web of Science (http://wokinfo.com/, including CAB Abstracts, MEDLINE, Biological Abstracts, Web of Science Core Collection) and Scopus (www.scopus.com/). These databases were chosen because they have high coverage rates of veterinary journals and others with significant veterinary content [Grindlay et al., 2012]. Scientific articles (both peer-reviewed and non peer-reviewed) and conference proceedings, written in English; or written in Spanish, French or German, if their titles or abstracts were in English; were eligible for appraisal. The literature search ceased in December 2014. The population search terms were: dairy, cattle, calf OR calves, replacement, heifer OR heifers, cow OR cows, bovine. The outcome search terms were lifetime OR life-time OR survival OR survivorship OR culling OR removal OR death OR dead OR died OR loss OR fatality OR mortality OR euthanasia OR euthanized OR sale OR sold OR loss OR longevity OR disposal OR stayability OR productive life OR functional life.

Screening and Appraisal of Articles. Primary screening of articles was based on information in the title and abstracts to three questions: “Are the words in the title or abstract, or both, directly related to or included in the main study aim?", "Does the title or abstract, or both, describe an original research study (as opposed to a review)?", and, "Was measurement of an outcome of interest (e.g. mortality, culling, etc.) an important objective of the study?" Only articles with a positive response to all 3 questions were eligible to proceed to the next stage. Primary screening of every article was undertaken by the first author (C.W.R. Compton) and the reasons for inclusion and exclusion and their frequency summarized using a flowchart. Additionally, a manual search was undertaken in articles passing the primary screen of further articles cited by their authors. The search strategy was assessed by checking references from the 10 most recent articles on the topic and checking back against articles identified by the search strategy, and by checking the 10 oldest articles and citation-searching forward.

Where two or more companion articles reported on the same study, the year of publication of the last-published paper was taken as the year for deciding on inclusion. In cases where a study published in a non peer-reviewed source was also published in a peer-reviewed source, the latter was preferred for assessment. Where two articles reported the same study, the later published article was preferred, except where additional new material was provided in the earlier article, in which case it was considered independently. Articles that focused on risk factors for culling or mortality were considered, where incidence or productive life were also reported.

During secondary screening of articles we aimed to appraise how completely the methods were described, and the risk of bias in the results arising from the design and conduct of the study. The appraisal tool used to assess each article for inclusion in the review was in the form of a checklist (Appendix, Table 1) and was based on those of Sargeant and Del Rocio Amezcua [2005] and Sanderson et al. [2007]. Most elements required a "Yes" or "No" response, except for some for which a "Not applicable" response was possible because the element was not relevant. Finally, the reviewers indicated whether or not the article was eligible for inclusion in the review. The article appraisal tool was pre-tested by all reviewers on 6 articles and minor modifications made to the responses allowable for some questions. Each article was appraised by two reviewers (C.W.R. Compton and P.T. Thomsen), except where a reviewer was also an author of the article. In these cases, and when differences occurred between the first two reviewers as to whether or not the article was eligible, a third reviewer (C. Heuer) appraised the article, and the majority finding was final.

Studies not excluded at the primary or secondary screening formed a preliminary final set of articles for review. The authors of articles from which additional data were required for meta-analysis were contacted and these data requested. Articles that did not require additional data, and those for which an author provided the requested data formed the final set of articles for review.

2.2.4 Data Management

The year the results were collected in was included as a continuous variable in the MR models. When data was collected over more than 1 year, and the annual results were not available, the results were combined and the median year of data collection used for MA-MR (Table 2.1). Study design characteristics were used as possible moderator variables in subsequent MR, and were categorized by their type (prospective, retrospective, cross-sectional), the main aim of the study (descriptive, analysis of risk factors, or a combination of both), the sample selection method (census, convenience, randomized, restricted by design, self-selection or a mixed selection method), the source of the data (primary, i.e. actively collected by the researcher for the purpose of the study, or secondary, i.e. data originally collected for other purposes), and, the persons responsible for attributing the cause of culling or mortality (farmer, veterinarian, or results from a necropsy).

The data required for MA-MR depended on the outcome measure. For IR, we extracted both the number of cases in the defined time period and the number of animals in the population at the start or end of the observation period; and for ID, both the number of cases in the defined time period and total animal-time at risk. For LPL, both the mean and its standard deviation were required. Where the data available in an article were not immediately suitable for meta-analysis, they were reconstructed. For example, when the IR of culling was reported as a percentage, and the population at risk was known, then the number culled was the multiple of the IR and the population at risk. Where an IR was reported with a standard error, for example the USDA report [2007], the standard error of the IR (a proportion, p) was used to estimate the number of animals at risk (n), by re-arranging the formula $SE_p = \sqrt{\frac{p\times(1-p)}{n}}$ to $n = \frac{p\times(1-p)}{SE_p^2}$; and the number of culls estimated as described previously. When we could not reconstruct data for meta-analysis, we requested additional data from the authors of the articles. Where these data were provided, those studies were included in the meta-analysis, otherwise, they were excluded.

Data on the attributed causes of culling or mortality were only considered for meta-analysis when the IR or ID for that particular cause was either reported or could be reconstructed from the data. In this way, comparisons between the findings of different studies were possible, which is not the case when causes of removal are only reported as proportions without an overall population incidence.

Extracted data were entered into and managed in a custom-built Microsoft Access database (Version 2010, Redmond, WA, USA).

2.2.5 Analytical Methods

Bias Assessment. The results of the qualitative assessment of four elements from appraisal of the articles (Appendix, Table 2, sections 2a, 4a, 4b and 5a) relevant to selection or information bias were used to form a composite score to assess the risk of bias in each article. Individual reviewer appraisal scores for the risk of each element to contribute to bias were on a binary scale ("No" or "Yes"). Where there was agreement between the reviewers, that finding was reported, otherwise the finding was "unclear".

Meta-Analysis and Meta-Regression. Separate MA-MR were undertaken for each combination of alike outcome, outcome measure, and age or parity group, using R statistical software (version 3.2.2.; R Foundation for Statistical Computing, Vienna, Austria) and the R package "metafor" version 1.9-7 [Viechtbauer, 2010]. The main outcome measures (IR or ID) were calculated for each study and double arcsine transformed [Freeman and Tukey, 1950] to stabilize their variances for meta-analysis and meta-regression. Point estimates and confidence intervals were transformed for display in forest plots. Symbol sizes of the study estimates were drawn in proportion to their precision, and thus dependent on sample size. We used random mixed effects models for meta-regression because we believed it implausible that the incidences of culling and mortality would be constant across studies and years, and because we wanted to make an inference from our results to a larger set of studies, from which the studies included in the current MA-MR were assumed to be a random sample [Hedges, 1998]. Data from studies that reported multiple years of results were considered correlated. Therefore, for analysis of these datasets, a separate random effect term for each study-year, with a compound symmetry correlation structure, was added [Konstantopoulos, 2011]. Thus, depending on the data available for each MA-MR, data was structured in either a 2-level (no years within study data, lowest level was the within study-year variance, highest level was the study variance), or 3-level model (years within study data available, lowest level was the within study-year variance, middle level was the years within study, highest level was the study variance). An aim of the analysis was to investigate the effect of study-level moderator or predictor variables on the outcomes, and hence these factors were consisered in the MR models. Mathematical notation of the 3-level MR model with p predictors included at the second level is shown as:

$$\vartheta_{ig} = \beta_{0g} + \beta_{1g}X_{1ig} + \ldots + \beta_{pg}X_{pig} + \eta_{ig} + e_{ig}$$

where ϑ_{ig} is the unknown IR or ID which varies around a level-3 unit g mean, $X_{1ig}, \ldots, X_{pig}$ are study-specific predictors (e.g., year of data collection), $\beta_{0g}, \beta_{1g} \ldots \beta_{pg}$ are unknown regression coefficents that need to be estimated, η_{ig} is a level-2 random effect term with distribution $N\left(0, \tau^2\right)$, where τ^2 is the residual variance, and, e_{ig} is the level-1 error term with distribution $N\left(0, v_i\right)$, and v_i is the variance of the effect size estimate. The level-3 unit means are estimated from the overall mean and level-3 unit specific random effect: $\beta_{0g} = \gamma_{00} + \nu_{0g}$, where γ_{00} is the overall mean and ν_{0g} are the level-3 unit random effects.

The effect of possible moderator variables and the level-2 random effect term were examined in each model by manual forward stepwise addition, and retained when Wald-type and likelihood ratio tests, respectively, for their addition, were significant ($P< 0.05$). All excluded variables were re-entered to the model as a final check of their statistical significance. Plots of influential studies were available for each simple random effects model, and these were assessed by visual inspection of the studentized residuals and Cook's distances, for the effect of individual studies on heterogeneity and model fit, respectively. Influential studies were identified from diagnostic plots, and, by determining whether model coefficients changed by more than 15% when the study was removed from analysis. Final meta-regression models were used to predict mean effects of any retained moderator variables and their 95% confidence intervals, and the point estimates and confidence intervals added to forest plots. Funnel plots of the transformed proportion against the standard error of each model were investigated for assymetry which might have been evidence of missing studies due to publication bias [Egger et al., 1997] and heterogeneity among studies [Egger and Davey Smith, 1998]. Meta-regression was only undertaken when there were at least 5 studies with the same outcome and measure, and among the same age or parity group, in order to reduce the risk of unreliable estimates.

2.3 RESULTS

2.3.1 Description of Articles and Studies

From a total of 3,275 articles retrieved by electronic database and manual searching, 4% (n = 118) were assessed as potentially relevant from the primary screening. Of those, 53% (n = 63) were appraised as eligible for inclusion in the review from the secondary screening. A further 19% of articles (n = 12) did not have, or their authors could not provide, suitable data for meta-analysis. The final review set consisted of 51 articles reporting 54 studies (Figure 2.1). A total of 34 and 26 studies reported on findings of cows, and calves or nulliparous heifers (or both calves and nulliparous heifers), respectively. Culling and mortality were measured in 22 and 47 studies, respectively, whilst 5 studies reported LPL. The main characteristics of the reviewed studies, ordered by year of publication, and their design features are summarized in Tables 2.1 and 2.2.

2.3.2 Assessment of Risk of Bias

The risk of bias in the results from each of the studies included in the review was assessed as low from each of the following: selection of the source population and sampling methods (80% of studies), definition of outcome variables (96% of studies), measurement of the outcome variables (96% of studies), and, methods of statistical analysis (84% of studies). (See Appendix Table 2)

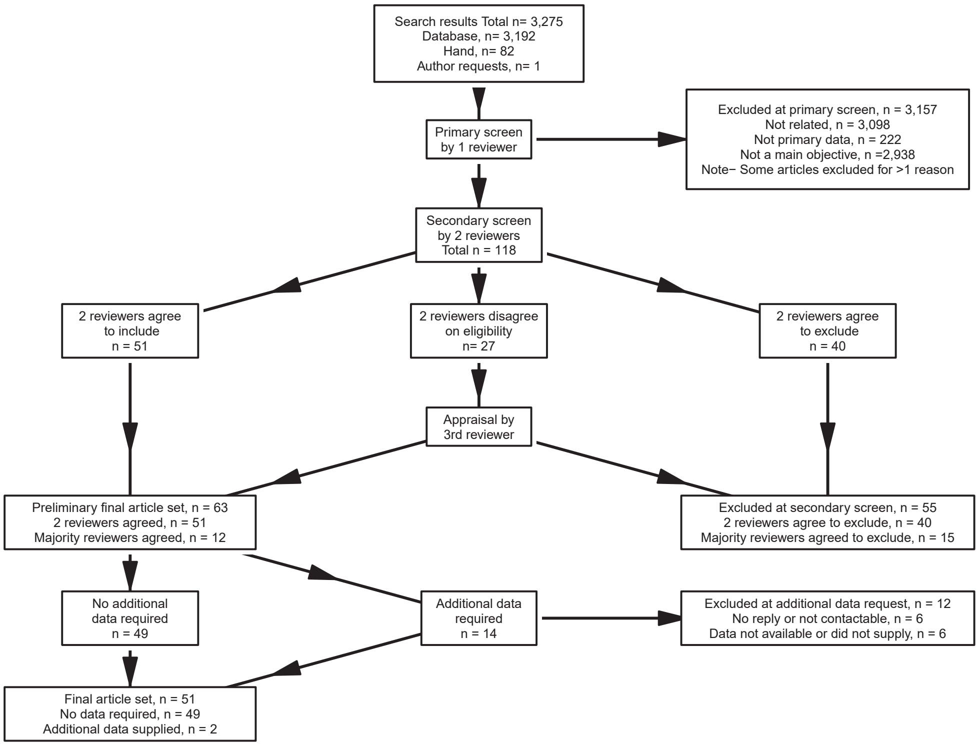

Figure 2.1: Flow chart of selection of articles for systematic review

Table 2.1: Summary of 54 studies from 51 articles included in a systematic review and meta-analysis of culling and mortality in dairy animals, sorted by year of publication

Author(s) and year	Country	Age group[1]	Aim[2]	Outcome[3]	Period[4]	N herds[5]	N animals[6]
Milian-Suazo et al 1988	USA	A	D	C, M	81-85	34	7,763 **
Bendixen & Astrand 1989	Sweden	A	D	C, M	70-74	950 *	21,266
Gardner et al 1990	USA	CHA	D	C, M	86-87	43	15,246
Perez et al 1990	The Netherlands	C	M	M	86-87	63	1,037
Agger & Willeberg 1991	Denmark	A	D	M	90	NA	760,000
Olsson et al 1993	Sweden	CH	M	M	87-88	131	5,050
Olsson et al 1993	Sweden	CH	D	M	87-88	131	885
USDA 1993	USA	CH	M	M	91-92	1,811	21,516
Beaudeau et al 1994	France	A	R	C	86-90	47	3,671
USDA 1994	USA	CH	M	M	92	921	11,674
Menzies et al 1995	UK	A	D	M	92	NA	273,935
Sivula et al 1996	USA	C	M	M	91-92	29	845
USDA 1996	USA	CHA	M	C, M	95	2,542	23,424
Durr et al 1997	Canada	A	D	C, M	79-94	NA	1,558,080
Seegers et al 1998	France	A	D	C, M	88-94	79	5,133
Stevenson & Lean 1998	Australia	A	M	PL	92-94	8	1,642
Rajala-Schultz & Grohn 1999	Finland	A	R	C, M	93	2,338 *	38,228
Meyer et al 2001	USA	C	M	M	85-96	NA	66,341
USDA 2002	USA	CHA	M	C, M	01	2,461	19,858
Thomsen et al 2004	Denmark	A	D	M	90-01	NA	7,206,629 ***
Whitaker et al 2004	UK	A	D	C, M	98-02	219	52,725
Hadley et al 2006	USA	A	M	C, M	95-99	NA	7,087,699 ***
Pryce et al 2006	New Zealand	C	R	M	87-04	NA	773,904
Svensson et al 2006	Sweden	C	M	M	98-00	122	8,964
Thomsen et al 2006	Denmark	A	R	M	00-01	6,839	458,213
Lopez de Maturana et al 2007	Spain	A	R	PL	95-02	781	25,810
Schneider et al 2007	Sweden	A	R	PL	88-96	15,234	978,780
Sogstad et al 2007	Norway	A	R	C	02	112	2,645
USDA 2007	USA	CHA	M	C, M	06	1,077	19,600
Dechow and Goodling 2008	USA	A	D	C, M	05	2,574	221,832
Hultgren et al 2008	Sweden	CH	M	C, M	98-01	122	3,081
Maher et al 2008	Ireland	A	D	C, M	03-06	NA	4,218,737
Mee et al 2008	Ireland	C	M	M	02-05	NA	182,026
Gulliksen et al 2009	Norway	CH	M	M	05	14,474	289,038
Hultgren & Svensson 2009	Sweden	A	R	PL	98-06	109	2,124
de Vries et al 2010	USA	A	M	C, M	01-08	727	2,345,015
Fuerst-Waltl & Sorensen 2010	Denmark	CH	D	M	98-07	NA	843,774
Pinedo et al 2010	USA	A	M	C, M	01-06	2,054	14,000,000 *
USDA 2010	USA	C	M	M	06	1,077	8,271
Ahlman et al 2011	Sweden	A	R	PL	98-09	5,737 *	316,173 *
Burow et al 2011	Denmark	A	R	M	08	391	33,747
Perrin et al 2011	France	CHA	D	M	03-09	NA	34,149,668
Raboisson et al 2011	France	A	D	C, M	05-06	198,399	7,581,000 **
Alvasen et al 2012	Sweden	A	M	M	02-10	6,898	41,352
Alvasen et al 2012	Sweden	A	M	M	09-10	4,252	264,352
USDA 2012	USA	CH	M	M	10	228	1,749
Walker et al 2012	USA	C	M	M	06	48	14,448
Gates 2013	UK	CHA	M	C, M	07	10,243 *	1,306,468
Raboisson et al 2013	France	CH	M	M	05-06	193,897	6,997,093
Zucali et al 2013	Italy	C	R	M	09	28	739
Alvasen et al 2014	Sweden	A	R	C, M	08-09	2,084	206,752
Mohd Nor et al 2014	The Netherlands	A	M	C, M	07-10	1,903	157,949
Santman-Berends et al 2014	The Netherlands	CH	R	M	09-10	18,387 *	625,977
Santman-Berends et al 2014	The Netherlands	CH	R	M	10	236	7,552

[1] A = adult cows (calved >= 1 times), H = heifers (age: weaning to first calving), C = calves (age: birth to weaning), multiple letters denote a combination of ages

[2] Main study aim: D = descriptive, R = risk factor analysis, M = mixed

[3] Main study outcomes measured: C = culling, M = mortality, PL = productive life

[4] Data collection period (yr)

[5] Number of herds analyzed (asterisk denotes number of herds selected for the study where the number analyzed was not stated, NA = not available)

[6] Number of animals analyzed (1 asterisk = number of animals selected, 2 asterisk = number of lactations analyzed, 3 asterisk = number of lactations selected)

Table 2.2: Summary descriptive statistics of design features[1] of 54 studies from 51 articles included in a systematic review and meta-analysis of culling and mortality in dairy animals

Study feature	n (%)	N
	N=54	
Study design:		54
Cross-sectional	1 (2%)	
Prospective	17 (31%)	
Retrospective	36 (67%)	
Data source:		54
Mixed		
	1 (2%)	
Primary	24 (44%)	
Secondary	29 (54%)	
Sample selection method:		54
Census	12 (22%)	
Convenience	6 (11%)	
Mixed	1 (2%)	
Random	9 (17%)	
Restricted	25 (46%)	
Self-selected	1 (2%)	
Denominator definition:		54
ID Std	12 (22%)	
IR Std	20 (37%)	
IR StrtMinHlfRm	2 (4%)	
IR Avg	6 (11%)	
IR PdEndInvnt	3 (6%)	
IR PdClvd	5 (9%)	
NotApplic	5 (9%)	
IR PdLctEnd	1 (2%)	
Data validated	12 (24%)	51
Causes of exit defined	5 (10%)	51

[1] Cross-sectional = measurements made at a single point in time, Prospective = measurements taken as time progressed during study, Retrospective = measurements taken prior to start of study, ID = incidence density, IR = incidence risk, ID Std = Sum of animal-time in risk period, IR Std = number of animals at start of risk period, IR StrtMinHlfRm = number of animals at start less half of the animals removed in the risk period, IR Avg = average number of animals in the risk period, IR PdEndInvnt = number of animals at the end of the risk period, IR PdClvd = number of cows that calved in the risk period, NotApplic = not applicable as not a ratio measure e.g. productive life, IR PdLctEnd = number of animals ending a lactation in the risk period

2.3.3 Meta-analyses and Meta-regressions

Tests for residual heterogeneity (Cochran's Q test) of meta-analysis in all final models were highly significant ($P < 0.001$), and Higgins I^2 were approximately 100% in all instances (Appendix, Table 3). These findings indicated significant variation among studies that was not accounted for by the moderator variables and that almost all the variation across the studies in each MR was due to heterogeneity rather than chance. Therefore, no overall summary measures were reported, rather individual study, and where calculated, predicted effects, were used in forest plots. There was no indication of publication bias from visual examination of funnel plots of all final models (not shown), although the usefulness of this assessment was limited by the heterogeneity among studies.

Adult Cows. A total of 25 years within study (median =1 and maximum = 11 years per study) and 12 studies were analysed for annual IR of mortality. Figure 2.2 indicates a range of annual IR of mortality between approximately 0.02 to 0.08, and an apparent increase over time. The final MR model predicted that the annual IR of mortality of cows increased in the decade between 1990 and 2000 by an absolute 0.02. A total of 15 years within study (median =1 and maximum = 8 years per study) and 7 studies were analysed for annual ID of mortality. Similarly to IR of mortality, the ID of mortality of cows was predicted to have increased in the same period by 1.42 cases per 100 cow years (Figure 2.3).

A total of 11 years within study (median =1 and maximum = 4 years per study) and 8 studies were analysed for annual IR of culling. The annual IR of culling varied between 0.14 and 0.28, and no evidence of overall change in IR over time is apparent in the forest plot (Figure 2.4). No inferences were made from a meta-regression model of the annual IR of culling because one study [Gates, 2013] was influential. Similarly, the results from studies that combined the IR of different outcomes reveal no discernible change over time (Figure 2.5). The effect of year of data collection was not significant in the MR models for culling and mortality (12 years within study (median =1 and maximum = 5 years per study) and 5 studies); and culling, mortality and sale (10 years within study (median =2.5 and maximum = 4 years per study) and 4 studies) combined ($P = 0.085$ and $P = 0.678$, respectively).

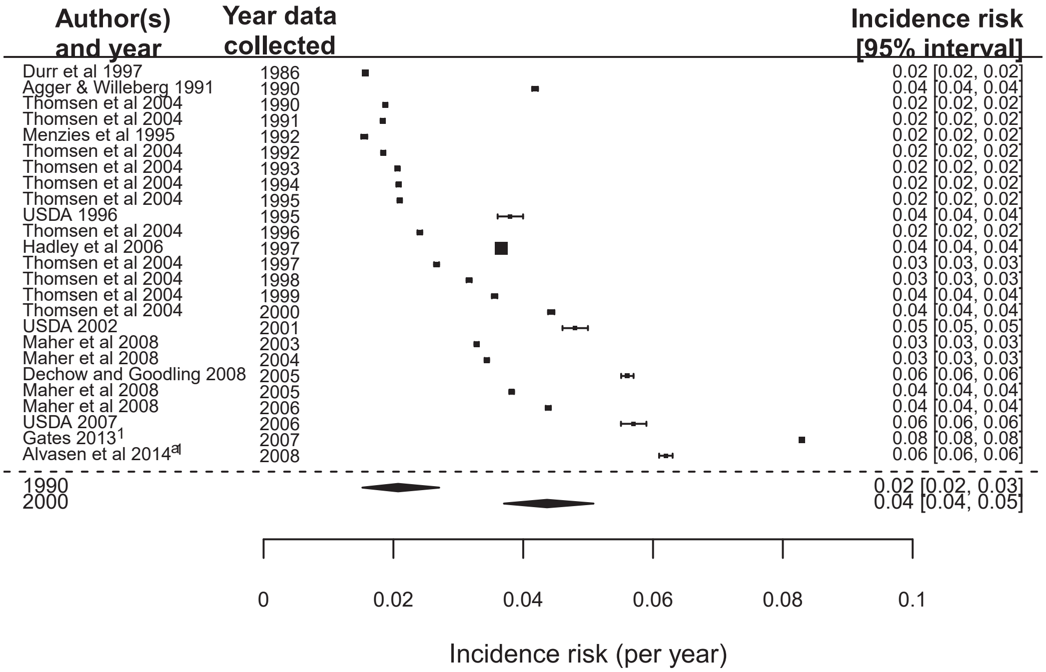

Figure 2.2: Annual[1] incidence risk (■) and 95% CI of mortality of cows in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision). Predicted annual incidence risk (◆) and 95% CI of mortality at different levels of moderator variables from the meta-regression model are plotted below the dashed line ([1]result measured per lactation)

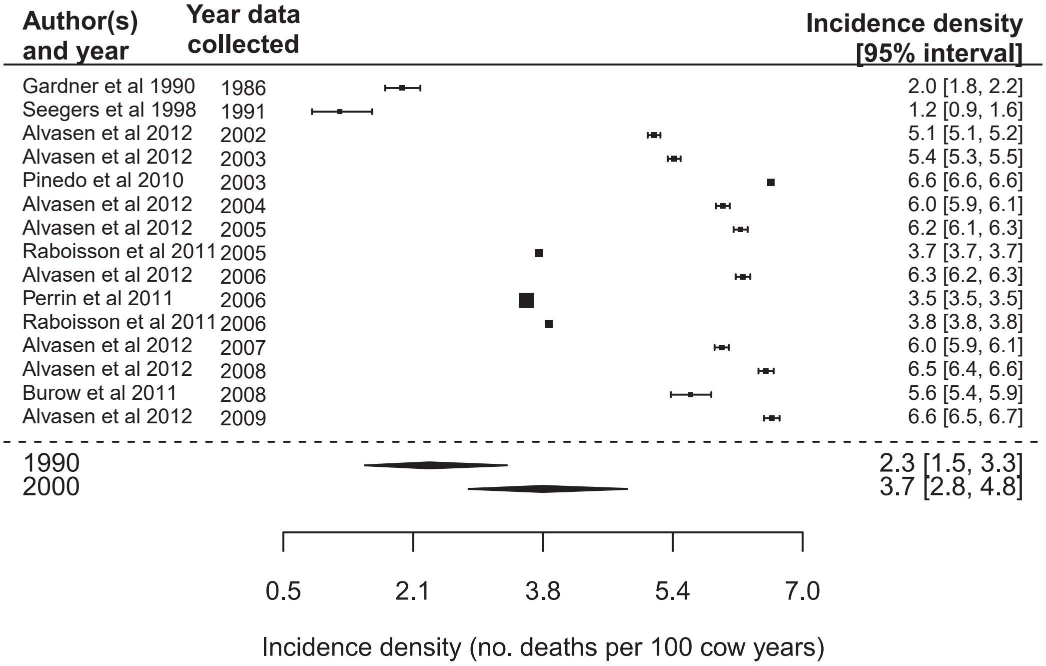

Figure 2.3: Incidence density (■) and 95% CI of mortality in cows in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision). Predicted incidence density and 95% CI ♦) of mortality at different levels of moderator variables from the meta-regression model are plotted below the dashed line

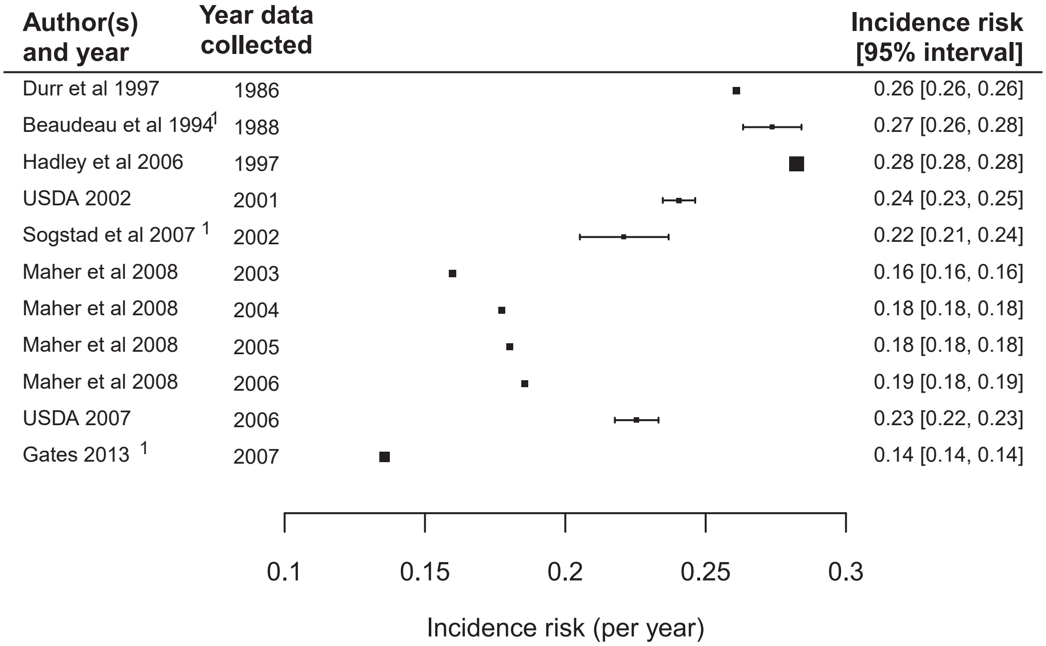

Figure 2.4: Annual[1] incidence risk (■) and 95% CI of culling of cows in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision) ([1]result measured per lactation)

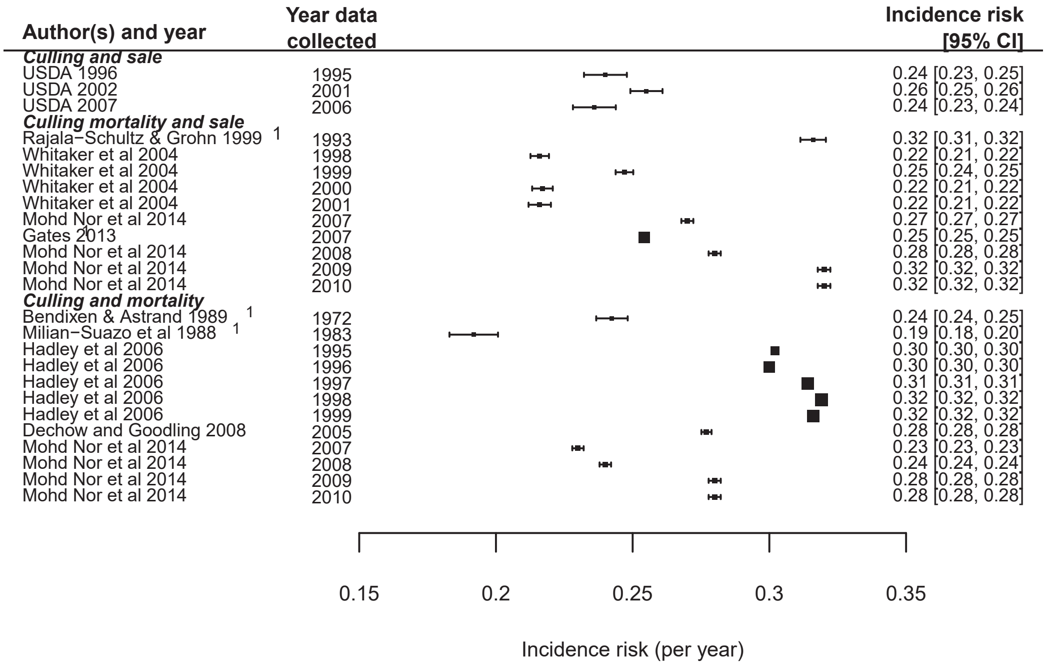

Figure 2.5: Annual[1] incidence risk (■) and 95% CI of culling and sale; culling, mortality and sale; and culling and sale in cows in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision) ([1]result measured per lactation)

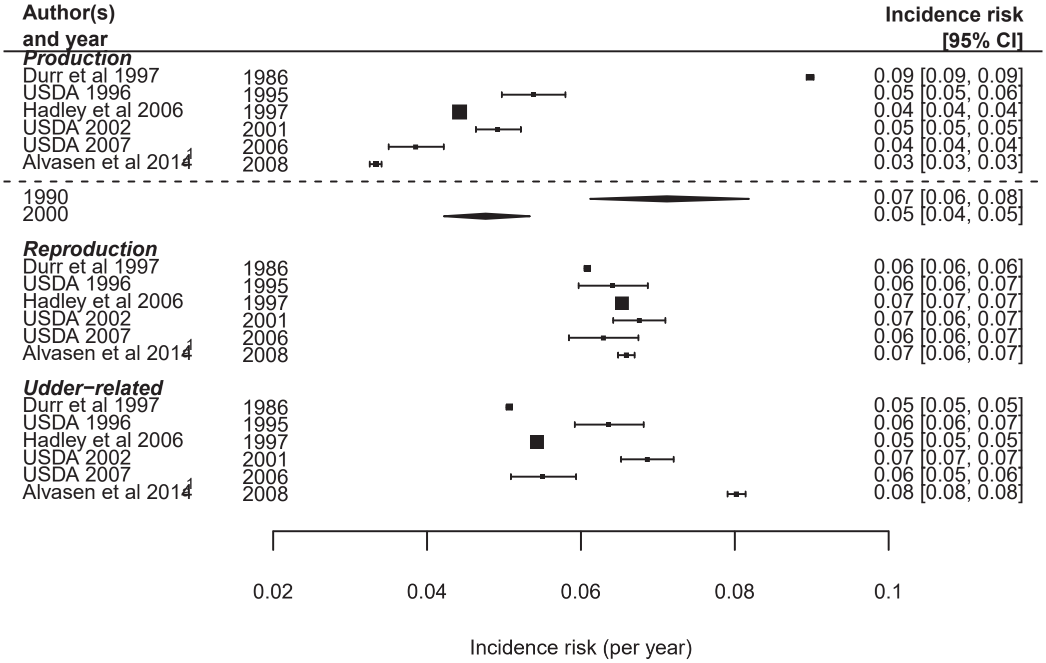

Figure 2.6: Annual^1 incidence risk (■) and 95% CI of culling of adult cows grouped by attributed cause category in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision). Predicted annual incidence risk and 95% CI (⧫) of culling at different levels of moderator variables from the meta-regression models are plotted below the dashed line (^{1}result measured per lactation)

A total of 6 studies were analysed for cause-specific annual IR of culling. Forest plots of the study results of annual IR of culling of adult cows attributed to categories of causes reveals a decrease in IR of culling for “production”, but no change for the categories for “reproduction” and “udder-related” causes (Figure 2.6). The annual IR of culling attributed to lower production was predicted to have decreased between 1990 and 2000 by 0.02 ($P < 0.001$).

There were insufficient studies that reported mean (n = 3) or median LPL (n = 2) as an outcome for meta-analysis. Stevenson and Lean [1998], Lopez de Maturana et al. [2007], and Ahlman et al. [2011] reported mean LPL of 1,418, 786 and 1,111 d, respectively, whilst Schneider et al. [2007] and Hultgren and Svensson [2009] reported median LPL of 640 and 780 d, respectively.

Calves and Heifers. A total of 20 years within study (median =1 and maximum = 12 years

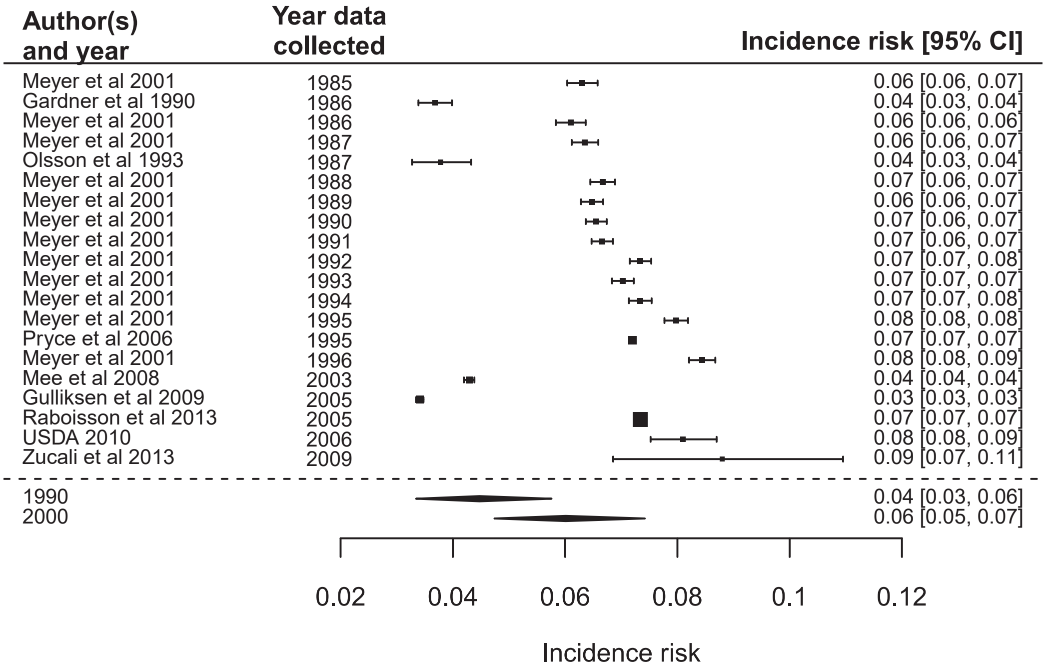

Figure 2.7: Incidence risk (■) and 95% CI of perinatal mortality of female calves (full-term birth to 2 d of age) in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision). Predicted incidence risk and 95% CI (♦) of mortality at different levels of moderator variables from the meta-regression models are plotted below the dashed line

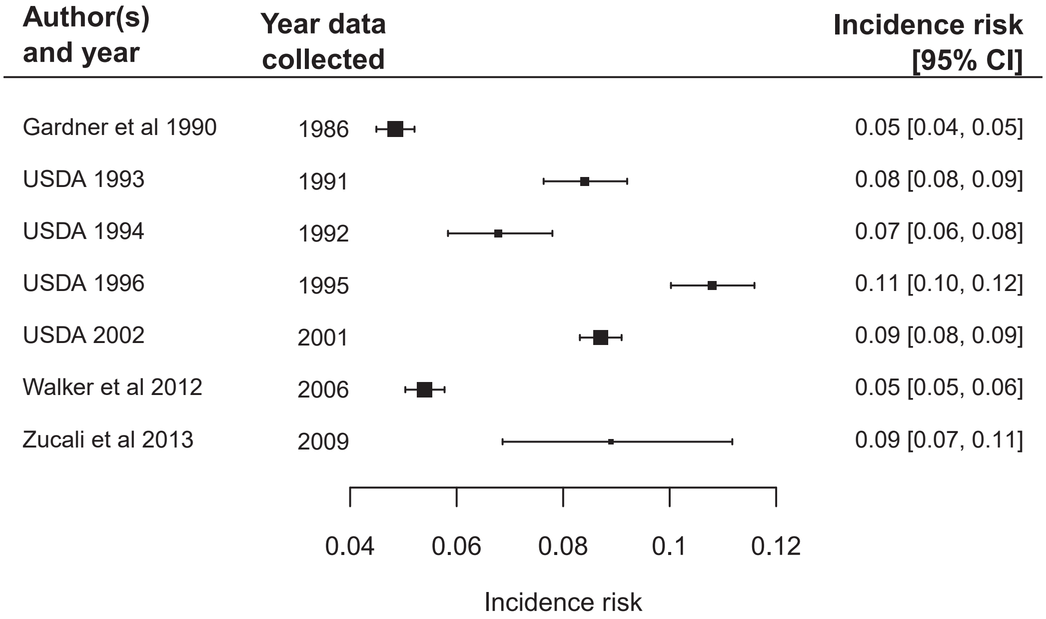

Figure 2.8: Incidence risk (■) and 95% CI of neonatal mortality (1 d of age to weaning) in studies included in the meta-analysis (point estimate sizes plotted in proportion to their precision)

per study) and 9 studies were analysed for IR of perinatal mortality. The IR of perinatal mortality varied from 0.03 to 0.09 (Figure 2.7) and was predicted to have increased between 1990 and 2000 by an absolute 0.02. Each study (n = 7) contributed only one year in the MA-MR of IR of neonatal mortality. The range of reported IR of neonatal mortality varied between 0.05 to 0.11 (Figure 2.8), but had not changed over time ($P = 0.618$). Diarrhea was the most frequently recorded cause of neonatal mortality in 4 studies from the USA [Gardner et al., 1990, USDA, 1993, 1996, 2002]: the IR of neonatal mortality attributed to diarrhea varied from 0.02 to 0.03.

2.4 DISCUSSION

2.4.1 Increased Incidence of Mortality in Cows

Results of our MA-MR, indicate that the problem of increased incidence of mortality reported in a small number of countries, is in fact widespread in modern dairy production systems. The magnitude of change was less for the measure of ID than for IR, but this was likely due to the studies of Perrin et al. [2011] and Raboisson et al. [2011], which were conductedin a different country (France) to those that reported IR, and, in large populations, which weighted the predicted change over time towards their results. Our findings are in agreement with the direction of the multi-year studies included in this review, but even greater in magnitude. Thomsen et al. [2004] indicated that lactational mortality IR had increased from 2% in 1990 to 3.5% in 1999 in Danish cows, and Alvasen et al. [2012] reported a change in the ID of mortality in Swedish cows over the period from 2002 to 2010 of 5.1 to 6.6 events per 100 cow years. Perrin et al. [2011] also reported that mortality ID had increased in French dairy cows between 2003 and 2009 in the order of an absolute 2 to 4 cases per 100 cow yr, depending on cow age. Increased IR and ID of mortality in cows in recent decades adds weight to the calls of other authors to bring this problem into sharper focus of the international dairy industry. Control schemes are required to not only reduce the economic and animal welfare costs this change has caused, but also manage the reputational risk posed to dairy industries by this change. This task is urgent, as no reports are currently known to the authors, of programs that have successfully controlled mortality in dairy cows.

Our findings of increased IR and ID of mortality in cows are associations with time, and, in themselves, are not causal. Other, off-farm changes in the regulatory, social and commercial environments in some countries may have contributed in part to these recorded changes, but were not considered in the current study. For example, changes in the regulations for emergency slaughter of defective stock [Alvasen et al., 2012] and increased concern about investigation by authorities of possible animal welfare violations, if even slightly defective animals are sent for slaughter [Thomsen and Sorensen, 2008], may both have contributed to the overall increase in recorded IR or ID of mortality of cows. We were unable to investigate possible associations between production system characteristics and incidence of mortality (or culling) because data on those factors were often unavailable, and because of the small number of studies for some MR. However, this analysis might be possible in the future if more studies with the necessary data become available.

2.4.2 No Change in the Incidence Risk of Culling of Cows

We found no indication of overall change in the annual IR of culling of cows in countries with modern dairy systems, over the period of data collection for this outcome (1986 to 2007). Few studies reported data collected from more than one year. Of those that did, Maher et al. [2008] reported that the IR of culling in Irish cows had increased, but conversely, two studies with longitudinal data that were aggregated in our analysis, indicated the reverse: Durr et al. [1997] reported that annual IR of culling had decreased by an absolute 4% between 1981 and 1994 among cows in Quebec, Canada, and Pinedo et al. [2010], reported that the ID of culling had decreased from 30 to 25 per 100 cow years among Eastern United States herds in the period between 2001 and 2006. Further evidence for lack of change in the IR of culling of cows, at least in the USA, comes from 2 studies that used similar designs [USDA, 2002, 2007] and reported almost no change between the years 2001, and 2006. Reasons for the inconsistent patterns of change, and single year results between studies were not determined in the current study, but we speculate that other factors associated with culling, such as characteristics of the production systems, economic conditions and availability of replacements [Beaudeau et al., 2000, Hadley et al., 2006], also varied between study populations and over the years of data collection.

2.4.3 Decreased Incidence Risk of Culling Attributed to Poor Production

We found that over approximately 2 decades from the mid 1980's, the annual IR of culling for production-related reasons decreased, while that for reproduction- and udder-related causes was unchanged. This finding is supported by that of Durr [1997], who reported that the annual IR for culling attributed to poor production had decreased from 17% in 1981 to 4% in 1994. It is commonly believed that in order to maintain or improve herd productivity, farmers will make an economic decision to cull cows with poor milk production, and replace them with more productive cows. However, our findings indicate that farmers have been increasingly constrained from doing this. Reasons for this are unclear from our data, but may be associated with a change towards other disease-related reasons for culling, such as lameness or injury, that were not categorized in a way to make them available for this MA-MR. However, it should be acknowledged that single farmer-recorded reasons for culling or grouping causes as “non-production” may not always capture the complexity of causes contributing to culling [Bascom and Young, 1998, Stevenson and Lean, 1998], and therefore, measures of cause-specific culling should be viewed with this limitation in mind. Nevertheless, it is likely that improving production efficiency will continue to be an objective of dairy farmers, and therefore, discovery and implementation of practices to reverse reduction in culling for the reason of poor production, should be an objective of research and extension.

2.4.4 Increased Perinatal but not Neonatal Calf Mortality

Fewer studies were available from studies on calves, and what was available could often not be fully utilized because there were too few studies using the same or similar age range categories to allow comparisons. Nevertheless, sufficient data were available for MA-MR of IR of perinatal and neonatal mortality. Estimates of the IR of perinatal mortality (born full-term but died before 1 or 2 d of age) varied between studies, but this is not unexpected because of the difficulties and various methods used to record these cases. For example, the upper age limit used to define the period at risk was either 1 or 2 d. The practical impact of this is unclear, but presumably use of the higher limit (2 d) would reflect in higher mortality estimates because of increased time at risk. It is also likely that perinatal mortality is incompletely recorded because not all calves are registered by farmers, and the loss of these records would result in an underestimate of perinatal mortality. Notwithstanding these difficulties, we estimated by MR that the IR of perinatal mortality increased by an absolute 0.02 between 1990 and 2000. An increase in the IR of perinatal mortality over time was also reported by Mee et al. [2008], but the causes for the change were not explained by known risk factors, such as age of the dam, degree of calving difficulty, or gestational age. Increased perinatal mortality in modern dairy countries reduces production efficiency by reducing availability of calves to act as replacements or for sale, and additionally incurs welfare costs. The authors are unaware of control programmes for perinatal mortality, and we urge further efforts for that purpose.

In contrast, we found no evidence that the IR of neonatal mortality had increased in the 2 decades from 1990. The most commonly attributed causes of mortality in this age group, as reported in other studies, were enteritis and pneumonia. Nevertheless, mortality in this age group represents an important financial loss to dairy farmers and again, reflects poorly on the welfare status of this age group. Consequently, the current status quo is not desirable, and control programmes that instead reduce mortality in neonatal calves would be valuable to farmers.

2.4.5 Bias

The possibility and consequences of bias should be considered in this, as with all SR. A total of 12 articles were excluded from the review because requested data were either not supplied or because the authors could not be contacted or did not respond. We received fewer responses, and fewer responses with data, following requests to the authors of articles published before the year 2000. Although these problems were unavoidable, they may have biased selection towards more recently published articles. However, the overall risk of bias independently assessed by the reviewers and reported here was low. Despite this, it is probable that the usual forms of bias in data from observational studies also exist in these data, such as information bias due to inaccurate and incomplete records, particularly of the previously mentioned risk of misclassification of sold animals when they may have been culled for slaughter, and farmer-attributed causes of culling and mortality. Explicit mention of data validation was reported in 24% of studies, and of them, only in 2 of the 29 studies that used secondary data. The direction and extent to which these biases affected the results in the reviewed studies is unknown and seldom commented on by the authors, but should also be considered when interpreting the findings of this review. We further investigated by sensitivity analysis the possibility that studies that reported multiple years of data were influential in the MR models, but this was not found to be the case, as the magnitude and direction of the coefficients were robust to removing these studies individually, or entirely from the models; and in only 1 of the 3 models, did the p-value become non-significant ($P = 0.11$).

2.4.6 Nomenclature

Several features of articles reduced the number of results available for MA-MR. For example, the definitions of outcomes involving culling and mortality have varied in the 25 yr of publication that the selected articles spanned, which increased the number of outcomes reported and reduced the number available for each comparison. A review article by Fetrow et al. [2006] recommended a two-level system to code animal removal events: firstly the destination or fate, then the attributed reason. They, and previous authors [Dohoo and Dijkhuizen, 1993, Radke and Lloyd, 2000], argued to distinguish the cause of culling as either “biological” (also known as “forced”) or “economic”. Biological culls are those animals without a possible productive future, e.g., permanently infertile or irreparably injured, and economic culls are those that will be replaced with a more profitable animal. We agree with these authors’ recommendations, and, furthermore, suggest that different destinations for cow disposals be reported separately to preserve information for use by researchers in other countries who use different definitions for culling. Additionally, we recommend that farmers are able to record euthanized animals in order to distinguish these animals from those that die unassisted, as has been instituted in some European countries, such as Denmark and Sweden [Thomsen et al., 2004, Alvasen et al., 2012]. Similarly, we recommend a reduced and standardized range of categories for reasons attributed to mortality and culling. Two examples of categorization schemes that are simple and provide meaningful information are those used by the USDA in the National Animal Health Monitoring Scheme, which used 7 categories (not including death) for culling: udder/mastitis, reproduction, lameness/injury, poor production unrelated to other disease, other disease, behavior, and unspecified; and that of Thomsen and Houe [2006], who used 8 categories for mortality: accident, calving, digestive, locomotor, metabolic, udder/teat, other known, and unknown causes. Together, implementation of these suggested changes would enhance the reporting and understanding of mortality and culling of dairy animals.

2.5 ACKNOWLEDGEMENTS

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Chapter 3

Incidence of culling, sale, and mortality in New Zealand dairy herds

ABSTRACT

Our main aim was to define the incidences and farmer-reported causes of culling, sale, and mortality in a recent sample of pasture-based, seasonal-calving dairy herds from four regions of New Zealand. Our secondary aims were to investigate possible underreporting of neonatal mortality, and to compare different methods to calculate incidences of removal, either as incidence risk (IR) or incidence density or rate (ID), based on either seasonal calendar dates or a parity (interval between birth or calving, and subsequent calving or removal). We used data from a previous observational and intervention study of cow reproductive performance consisting of 113 dairy herds. Electronic data included records between June 2009 and May 2012 of animal identification and birth dates, calving and animal removal events, and farmer-reported reasons for animal removal from the herd. The first quartile and median herd-level IR per parity of culling in 0 to 2 yr old replacements and mortality in mixed-age cows were 1.5 and 3.7%, and 1.2 and 1.7%, respectively. However, the third and fourth quartiles were 6.3 and 25.8%, and 2.8 and 6.7%, respectively, indicating large between-herd variation. The greatest ID of mortality occurred in cows aged 5 yr and older during the first two weeks following calving, and approximately 13 and 22 mo later, which coincided with subsequent pre-partum periods. Furthermore, the timing and reported reasons for sale of mixed-age cows indicate that the IR of culling alone does not reflect the full burden of animal removals due to disease and reproductive failure. For example, reproductive failure was the most frequently reported cause of culling among both replacements (60.4%) and mixed-age cows (42%), but was also common among sold cows (33.1%). Causes of mortality were less clearly characterized. In addition, our analyses indicated that neonatal mortality among replacement heifers was underreported, and that the different methods used to calculate incidences of removal among mixed-age cows produced comparable results. Overall, the population incidences of culling, sale and mortality were less than reported from other countries with modern dairy industries. The wide range in the IR of culling of replacements and mortality in mixed-ages cows and relatively high proportion of removals for non-production causes, reveal opportunities to reduce economic losses and improve dairy animal welfare.

Keywords: culling, mortality, peripartum, incidence risk, incidence density

3.1 INTRODUCTION

Culling and on-farm mortality of animals have important implications for the economic performance of dairy herds. High and sustained incidences of culling or mortality reduce farm profit because of additional costs associated with the purchase or rearing of replacement animals, and income, because younger replacements produce less milk initially than animals removed from the herd [Renkema and Stelwagen, 1979, Rogers et al., 1988]. In a study of UK herds, Orpin and Esslemont [2010] reported that the costs attributed to culling or mortality were between UK £1,200 and £3,500 per animal, and were largely determined by the reason for removal, the stage of lactation at removal (earlier removal resulted in greater costs), and whether the animal was culled or died on-farm (mortality resulted in greater costs). Furthermore, analysis of data from their web-based animal health and evaluation tool [Orpin and Sibley, 2007] revealed substantial variation among herds in their incidences of culling and mortality, and, consequently, substantial opportunity for improvement among many herds.

High and sustained rates of mortality, and to a lesser extent, culling, are also indicators of poor welfare [de Vries et al., 2011]. Increasingly, consumers and animal welfare advocates are scrutinizing dairy animal welfare. This attention is given both to housed systems, as are common in the northern hemisphere, and to pasture-grazing systems such as those operated in New Zealand, Australia, Ireland and other parts of Europe [Hemsworth et al., 1995]. Increased awareness and effective control programs to mitigate against these risks will not only benefit the welfare of dairy animals but also guard the reputation of these industries and their access to markets.

For these reasons, an accurate quantitative description of culling, and mortality of dairy animals is necessary to provide a measure of current performance in various industries and to act as a foundation for further research and extension. In many cases, the incidence of sale is also required as culling alone does not provide an accurate assessment of cow removals because many animals with disorders may be sold to other farmers rather than sent for slaughter depending on financial reasons and other factors. Furthermore, as production systems have intensified in these pasture-grazed systems, exemplified by increased herd size, more cows per labour unit, greater milk production per cow and an increased proportion of the diet as non-pasture, brought-in supplementary feed [Anonymous, 2011, 2017e], the risk of mortality and culling may also have increased [Lean et al., 2008]. However, few recent studies are available from pasture-grazed, seasonal-calving dairy systems to determine if this has occurred.

Our main aim in this study was to describe the incidence and farmer-reported causes of culling, sale and mortality in a recent sample of spring-calving, pasture-grazed dairy herds from four regions in New Zealand. Our other aims were to investigate any differences or biases arising from different methods used to estimate the incidence of cow removals or due to underreporting of removals or inaccuracies when describing the population at risk. We aimed to use these findings to: 1) benchmark population and herd incidence of culling, sale, and mortality in New Zealand dairy herds; 2) compare with international reports; 3) advise on preferred methods for their calculation; and 4) to provide information for animal health management programs.

3.2 MATERIALS AND METHODS

3.2.1 Data Source and Management

Data for this study were previously retrieved electronically from LIC (Hamilton, New Zealand) for use in the National Herd Fertility Study [NHFS; Brownlie et al., 2011, 2014]. The NHFS described reproductive performance and a management intervention in a non-random sample of 143 pasture-grazed (non-housed), herds with seasonal, spring-calving patterns, from four dairy regions of New Zealand (Waikato, Taranaki, South Canterbury, North Otago), over two consecutive seasons commencing in 2009. These data included the 46 legislated fields from the New Zealand Dairy Industry Core Database (Dairy Industry Regulations, 2001) for all animals present at any time in the enrolled herds over the study period between June 2008 to May 2012, including a unique animal identifier, demographic information on date of birth and breed, date of entry into a herd, date of and fate (culled, sold, died, or moved) and reason for exit from a herd, and records of calving events.

Two datasets were used for this analysis. First, a ‘parity’ data set was created to capture the follow-up time periods for individual animal between the date of birth or the date it calved in 2009, and the next date it was culled, sold, died, moved or was censored. The maximum observation period was 37 mo. An animal was right-censored if it calved and began a new parity, was moved off the farm, or had no further calving or removal recorded in the observation period (n = 1,279, 1.6%). A parity number could not be assigned accurately because the complete history of calvings for each animal were not available; however, the age at first calving was assumed to be 2 yr; and for subsequent parities, one less than the age in yr at the start of that parity. Instead, a ‘parity age group’ was defined by the age in yr rounded to the nearest whole number of an animal at the start of a parity: ‘0 yr’ (birth to < 2 yr); and for cows (animals with ≥ 1 calving) ‘2 yr’, ‘3-4 yr’, ‘5-7 yr’, ‘8+ yr’.

Second, we created a ‘season’ data set to compare the results of different methods to calculate the incidence of culling, sale, and mortality in mixed-age cows. In this data set, the observation period for each animal on a farm started on the same calendar date, and was not related to date of calving. Farm events in seasonal-calving herds fit within a management cycle of approximately 1 yr. The key dates for herd management in seasonal-calving herds are defined from the mating start date (**MSD**) of any season, which may differ between herds. The MSD was defined for each herd as the first of a sequence of 6 d whereby at least 4 of the 6 had mating events recorded [Creagh et al., 2013]. The start of the follow-up time for each animal in this data set was the herd season start date (**HSSD**), defined as 130 d prior to the MSD in the current season, and the herd season end date (**HSED**) was 130 d prior to the MSD in the subsequent season [Brownlie et al., 2014]. All animals present in the herd at the HSSD or born in the herd for the season starting in 2009, or that were purchased in the season (n = 2,712, 2.5%), were included in the analysis. The age group of animals at the start of a season in this data set was defined in the same way as in the 'parity' data set.

Farmers used a restricted set of codes to report the fate of removed animals when their records were submitted to an electronic database, but these were not verified by the study investigator. The removal codes and their common definitions were: culled (sold for immediate slaughter); dead (died on-farm, either unassisted or euthanized), moved (transferred to another location off the farm; for example, temporarily transferred to graze elsewhere), and sold (purchased by another farmer). Farmers also had the option of reporting the cause of removal using one of approximately 40 codes for disorders.

We categorised cows that died on-farm $\leq$ 30d or $>$ 330 d post- calving as transition period deaths. The farmer-reported codes for cause of removal were categorized according to the animal fate, and some, but not all causes were available for each fate. The categories for culled animals were: accident-injury (**ACC**), behavior (**BEH**), lameness (**LMN**), low production (**LPR**), other known (**OTH**), reproduction (**RPR**), udder-mastitis (**UDD**), unknown (**UNK**) and missing (**MIS**); for dead animals: ACC, calving-related (**CLV**), digestive (**DIG**), LMN, metabolic (**MET**), OTH, UDD, UNK and MIS; and for sold animals: as for culled animals with the addition of dairy purposes (**DAI**). These categories are the same as those used previously by Thomsen [2004] for mortality, and by the USDA [2007] for culling, with the exception that in the latter, accident and injury were given separate categories for culling rather than combined. The ages of animals were defined in yr at the start of their parity or the HSSD, and breed was categorized as Holstein-Friesian or Jersey when $> \frac{12}{16}$ of that breed, otherwise as Crossbred. Herd size was defined as the number of cows that calved in a herd in a season.

In both data sets, herds were excluded from analysis if they were not actively monitored in the NHFS or withdrew from the study. In the 'parity' data set, only records from animals that started a parity (including those born) in 2009 in included herds were analyzed because there were approximately three yr available to follow-up female replacements from birth to determine if they were culled, sold, died, or censored. Only records from the 2009 season were analyzed in the 'season' data set so that the two data sets were comparable. Additionally, records were excluded from animals in either data set if they had missing birth dates or implausible date records, for example, calving dates before birth dates, or if a calving date was > 180 d after the HSSD.

3.2.2 Main Outcomes

Incidence is a binary variable (yes/no) that describes, for an individual, whether or not an event, for example culling, occurred in a defined period of observation. When the variable is aggregated to a group level, for example, an age group or herd, incidence risk (**IR**) describes the proportion of animals that experience the event within a specified time period out of the total population of animals at risk of experiencing the event at the start of the period of observation where each was observed until either they experience the event or the end of a specified time period, whichever occurred first:

$$IR = \frac{\sum \text{events during the period}}{\sum \text{animals at risk at the start of the period}}$$

Incidence may also be defined as a density (**ID**) (or rate), where the denominator is the total time that animals in the population are at risk of experiencing the event over the period of observation:

$$ID = \frac{\sum \text{events during the period}}{\sum \text{animal time at risk over the period}}$$

Time at risk was calculated exactly and scaled to 100 × 365 d (ID per 100 cow years). Animals and their accumulated time of observation where they were removed with fates other than the one analyzed, remained in the denominators for calculations. Outcome measures had the subscripts 'p' or 's' to denote either the 'parity' or 'season' data set were used, respectively, for their analysis.

3.2.3 Statistical Methods

We estimated the $\mathrm{IR_p}$ of culling, sale, and mortality, stratified by age group, from the 'parity' data set. Differences between the mean $\mathrm{IR_p}$ of five parity age groups were tested by all pairwise Tukey contrasts from generalized linear mixed models for each outcome (with random intercepts fitted for each herd) and a single step method for adjustment for multiple comparisons [Hothorn et al., 2008] implemented in the 'R' package 'multcomp'. These mean $\mathrm{IR_p}$ were, therefore, adjusted for the effect of clustering of age-groups within herds. The mean $\mathrm{IR_p}$ of culling, sale and mortality were estimated for each herd, stratified into two age groups (replacements and mixed-age cows), and box plots drawn to depict their distributions. Additionally, $\mathrm{IR_p}$ of transition period deaths were estimated for each parity age group and pairwise differences calculated as described previously. The $\mathrm{ID_p}$ for the main outcomes were calculated for each of the five age groups over 14 d intervals from the start of a parity for 25 mo. These estimates were loess-smoothed with a span of 0.25 and plotted to visualize patterns of $\mathrm{ID_p}$ among the age groups over time from the start of a parity.

We calculated an adjusted estimate of IR of mortality in female replacement calves at the herd-level to account for any unrecorded deaths before they were registered in the electronic database. It was assumed that female replacement calves were alive when they were ear-tagged using tags with an ascending sequence lifetime identity number (usually within 24 h of birth). The maximum lifetime identity number (**MaxBirthIDNum**) was retrieved for each herd, and the number of unaccounted calves ($\mathbf{N_{Unacctd}}$) calculated as the difference between that number and the number of calves registered. The adjusted mortality IR ($\mathbf{IR_{M\ Adj}}$) for replacements was calculated as:

$$IR_{MAdj} = \frac{\sum \text{N died} + \sum \text{N Unacctd}}{\text{MaxBirthIDNum}}$$

where $\sum$N died is the number of recorded mortalities in replacements. Results from herds with $\geq$ 20% of replacement calves unaccounted for were discarded (n = 16) because these appeared to be outliers in that distribution, as were results from herds where more calves were registered than the MaxBirthIDNum (n = 4). Results of our estimates of $\mathrm{IR_{M\ Adj}}$ were reported for 93 herds.

We estimated the intraclass correlation (ICC) separately for replacements and mixed-age cows, for the clustering of each fate at removal within a herd, using a 1-way generalized linear mixed model as described in Goldstein et al [2002]. Faceted bar plots were created for each fate and age group (replacements and mixed-age cows) of the percentage of animals removed by category of reported cause. Finally, the IR and 95% confidence limits of cause-specific IR of culling, sale, or mortality were estimated as previously for the three most frequently attributed causes, with stratification by two age groups (replacements and mixed-age cows).

To compare the $\mathrm{IR_s}$ estimates with the $\mathrm{IR_p}$ estimates, and similarly the $\mathrm{ID_s}$ and $\mathrm{ID_p}$ estimates, we created two data sets; one from the 'parity' and one from the 'season' data sets, grouped for each herd, with sums of the number of mixed-age cows culled, sold or died, the number of mixed-age cows at risk and the sum of their follow-up time. From these data sets we estimated the least square mean and 95% confidence intervals for the IR and ID for each fate at removal in each data set. We used univariate quasi-binomial (dependent variable was a two-column vector of number of cases and number of animals observed per herd) and negative binomial (dependent variable was number of cases and the independent variable was an offset of the logarithm of time at risk per herd) regression models to calculate IR and ID, respectively, and plotted the estimates and confidence intervals. Because the estimates were from different data sets, they could not be formally tested; hence we compared their confidence intervals to assess differences. We did not consider replacements for these comparisons because their follow-up period was greater than one season.

Data were managed in a Microsoft SQL Server database (Version 2008, Redmond, WA, USA), and statistical analysis undertaken in R (version 3.3.3.; R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was declared at $P < 0.05$.

3.3 RESULTS

3.3.1 Study Population

The initial 'parity' data set contained records from 113 herds and 86,238 animals. Data were excluded from 781 animals with missing or implausible date records, 3,197 animals that were not born or did not

Table 3.1: Summary descriptive statistics of 113 herds from four regions of New Zealand included in a study of the incidence and causes of culling, sale and mortality, and mean national statisitics

	Study herds		National herds
	n (SD or %)	N	n or %
	N=113		N=11691
Herd size	567 (307)	113	376
Herd replacement rate (percent)	25.4 (7.4)	113	19.3
Milk production per cow (kg MS)	381 (69.1)	56	318
Milk yield per cow (l)	4442 (901)	56	3642
Region:		113	
Waikato	31 (27%)		3571 (31%)
Taranaki	28 (25%)		1759 (15%)
Canterbury	27 (24%)		891 (8%)
Otago	27 (24%)		368 (3%)
Business type:		113	
Owner-manager	92 (81%)		7534 (64%)
Other	21 (19%)		4125 (36%)
Feed system:		110	
1	3 (3%)		
2	8 (7%)		
3	19 (17%)		
4	46 (42%)		
5	34 (31%)		

Note:
Herd size = Number of cows that calved in the season, Herd replacement rate = percentage of cows that calved in the herd that were 2 yr old, MS = milk protein + milk fat, DairyNZ Feed System categories: 1 = All grass self-contained and all stock on the dairy platform and no feed imported 2 = Approx 4-14 percent of feed is imported as supplement or grazing off for dry cows 3 = Approx 10-20 percent of feed is imported to extend lactation and for dry cows 4 = Approx 20-30 percent of feed is imported and used at both ends of lactation and for dry cows 5 = Approx 25-40 percent of feed is imported and used all yr

calve in a study herd in the season of 2009, and 119 cows that calved > 180 d following the HSSD. The final data set for analysis consisted of 82,141 animals from 113 herds. Summary descriptive statistics of the study herds in the parity data set and comparable measures from national statistics from the 2009 season [Anonymous, 2010] are presented in Table 3.1.

Among the study population 22.0% were replacements and 78.0% were mixed-age cows, and among the mixed-age cows, 20.1, 33.5, 29.7, and 16.7% were 2, 3-4, 5-7 or 8+ yr of age, respectively, at calving. The breed composition of the study compared with the national cow populations were: Crossbred, 56.2 and 42%, Holstein-Friesian, 34.7 and 42%, and Jersey, 9.1 and 16%, respectively.

Table 3.2: Overall incidence risk[1] (IR) per parity[2] of culling, sale and mortality by the age of animals at the start of that parity[3] among 113 herds from four regions of New Zealand

Age category	Total	N culls	IR culling	N sales	IR sale	N mortalities	IR mortality
0 yr	18,048	790	4.4^{a}	2,858	15.8^{d}	506	2.8^{a}
2 yr	12,866	942	7.3^{b}	709	5.5^{c}	213	1.7^{b}
3-4 yr	21,456	1,818	8.5^{c}	851	4.0^{b}	311	1.4^{c}
5-7 yr	19,044	3,256	17.1^{d}	446	2.3^{a}	432	2.3^{d}
8+ yr	10,727	4,006	37.3^{e}	205	1.9^{a}	372	3.5^{e}
Mixed-age cows	64,093	10,022	15.6	2,211	3.4	1,328	2.1
Total	82,141	10,812	13.2	5,069	6.2	1,834	2.2

[1] Percentage, estimates within a column with different superscripts differ ($P < 0.05$)

[2] Time period between birth or calving, and subsequent calving or removal from a herd

[3] 0 yr = Replacement 0 to 2 yr of age

3.3.2 Animal-Level Incidence of Culling, Sale and Mortality

Overall, 15.6, 3.4, and 2.1% of mixed-age cows were culled, sold, or died per parity, respectively (Table 3.2). The IR_p of culling increased with each increment in age among the parity age groups, and approximately doubled between each of the three older age groups (Table 1). Conversely, the IR_p of sale was greatest among replacements, and decreased between each of the successive age groups. The oldest (8+ yr), followed by the youngest (0 yr) age categories had the greatest IR_p of mortality, followed by 5-7 yr and then 2 yr cows, whereas 3-4 yr cows had the least IR_p of mortality.

The evolution of ID_p of culling, sale and mortality following birth of replacements or over the duration of a parity and for the 2-yr period thereafter (follow-up period) for each of five age groups is presented in Figure 3.1. The ID_p of culling from the start of each parity had three peaks at approximately 8, 15 and 22 mo post-calving, and at each peak, older animals had a greater ID_p of culling. Additionally, the increase in the ID_p of culling began earlier post-calving and increased at a greater rate with increasing age in successive parity groups. The plot of ID_p of sale over time had a similar pattern of three peaks. However, there were three main differences between the sale and culling plots: replacements (0 yr) had two earlier peaks of sale immediately following birth and at 5 mo of age, the order of magnitude of ID_s with respect to age category was reversed compared with culling (younger age groups had greater ID_p of sale than older age groups), and the absolute ID_p of sale for each age group were much less than those for culling. Again, three peaks of the ID_p of mortality were apparent, but the timing of

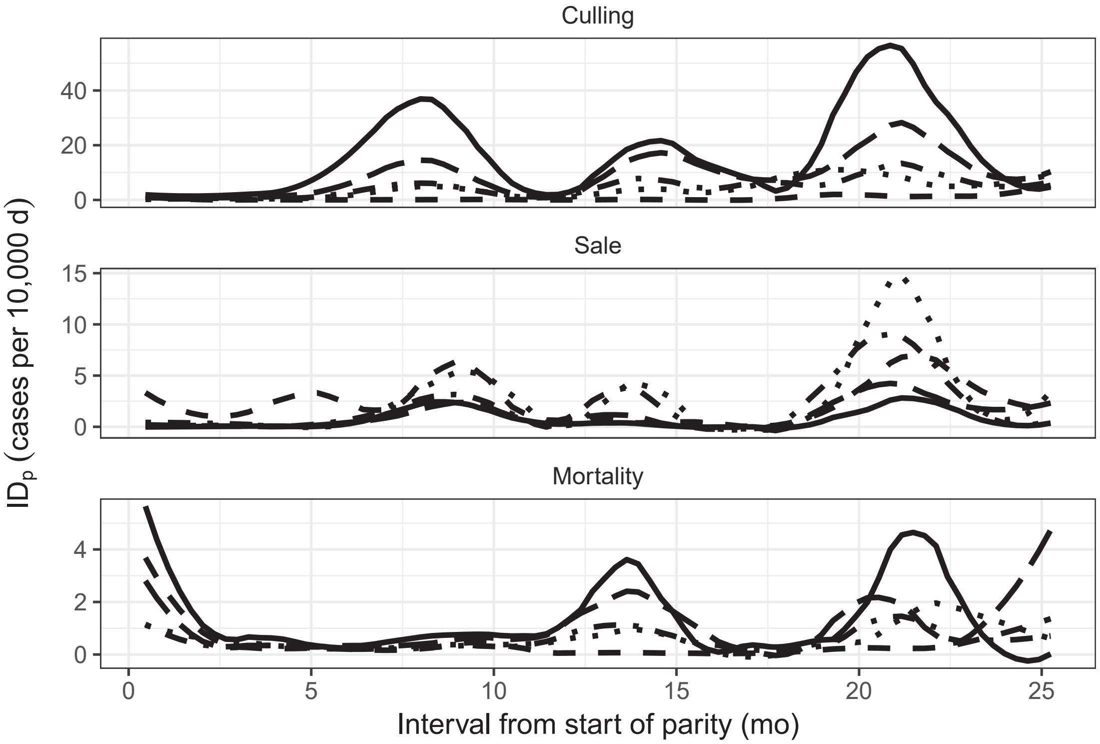

Figure 3.1: Smoothed incidence densities per parity (ID$_p$) of culling, sale and mortality by age group at start of parity and interval from start of parity (birth for 0 yr, or calving for mixed-age cows) among 113 herds from four regions of New Zealand (0 yr = short-dashes, 2 yr = dots, 3-4 yr = short-dashes dot, 5-7 yr = long-dashes , 8+ yr = solid line)

the first peak differed from those of culling and sale. The first peak of mortality occurred at either birth or calving for all age groups and reduced sharply in the following 2 mo. Cows 5 yr of age and older, and replacements (0 yr), had a relatively greater ID$_p$ of mortality in this period compared with cows in other age groups. Following the neonatal period, replacements (0 yr) had a reduced ID$_p$ of mortality until a minor increase at 24 mo, which probably represents pre-partum mortalities. The other intervals of increased ID$_p$ of mortality for mixed-age groups cows were at 12-13 mo and 22-24 mo, representing the same pre-partum period, and at each of these peak periods, cows of greater age had greater incidence of mortality. Transition period mortalities represented 45.4% of all mortalities in mixed-age cows, and the ratios of IR$_p$ for mortality in the transition period compared with 2-yr old cows (risk ratios) were 0.9 ($P \geq 0.05$), 1.8 ($P < 0.05$), and 3 ($P < 0.05$) for 3-4 yr, 5-7 yr, and 8+ yr old cows, respectively.

3.3.3 Herd-Level Incidence of Culling, Sale, and Mortality

The upper, median, and lower 25% quartiles of herd-level $\mathrm{IR_p}$ of culling for replacements were 6.3, 3.7 and 1.5%, and the same for mortality were 3.5, 1.7 and 0.8%, respectively (Figure 3.2). There were several outlier herds with greater $\mathrm{IR_p}$ for culling and mortality in replacements, with herd-level $\mathrm{IR_p}$s for each outcome as high as 25.8 and 47.8%, respectively. Amongst mixed-age cows, the upper, median, and lower 25% quartiles of herd-level $\mathrm{IR_p}$ of culling per parity were 18.5, 15.5 and 12.9%, respectively; and the same quartiles for mortality were 2.8, 1.7 and 1.2%, respectively. Greater variation and more outliers was evident among $\mathrm{IR_p}$ of sale than for culling or mortality. The upper, middle and lower 25% quartiles of sale were 25.4, 10.3 and 0%, respectively, among replacements, and the corresponding $\mathrm{IR_p}$ of sale in mixed-age cows were 5.2, 2.1 and 0%, respectively. However, the $\mathrm{IR_p}$ of culling and mortality in mixed-age cows varied among herds from as little as 1.4 and 0%, to as great as 28.1 and 6.7%, respectively. The estimates of ICC for the main outcomes in the 'parity' data set were generally small and varied between 0.005 and 0.05, except for the ICC for sale in replacements, which was 0.2.

The median and maximum number of unaccounted replacements per herd were 2 (2%), and 74 (19%), respectively. The mean, upper, median, and lower 25% quartiles of IR_{MAdj} in replacements were estimated as 5.9, 7.4, 3.7, and 2.1%, respectively (these data are not presented in other tables and figures).

3.3.4 Reported Causes and Cause-Specific Incidence of Culling, Mortality, and Sale

Reproductive-related causes (RPR) were the most frequently reported category of reasons for removal across all age groups and fates combined (Figure 3.3, 31.7%); of which most were culled (26.5%), and the rest were sold (5.1%). When considering only culled animals, RPR causes were the most commonly reported cause in both replacements (60.4%) and mixed-age cows (42%), followed by OTH (23 and 25.6% for replacements and mixed-age cows, respectively). Udder health (14.1), LPR (10) and UNK (3.6%) were also frequently reported reasons for culling of mixed-age cows. Reproductive-related causes were also the most frequently reported reason for sale of mixed-age cows, followed by DAI (33.1 and

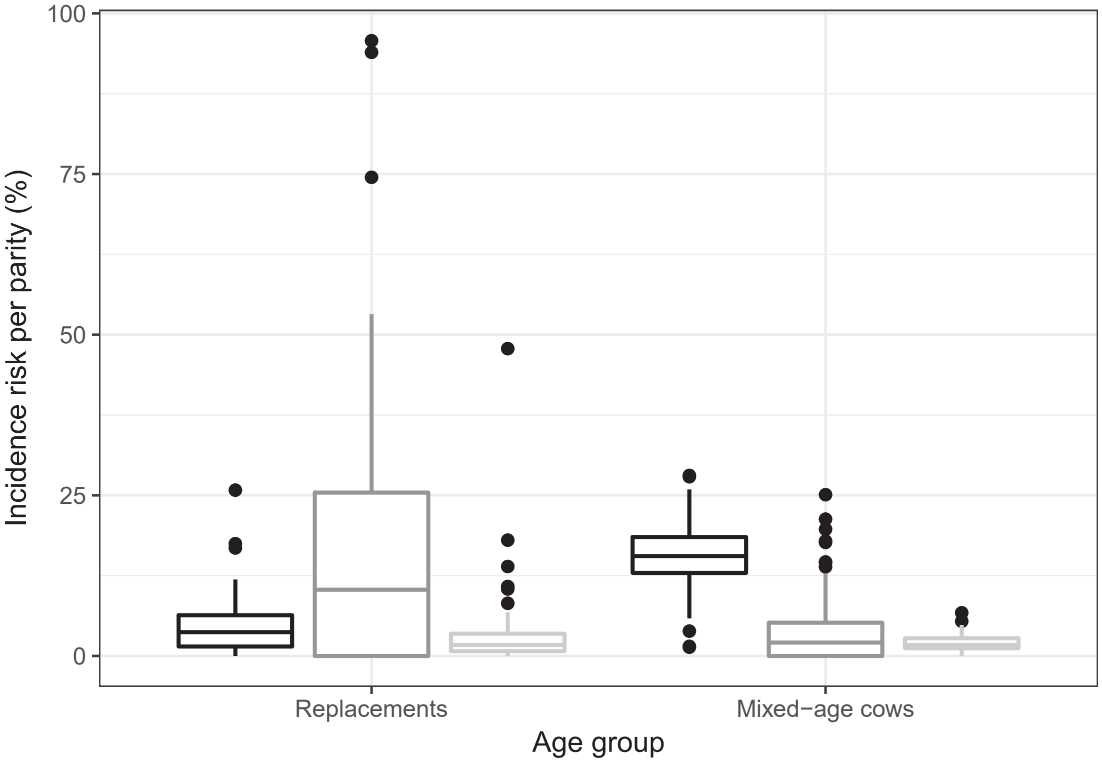

Figure 3.2: Boxplots of the distribution of herd-level incidence risk per parity (IR p) of culling (black), sale (mid-grey) and mortality (light grey) by age group at the start of parity (birth for replacements = 0 yr, calving for mixed-age cows = 2+ yr) among 113 herds from four regions of New Zealand

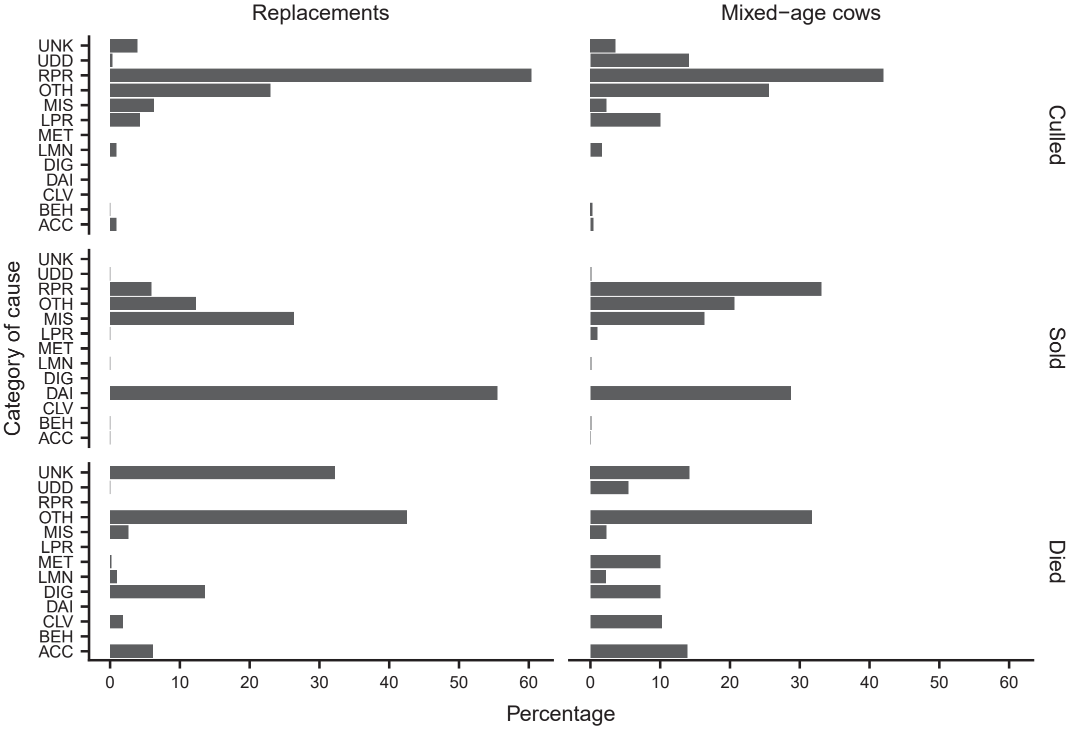

Figure 3.3: Percentage of removed animals grouped by category of cause attributed by farmers and by fate of animal at removal among 113 herds from 4 regions of New Zealand (ACC = accident-injury, BEH = behavior, CLV = calving-related, DAI = for dairy purposes, DIG = digestive, LMN = lameness, LPR = low production, MET = metabolic, MIS = cause not recorded, OTH = other known cause, RPR = reproductive-related, UDD = udder-related, UNK = unknown cause)

28.7% of sales, respectively), whereas DAI was most frequently reported for sold replacements (55.5% of sales). Other known causes, followed by UNK, were the most frequently reported categories for mortalities in both replacements (42.5 and 32.2%, respectively) and mixed-age cows (31.7 and 14.2%, respectively). Other important known reasons reported for mortality in mixed-age cows were ACC, CLV, DIG and MTB disorders. The pecentages of animals removed, grouped by age (replacements and mixed-age cows), fate at removal, and category of reported cause of removal are presented in Tables 4 and 5 in the Appendix.

The IR_p of culling, sale and mortality for each of the four most frequently reported cause categories among replacements and mixed-age cows are presented in Table 3.3.

Table 3.3: Incidence risk (IR)[1] of removal per parity[2] grouped by age group and fate, for each of the four greatest IR categories[3] of reported cause

Age group	Fate	Cause category	Number cases	IR	95% CI
Replacements	Culled	RPR	477	2.6	(2.4, 2.9)
		OTH	182	1.0	(0.9, 1.2)
		MIS	50	0.3	(0.2, 0.4)
		LPR	34	0.2	(0.1, 0.3)
	Sold	DAI	1,586	8.8	(8.4, 9.2)
		MIS	753	4.2	(3.9, 4.5)
		OTH	351	1.9	(1.7, 2.2)
		RPR	168	0.9	(0.8, 1.1)
	Died	OTH	215	1.2	(1, 1.4)
		UNK	163	0.9	(0.8, 1.1)
		DIG	69	0.4	(0.3, 0.5)
		ACC	31	0.2	(0.1, 0.2)
Mixed-age cows	Culled	RPR	4,214	6.6	(6.4, 6.8)
		OTH	2,563	4.0	(3.8, 4.2)
		UDD	1,414	2.2	(2.1, 2.3)
		LPR	1,007	1.6	(1.5, 1.7)
	Sold	RPR	732	1.1	(1.1, 1.2)
		DAI	634	1.0	(0.9, 1.1)
		OTH	455	0.7	(0.6, 0.8)
		MIS	360	0.6	(0.5, 0.6)
	Died	OTH	421	0.7	(0.6, 0.7)
		UNK	189	0.3	(0.3, 0.3)
		ACC	184	0.3	(0.2, 0.3)
		CLV	136	0.2	(0.2, 0.3)

[1] Percentage

[2] Time period between birth or calving, and subsequent calving or removal from a herd

[3] ACC = accident-injury, DAI = dairy purposes, DIG = digestive, MIS = cause not recorded, OTH = other known cause, RPR = reproductive-related, UDD = udder-mastitis, UNK = unknown cause

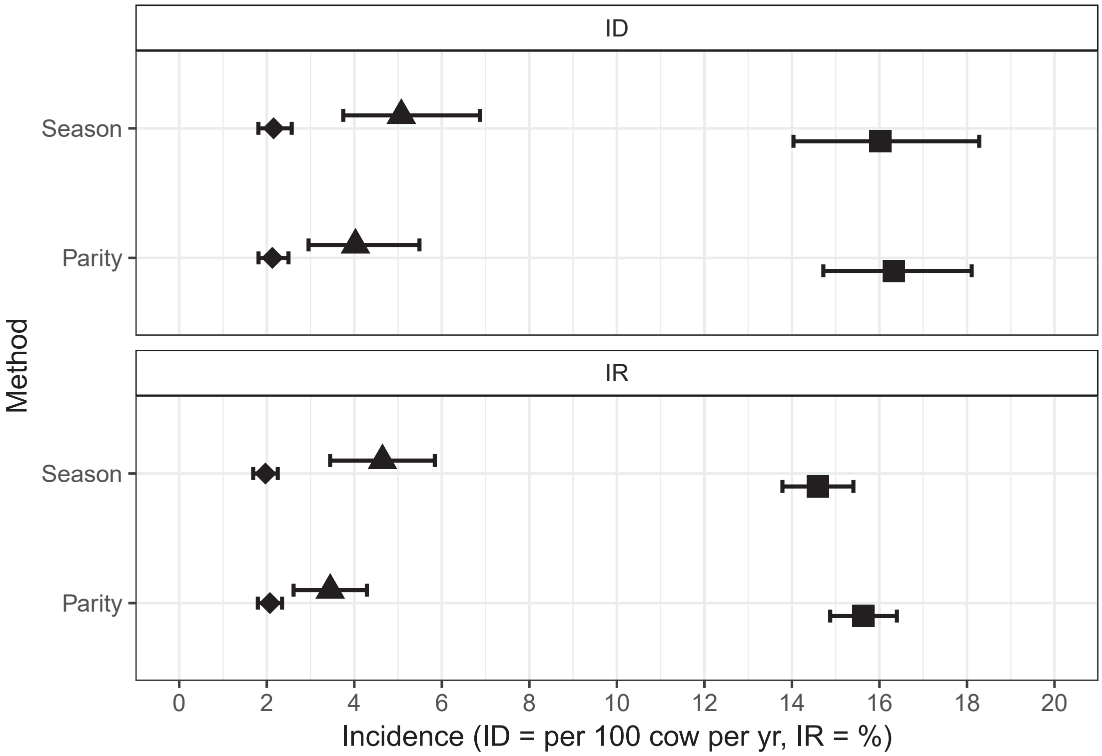

Figure 3.4: Incidence density (ID) and incidence risk (IR) of culling (■), sale (▲) and mortality (⧫) with 95% confidence intervals of mixed-age cows from two different data sets based on the same population of 113 seasonal-calving herds from four regions of New Zealand

3.3.5 Comparison of Different Methods to Measure Incidence

The maximum difference for each of the ID or IR estimates for the 'season' compared with the 'parity' data sets were 1.1 cases per 100 animals per yr and 1.2%, respectively, for sold mixed-age cows (Figure 3.4). Despite the numerical differences, the confidence intervals of the estimates for each comparison overlapped widely, and therefore, we concluded that there were no significant differences between the estimates for measuring IR or ID using either data set.

3.4 DISCUSSION

The IR_p of culling and mortality of mixed-age cows in the seasonal-calving, pasture-based New Zealand dairy herds were less than those of other countries with modern dairy industries, but the percentage of mixed-age cows culled for RPR causes and the percentage of mortalities that occurred in the transition period were greater than reported elsewhere. Furthermore, we deduced that the IR_p mortality in replacements was likely under-reported, and that the true burden of animal health disorders in mixed-age cows needed to include cows that were sold in addition to those reported as culled or died on-farm. Overall, our results indicate that there are opportunities to reduce the avoidable losses of dairy animals in pasture-grazed herds and thereby improve cow welfare and lifetime productivity.

3.4.1 Animal-Level Incidence of Culling, Sale, and Mortality

The $\mathrm{IR_p}$ of culling (15.6%), sale (3.4%) and mortality (2.1%) in mixed-age cows in our study were generally less than those from countries with housed dairy systems [Compton et al., 2017]. Mohd Nor [2014] reported that the IR of culling and mortality combined averaged 25.4% annually in Dutch cows, and, in the USA, Pinedo et al. [2010] reported annual culling and mortality rates in cows of 25 and 7%, respectively. The $\mathrm{IR_p}$ of culling in our study is more comparable with that of Irish dairy farms, which also have a seasonal, spring-calving pattern, with most feed provided by pasture grazed in-situ [McCarthy et al., 2007]. Leonard et al. [2001] estimated the annual IR of culling and mortality in Irish cows was 17 and 1%, respectively, and these data were updated in 2006 to 23 and 4%, respectively, by Maher et al. [2008]. Our results are consistent with both observational [Dechow et al., 2011, Burow et al., 2011, Alvasen et al., 2012] and experimental studies [White et al., 2002] that indicate reduced IR of culling and mortality in systemes where cows are pasture-grazed, or at least when access is available to pasture, compared with housed cows.

Our results also indicate that the seasonal IR of culling and mortality in New Zealand dairy cows are little different compared with earlier reports. Anderson [1985] estimated that the annual IR of culling and sale combined across mixed-age cows in one region of New Zealand was 20%, whereas Harris [1989] and Xu and Burton [2003] reported that annual culling rates varied from 7.6% in 2 yr olds to 19.9% in cows ≥ 10 yr of age, and 13% in mixed-age cows, respectively. Additionally, the mean $\mathrm{IR_p}$ of mortality of mixed-age cows in the current study was similar to those of Anderson [1985, 2.5%], and Xu and Burton [2003, 2.1%] but it was greater than those of Harris [1989, 1.0% to 1.5% depending on cow age]. Although comparisons between results from previous and the current studies should be made with caution because of different study methods, this finding indicates that the international trends for increasing mortality associated with increasing herd size [Thomsen et al., 2006, Alvasen et al., 2012] over the past few decades have not occurred to the same extent in the pasture-grazed, seasonal-calving dairy systems common in New Zealand. Nevertheless, these data are were collected several years ago, and a longitudinal study of more current New Zealand data is required to confirm this.

The patterns observed in the plots of changing $\mathrm{ID_p}$ of culling, sale and mortality over time reflect the combined effects of risk periods for disorders associated with parturition and management practices in seasonal-calving herds. The peaks of $\mathrm{ID_p}$ of culling most likely represent periods of pregnancy testing approximately five weeks following the end of the breeding period, following which non-pregnant cows were culled, and subsequently at expected inter-calving intervals in non-pregnant cows that did not milk for one or more lactations (‘carried-over’, approximately 2% of cows that calved). Culling of cows in older age groups was more intense throughout the follow-up period, which was likely due to increased prevalence of disorders that occurs with increasing age. Notably, the peaks of $\mathrm{ID_p}$ of sale of mixed-age cows aligned approximately with those of culling, which indicates that a proportion of cows that might otherwise have been culled were instead sold for dairy purposes. Furthermore, younger compared with older mixed-age cows were sold at increased $\mathrm{ID_p}$, in reverse order to age-dependent $\mathrm{ID_p}$ of culling, which provides additional support for our hypothesis that culling and sale represent the effects of similar disorders.

The first peak of $\mathrm{ID_p}$ of mortality in mixed-age cows occurred at parturition, consistent with others’ findings that the transition from late pregnancy to early lactation is the period of greatest risk for on-farm deaths and associated health disorders [Thomsen et al., 2004, Pinedo et al., 2010, Alvasen et al., 2014b]. If we assumed that the cows that died > 330 d post-calving were in the last month of pregnancy and all cows had a 365 d inter-calving interval, the risk of mortality in all the transition period (30 d pre- to 30 d post-calving) was 4.3-fold greater than in other periods within the parity. Furthermore, the most productive cows aged 5 yr and older had greatest risk (1.8-fold increased risk) compared with cows aged 2 to 4 yr, indicating that they require improved preventive or intervention strategies to reduce mortality. Additionally, the proportion of mortalities in mixed-age cows in the transition period of this study (45.4%) was greater than that reported by Thomsen et al.[2004, 31% of parity 1 and 2 and 41% of parity 3 and greater] and Alvasen et al [2014a, 30% and 36% of primiparous and multiparous cows, respectively]. The increasing risk of mortality in late pregnancy was also reported by Pinedo et al.[2010], and was suggested in the survival curves presented by Thomsen et al. [2004], but not by Alvasen et al. [2014a], who instead reported an exponentially decreasing ID post-calving. These contrasting findings may reflect differences in the likelihood that farmers in different countries will record a calving in cows with peripartum disorders, and also, different risk factors for mortality in different farming systems.

3.4.2 Herd-Level Incidence of Culling, Sale, and Mortality

The herd-level measures of culling of replacements and mortality in mixed-age cows from this study provide benchmarks for farmers to compare their herd performance against national levels and act as starting points to set their performance targets. Neither mortality of mixed-age cows nor culling of replacements are economically beneficial to farmers, and especially in the case of the former, do not reflect favorably on the welfare state of cows. The case to establish performance benchmarks from these measures is arguably more straightforward, than, for example, setting benchmarks for culling and sale of mixed-age cows, which is mainly an economic decision [Dohoo and Dijkhuizen, 1993, Fetrow et al., 2006] and therefore subject to many influences. Individual farm performance targets may best be set by the owner, but we suggest measured against national targets set on the 25th percentile of herd-level $\mathrm{IR_p}$: 1.5% for culling of replacements, and 1.2% for mortality of mixed-age cows.

The box-plots of distributions of $\mathrm{IR_p}$ indicate relatively few outlier herds with high incidences of culling and mortality in replacements. Culling of replacements is likely to be financially damaging because the costs for breeding and rearing are considerable [Boulton et al., 2017], and may not be recovered by prices received for culled animals. The greatest number of outlier herds existed for $\mathrm{IR_p}$ for sale of both replacements and mixed-age cows. This finding for replacements may be explained by the active live export trade for nulliparous heifers in the study period. These findings are reflected in the greater ICC estimated for sale, and low estimates (< 0.1) for culling and mortality. These estimates of ICC may also be used by researchers to estimate samples sizes for sampling of similar populations to determine

IR of the same outcomes.

We attributed the difference between the mean herd-level IR_p of mortality in registered replacements (2.9%) and an adjusted measure (5.9%) to under-reporting of neonatal deaths by farmers. Our adjustment method would only account for those additional deaths occurring in the neonatal period between ear-tagging and registration, and would not include perinatal mortalities because dead heifer calves were unlikely to be ear-tagged and registered. Therefore, we do not suggest a benchmark for IR_p for mortality in replacements at present, but a more recent prospective study by Cuttance et al. [2017] in herds with similar management estimated the mean total perinatal (birth to 24 h or age) and neonatal (24 h to weaning) mortality to be 9.8%. Elevated and increasing incidence of perinatal and neonatal mortality of dairy calves are of concern internationally [Mee, 2013], and together these findings from New Zealand herds support the need to develop programs to reverse this trend.

We do not suggest a benchmark for IR_p of culling of mixed-age cows because the complex and interacting factors that influence farmer polices, such as, current and expected milk, beef and feed prices, and individual farm plans, are highly variable. For example, if a farmer plans to increase herd size, they are less likely to cull cows that are under-performing and retain them, instead of purchasing replacements [Faust et al., 2001]. Furthermore, an achievable IR of culling of cows that optimizes economic returns to the farmer under various scenarios has not been estimated. The most recent report to investigate the effect of herd replacement rate on economic return under New Zealand conditions indicated that an annual herd replacement rate of 15%, with selection of heifers on breeding worth, was most profitable [Lopez-Villalobos and Holmes, 2010]. However, this work did not consider the economic impact of different timing or relative proportion and causes of culling and mortality, and the authors concluded that excellent reproductive performance and animal health were required to achieve this replacement rate. The distribution and quartiles of herd-level IR_p of culling that we report should instead be considered as descriptive only.

3.4.3 Reported Causes and Cause-Specific Incidences of Culling, Sale, and Mortality

Reproduction-related causes were the most frequently reported reasons for culling in replacements (60.4%) and mixed-age cows (42%). While RPR causes have been consistently reported as important in previous studies, the percentage of culled cows attributed to RPR in the current study was approximately twice that of recent reports from continuous-calving, housed systems. For example, in USA herds, RPR codes were reported for 18.9 and 20.1% of culled cows by Hadley et al. [2006, including dead cows among culls] and Dechow and Goodling [2008], respectively. However, they were second in importance to injury or other causes (26.9 and 26.3% for each study, respectively). In Swedish herds, the percentage of RPR culls varied between 21.9 and 26.9%, depending on breed of cow and whether the herd was conventional or organic [Ahlman et al., 2011], but culling for UDD causes was similar or greater (18.7 to 30.7%). The reason for the differences between systems is that in seasonal-calving dairy systems, as are common in New Zealand and other pasture-grazing industries, it is necessary to maintain a concentrated-calving pattern and approximately 365-d mean calving interval to optimize milk production with pasture supply. Animals that fail to conceive in the limited breeding period will not commence a new lactation in the subsequent season, and because it is costly to feed them for a season without any economic return from milk, most are culled or sold. This constraint imposed by the calving pattern is a key factor contributing to the relatively high proportion of culling in replacements and mixed-age cows for RPR causes in seasonal-calving, pasture-grazing herds. Furthermore, herds with poor reproductive performance are less able to remove animals for other reasons, especially poor production, which reduces productivity, genetic improvement and ultimately, profitability of the herd.

After RPR and OTH causes, we determined that UDD was the next most frequent category of causes reported for culling of mixed-age cows in the current study (14.1% of all categories). In contrast, reports from confinement systems indicate greater relative percentages of culling attributed to udder-related and mastitis codes [Dechow and Goodling, 2008, 16.7%; Ahlman et al., 2011, 24 to 31% depending on whether conventional or organic system]. Comparatively few animals in the current study were culled for the cause LMN (1.6% of all categories) compared with other studies. In contrast, Dechow and Goodling [2008] reported 7% of cows culled in Pennsylvania, and Ahlman et al. [2011] reported 5 to 7% of cows culled in Sweden, had disposal codes related to lameness. The differences between the relative percentage of cows culled for these disorders in the different dairy systems may reflect reduced prevalence or severity of mastitis [Lean et al., 2008] and lameness [Fabian et al., 2014, Chesterton et al., 2008], or the indirect effect of these disorders on culling through reproductive failure, in pasture-grazing compared with confinement systems.

Interestingly, RPR was the most frequently reported cause for sale of mixed-age cows, and the next most frequent cause (after MIS and OTH) for sale in replacements. This finding is supported by the previously-mentioned alignment of the timing of culling and sale among mixed-age cows, and increased incidence of sale among younger compared with older cows. This result suggests that the effects of reproductive failure especially, and possibly other disorders, should be measured not only among culled, but also among sold cows and replacements.

A greater range of causes were reported for mortality among both replacements and mixed-age cows, as indicated by the fact that OTH category was most frequent in both age groups. Among mortalities in replacements, DIG (representing mainly diarrhea) was the most frequently reported explicit category, as reported in other studies [USDA, 2012, Santman-Berends et al., 2014]. Respiratory disease was seldom diagnosed as a cause of mortality in this age group in our study, in contrast with reports from many other countries where pathogens that cause more severe respiratory disease, such as *Mycoplasma bovis*, are present, and replacements are housed instead of pasture-grazed. Next in descending order of frequency of reported causes for mortality in mixed-age cows after the catch-all OTH, were UNK, ACC, MET, DIG and CLV, each of which had approximately equal proportions. Hence, effective programs for the control of neonatal diarrhea would likely result in the greatest reduction of mortality among replacements, and improved management of cows in the transition period to prevent metabolic and calving-related disorders would similarly benefit mixed-age cows. However, because of the wide range of reported causes of mortality in both age groups, it is likely that herd-specific factors are important for mortality, and that effective programs to control mortality will need to be holistic and designed for individual farms [McConnel et al., 2010].

3.4.4 Comparison of Different Methods to Measure Incidence

Standardized methods are needed to calculate incidence so that the results are comparable between populations and over time. The method chosen will depend upon the purpose that the results will be used for, the type of data available, and the computational power available to be applied to that data. For example, to calculate IR requires only the count of cases, and the count of animals in the population, and is, therefore, readily calculated by farmers and advisors, and the result in terms or probability is intuitively understood. The epidemiologically correct definition of IR requires a closed population and account of withdrawals [Dohoo et al., 2009], but the term "lactational incidence" is commonly used when describing disorders in dairy herds [Kelton et al., 1998] and hence we retain its use here. By contrast, ID requires not only the count of cases, but a summation of animal time, and, therefore, requires more computation, and the interpretation of the result in terms of animal time is less intuitive.

Because the season and parity methods used to calculate mean incidence measures generally provided equivalent estimates for each combination of measure and main outcome, we recommend either method. It is notable that the variances for the season estimates were greater than those of the parity estimates, as indicated by the greater width of their confidence intervals. One explanation may be that by use of calendar dates as cut-points for consecutive seasons, it is possible that in some seasons, culled or sold animals were recorded in a different season to the one in which animals were born or calved in, which would inflate or deflate the results, depending on the season they were counted in. The implication is that if the season method is used with individual farms, it is important to consider when animals were culled or sold with respect to the season start and end dates. This problem is less likely to occur for estimates of mortality because they occur more randomly in relation to season start and end dates. Another possible reason is that in seasons where purchase or sale of animals are frequent, considerable changes in the denominator of the equation will occur, which will affect the estimate. This could be avoided by including only animals born or calved in the season in the denominator. To summarize, in seasonal-calving dairy systems, with population data, either season or parity methods, or IR or ID measures, provide comparable estimates of mean incidence of culling, sale, or mortality; but the parity method with either measure is more robust for use with individual herd data.

3.4.5 Study Limitations

This study has two main forms of bias that may affect our findings. Selection bias is possible because the study herds were a convenience, rather than random selection of herds. When compared with those from the New Zealand population of dairy herds in that season, the study herds were larger, more productive, had increased replacement rates and were more likely to be owner-operated. It might be argued that progressive farmers of well-managed herds with reduced incidence of culling and mortality were more likely to enroll in the NHFS study, but they were also more likely to not withdraw and to provide high quality data than reluctant and less motivated farmers (whose poorer quality data or withdrawal themselves may cause bias). If this was the case, then our incidence measures might be biased downward, but we have no data to predict its extent. A further likely form of bias in this study arose from misclassification of, or missing records of causes of removal. When farmer-reported causes of death were compared with necropsy findings, farmers were correct in fewer than half of cases [McConnel et al., 2009, Thomsen et al., 2012]. Because of these problems, caution should be used when interpreting farmer-reported causes, and additional information sought from other data before a cause is attributed, such as the stage of parity at removal and any preceding treatment history. Moreover, UNK causes were frequently reported for mortality in both age groups, which further adds to the uncertainty in the estimates of their cause-specific percentages or IR_p. For these reasons, we make only general inferences from our analyses of farmer-reported causes of removal.

3.4.6 Conclusions

The results from this study provide data for farmers and industry stakeholders to describe culling, sale, and mortality of dairy animals, and to benchmark IR of mortality in cows and culling of replacements in a pasture-grazed, seasonal-calving system. The overall incidences of culling, sale and mortality of dairy animals were less than those reported in other modern dairy countries, but the between-herd variation indicates further scope for improvement. Reproduction-related disorders were the most frequently reported cause for culling of replacements and culling and sale of mixed-age cows; whereas, a greater range of causes of mortality were reported by farmers, although many were related to calving disorders. Effective programs for management of transition cows, reproduction, and udder health are needed to maintain and enhance the welfare and productive life of dairy animals.

3.5 ACKNOWLEDGEMENTS

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Chapter 4

Temporal and spatial analysis of culling and mortality of cows in New Zealand between 1990 and 2012

4.1 ABSTRACT

We aimed to investigate temporal trends and spatial patterns of the incidence of culling and sale combined (hereafter simply defined as culling), mortality, and length of herd life, of cows in seasonal-calving New Zealand dairy herds between between 1990 and 2012, and their associated herd-level risk factors. We defined a herd as all cows that calved in a unique combination of geographic location and herd identifier, a season as the period between June 1 of the calendar year in which it started and May 31 of the subsequent year, and a seasonal-calving herd as one in which $> 95\%$ of cows calved between June and November. Individual cow records were aggregated to the herd-season season level, the unit of analysis. The main outcome variables in our study were incidence density per parity of culling ($\mathbf{ID_{CS}}$), mortality ($\mathbf{ID_{M}}$), and median herd life (**HL**, median interval of cows in a herd-season between first calving and exit from the herd in which they first calved). Herd-season data were aggregated to 20 by 20 km polygons for spatial analysis and herd size and change in herd size categorized into quintiles for each season. We investigated time trends of the main outcomes with temporal random-effect models, and risk factors for $\mathrm{ID_{CS}}$ and $\mathrm{ID_{M}}$, including spatial patterns of excess risk, with separate Bayesian spatial regression models in each of eight seasons. The mean ID$_{\mathrm{CS}}$ and ID$_{\mathrm{M}}$ per parity over the study period were 17.5 and 2.3 per 100 cow yr, respectively, and their linear trends over the study period were stationary. The mean HL of cows in the study period was 4.5 yr, and had increased significantly by 0.2 mo per season between 1990 and 2003. Generally over the study period, increased ID$_{\mathrm{CS}}$ was associated with herds established $>$ one season compared with herds in their first season, herds predominantly of Holstein-Friesian compared with Jersey or other breeds, herds of smallest size and change in herd size in the subsequent season compared with larger herds or herds of greater increase in herd size. Increased ID$_{\mathrm{M}}$ was associated with herds of Jersey compared with Holstein-Friesian or other breeds, herds in the first season of establishment compared with herds established more than one season, herds of the first quintile of both herd size and change in herd size compared with the third quintiles of each, and with herds of the fifth quintile of herd size in 2008 and 2012 compared with the third quintile. The spatial patterns of variance of ID$_{\mathrm{CS}}$ unexplained by the models were homogeneous, but were more heterogeneous for ID$_{\mathrm{M}}$. This study provides the most recent information on culling and mortality and on their herd-level risk factors and spatial patterns in seasonal-calving herds in New Zealand. This information may be used to direct control programs, and indicates the need to further investigate why herds with particular characteristics perform more poorly than others.

Key words: culling, mortality, seasonal-calving, pasture-grazing

4.2 INTRODUCTION

Both dairy farmers and the public are concerned about the health, productivity and welfare of cows. Farmers aim to have healthy and productive cows with low rates of mortality and non production-related culling because those outcomes have been shown to increase profitability [Rogers et al., 1988], often with the belief that by doing so they will also achieve good animal welfare standards [von Keyserlingk et al., 2013]. Consumers increasingly seek affordable milk products from animals managed under high health and welfare standards [Wolf et al., 2016]. A group of North American dairy industry stakeholders (including farmers) recently interviewed about the welfare of cows raised concerns related to on-farm mortality and culling, especially when their incidence was high [Ventura et al., 2014]. For these reasons, it is important to accurately report the incidence of culling and mortality in dairy herds to create awareness of any problem, should it exist, and to benchmark national or individual herd performance which should then motivate change to improve both animal welfare [von Keyserlingk et al., 2013] and farm profitability.

Concerns about adverse welfare conditions of dairy animals have mostly been directed towards intensive, housed dairy systems, particularly because of the relatively high incidence of clinical disease and mortality, and lack of freedom to express normal behaviors [Arnott and Ferris, 2016]. However, welfare of animals in pasture-grazing systems, as are common in New Zealand, has also been scrutinized. Both Hemsworth et al. [1995], and more recently Arnott et al. [2016], reported that cows grazed continuously were more susceptible to climatic stressors than housed cows, and the latter authors raised concerns about more extreme cases of negative energy balance in extensive systems, visible as cows with very poor body condition. Despite reports that pasture-grazing systems confer advantages for cow survival over housed systems [Dechow et al., 2011, Alvasen et al., 2012], and that consumers may prefer them over the former because they are more 'natural' [von Keyserlingk et al., 2013], farmers with pasture-grazing systems are not beyond scrutiny. In response, farmers with pasture-grazing systems need to define their own indicators of animal welfare performance, including those related to the incidence of culling and mortality [de Vries et al., 2011].

Various authors have reported increased incidence of mortality of dairy cows in recent decades, both in individual countries [McConnel et al., 2008, Thomsen et al., 2004, Alvasen et al., 2014a], and across a range of countries with modern dairy systems [Compton et al., 2017]. One possible explanation is that intensification of dairy farming management, as indicated by increased herd size and annual milk production per cow, is associated with increased mortality. Dechow et al. [2008] reported a positive association between the incidence of mortality and mean cow milk production, but other more recent reports have contradicted those findings [Alvasen et al., 2012, Shahid et al., 2015]. However, positive associations between mortality incidence and herd size have been more consistently reported [Raboisson et al., 2011, Alvasen et al., 2012, Shahid et al., 2015]. Furthermore, a genetic basis for mortality has been reported in Swedish Holsteins by Alvasen et al. [2012], and McConnel et al. [2008]

reported different rates of mortality across dairying regions in the US. Harris [1989] reported on the incidence of age- and cause-specific culling and mortality in seasonal-calving herds in New Zealand in the mid 1980's, but between 1990 and 2012, mean milk production has increased 1.3-fold from 259 kg to 349 kg milk solids per cow per lactation, mean herd size has increased 2.5-fold from 164 to 402 cows, the relative proportion of Holstein-Friesian breed cows has decreased, and the proportion of herds and cows located in the South Island has increased [Anonymous, 1991, 2013c]. However, to the best of our knowledge, there are no detailed reports from New Zealand herds throughout this period of change that have investigated whether the incidence of mortality has varied over time or has been associated with these changed factors. Neither has there been any investigation of spatial patterns of culling or mortality in New Zealand dairy herds to determine if research or control programmes need to be targeted at particular geographic areas.

A dairy cow is culled when a farmer makes an economic decision to replace it with one that will be more profitable [Fetrow et al., 2006]. That decision is influenced by a complex of interacting factors, including cost and availability of replacements, the current price received for culled cows and the price expected for future milk production, expected feed costs, policy for culling for particular diseases or reproductive status, and, plans for future changes in herd size and genetic merit. Although farmers may not always make economically optimal culling decisions, Rajala-Schultz et al. [2000] reported that optimal culling policies responded to increased milk prices with decreased culling. Farm-specific policies are seldom recorded in studies, but external factors such as milk price may be measured, and in part explain observed variation in culling incidence at a national level over time. Both increased [Pinedo et al., 2014] and decreased [Gates, 2013] herd size have been associated with increased incidence of culling, and cause-specific culling risks have been reported to vary among cow breeds [Ahlman et al., 2011]. Yet these studies were in dissimilar management systems and there is a need to investigate whether these same risk factors for culling exist in a seasonal-calving pasture-grazing system.

We reasoned that the incidence of mortality, but not of culling, has increased with intensification in New Zealand dairy herds between 1990 and 2012, as has occurred in other countries with modern dairy industries [Compton et al., 2017]. We also expected that New Zealand herds would share similar risk factors for culling and mortality reported from other countries, but that novel factors might be identified that relate to its unique management systems and environment, including those in particular geographic areas of the country, such as feeding of crops in-situ in winter when pasture growth rates are insufficient for requirements. The primary aim of our study was to describe the temporal trends in incidence of culling, mortality, and length of herd life, in spring-calving dairy herds in New Zealand between 1990 and 2012. Our secondary aim was to investigate their associations with herd-level risk factors and identify any geographic areas of excess risk of culling and mortality over the same period.

4.3 MATERIALS AND METHODS

4.3.1 Data Sources

In New Zealand in 2016, approximately 90% of dairy herds [Anonymous, 2017e,f] were owned by shareholders of LIC (Hamilton, New Zealand) and who used them to manage routine demographic and breeding data, and optionally, records of production and animal treatments. Data for the current study were extracted from the NZ dairy industry database with permission from the Core Database Access Panel (DairyNZ, Hamilton, New Zealand, Decison Number 52). The data consisted of all the 46 core data fields of animal events recorded in herds with data recording services supplied by LIC, between June 1990 and May 2014, including records of cows that existed at the start of that period. We extracted uniquely-identified, individual-level records of births, movements into and out of herds including the event date, fate (culled, sold, died or temporarily moved out of the herd), and dates of calving events. Herds were uniquely identified by a combination of a geographic point location and a unique herd number. Milk prices adjusted for inflation were obtained from LIC and DairyNZ annual reports [Anonymous, 2013c, and earlier].

4.3.2 Definitions

The terms defined in the context of this study are presented in Table 4.1. This was a retrospective cohort study, and the unit of analysis was the individual herd for one season (a herd-season). The reference population were seasonal-calving herds in New Zealand over the study period.

Table 4.1: Definitions of terms

Term	Definition
Breed	Holstein-Friesian or Jersey if their pedigree was greater than three-quarters of that breed, else Other
Cow	A female dairy animal of mixed-age that has calved at least once
Culled	A cow sent from the herd for immediate slaughter for human consumption or sold to another farmer for dairy purposes
Died	A cow that died unassisted or was euthanized on-farm
Fate	The means by which a cow exited the herd (that is either culled or died)
Herd	A group of cows with a unique combination of geographically-coded location and herd identification number, typically managed as a single group. New herds were created when a new group of animals was moved to the same location, or a new farm location was created. A single location could have more than one herd present in a single season
Herd breed	The predominant (most numerous) breed of cows in a herd
Herd life (HL)	Interval (in yr) from the date of first calving of a cow to the date of culling, sale or death in the same herd in which the cow first calved
Herd size	The number of cows that calved in a herd in a given season
Incidence density (ID)	The number of cases during a defined time period divided by the total animal-time at risk in the same population and time period
Incidence density ratio (IDR)	The ratio formed by the division of the ID in one group by the ID of a comparative group
Incidence risk (IR)	The number of cases during a defined period divided by the number of animals present at the start of the period
Lost to follow-up (LFU)	A cow without a subsequent calving or record of being culled, sold, died or moved off off the dairy farm within 30 months of their most recent calving
Parity or time at risk (TAR)	The interval between calving and the date of culling, sale, mortality, movement out of the herd, or the subsequent calving in that herd. The maximum interval, or interval at which cows were censored, if LFU, was 30 mo
Replacement rate	The percentage of the herd comprized of cows that were 2 yr of age
Season	The interval from 1 June to 31 May in the subsequent year, coded as the year in which the season started
Standardised morbity or mortality ratios (SMR)	The ratio of the number of observed cases divided by the number of expected cases in a sub-population, where the number of expected cases equals the overall ID of cases in the total population multiplied by the total animal-time at risk in the sub-population
Seasonal-calving herd	A dairy herd in which $>$ 95 percent of calvings occurred in the six-month period between June and November in the season of interest

4.3.3 Data Management

Together with data retrieved from the LIC database listing animal and herd identifiers, date of birth, breed, calving date(s), and date and fate if an animal exited the herd, we created variables for TAR, age at start of TAR, HL, and dichotomous (no or yes) statuses for each of LFU, culled, or died. Dates of events and fates of animals that exited herds were farmer-recorded. Cows were censored at 30 mo if LFU. These variables were aggregated to the herd-season level to create the outcome and predictor variables, and to serve as indicators of the quality of herd records to form exclusion criteria when the final data set was created. The aggregated data set comprised records for 298,255 herd-seasons (Figure 4.1).

We excluded herds that were not seasonal-calving or changed their calving system in the subsequent season or were in their final season of operation, because their culling policies, particularly for non-pregnant cows, may have been different from our reference population. Herd-seasons with ≤ 50 cows were excluded because we believed they did not represent the reference population and that they may have created extreme outcomes through small numerical changes in the number of cows of any status that exited a herd. Over the study period, herds of this size were the smallest recorded category in annual national statistics, [2.3% and 0.1 % of herds in 1995 and 2012, respectively, Anonymous, 1996, 2013c]. We excluded herd-seasons with $> 5\%$ of cows LFU as we considered their data to be unreliable, and herds with a geographic location not on the North or South Islands of New Zealand (**NI**, **SI**, respectively) because of database errors. We further excluded herd-seasons with IR per parity of culling equal to zero or $> 60\%$ (n = 1,491, 0.9%) or IR of sale $> 30\%$ (n = 217, 0.1%) or IR of mortality $> 20\%$ (n = 83, 0%) because we believed them implausible for commercial herds and likely to rather be due to non-reporting or data entry error. Other researchers that analyzed LIC data also used similar exclusion criteria [Harris, 1989]. Finally, we excluded data from the 2013 season because it was the last season records were collected from and it was not possible to determine whether it was the final season of operation for each herd. We calculated the proportion of herds excluded from analysis by Territorial Authority, based on the number of herds reported in each area in each of four seasons equally distributed over the study period [Anonymous [2013c]; and earlier] and inspected choropleth

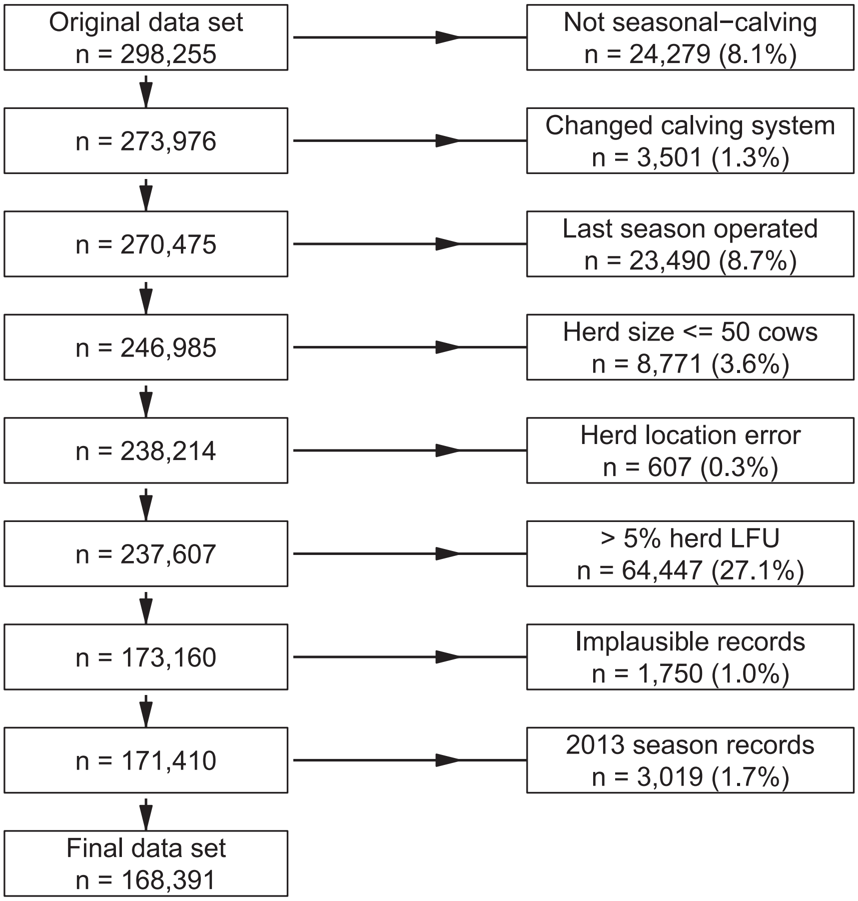


Figure 4.1: Flow-chart of number and reasons why herd-season records were excluded from final data set for analysis (The denominator to calculated percentages of records excluded is the immediate preceding number of records, herd-season refers to cows that calved in a season between 1 June and 31 May of the next year, and aggregated to the herd-level)

maps for patterns of varying representation. We analysed HL only from herd-seasons where $> 50\%$ of heifers born in that season were not LFU and for seasons commencing between 1990 and 2003 to allow at least 10 yr of opportunity to express that measure.

In total, 43.5% of herd-seasons were excluded, leaving 168,391 in the study sample. Data in the final data set were from a mean of 55.2% of herds and 54.2% of cows in the national population over the study period [Anonymous, 2013c]. We found no evidence that herds in any Territorial Authorities were differentially underrepresented in the final data set (maps not shown).

4.3.4 Main Variables

The outcome variables were ID of culling ($\mathbf{ID_{CS}}$), ID of mortality ($\mathbf{ID_{M}}$) and their respective ratios $\mathbf{IDR_{CS}}$ and $\mathbf{IDR_{M}}$ estimated from regression models; and HL. Incidence density of culling and mortality was calculated for each herd-season by summing the number of respecive cases and dividing by the exact time contributed by each cow in the herd-season. This estimate in cases per day was multiplied by 100×365 to provide units of cases per 100 cow yr. The main putative predictor variables were herd size and change in herd size in the subsequent season categorized into quintiles for each season, herd breed, and whether or not the herd was in the first season of operation.

4.3.5 Spatial Data Management

The original geographical point locations for each herd were recorded in NZMS1 map reference format (New Zealand Geodetic Datum 1949, EPSG code 27200). These were converted to New Zealand Geodetic Datum 2000 (EPSG code 2193) longitude and latitude coordinates in decimal degree format, by use of an online conversion tool provided by Land Information New Zealand (http://apps.linz.govt.nz/coordinate-conversion/). To meet the second goal of this study, we needed regression methods to separate any spatial effects from the putative herd-level risk factors. One accessible method with large data sets of individual subject locations is to group them within areas for analysis. These may be existing administrative areas, but where these are inadequate to provide the necessary spatial resolution, artificial areas can be constructed for grouping. For this purpose, we created regular grids of hexagonal polygons [Strimas-Mackey, 2016] of areas 400 (same area as 20 km by 20 km square) and 200 km^2 (same areas as approximately 14 km by 14 km square) to overlay the land area of New Zealand. The point location of each herd was then superimposed on the hexagonal polygon map and each herd assigned a hexagon identifier based on the hexagon in which it was located. New herd locations occurred over time, some of which were located in hexagons that were previously unoccupied by dairy herds, and conversely, some hexagons which previously had herds located within them ceased to do so. As a result, the total number of herds and the total number of hexagon polygons varied between seasons. Two different polygon areas were selected to investigate the effect of their size on the distribution of number of herds per polygon to inform our modeling strategy.

The number of polygons with herds located within them varied between season and by cell size. In seasons 1990, 1996, 2005 and 2012, there were 296, 340, 336 and 357 20 km-square polygons, respectively, and in the same seasons there were 438, 516, 509 and 553 14 km-square polygons. The mean number of herds located in each polygon varied with polygon size and season. The 25%, 50%, 75% quartiles of number of herds per 20 km polygon in seasons 1990, 1996, 2005 and 2012 (2.4, 7.8 and 22.3, respectively) were not greatly different from the same in 14 km polygons (2, 5.6 and 15.1 herds, respectively). The minimum number by design was always one. However, over all these seasons, there were approximately half the number of polygons that contained only 1 herd in the 20 km compared with the 14 km polygons (56.8 and 93.2, respectively). We therefore chose to use 20 km polygons for our analysis because we believed that size would both provide sufficient resolution to determine meaningful spatial differences but would also reduce the risk of spurious results from polygons that contained only one herd.

The data sets were constructed using Python (Version 3.6.0, Python Software Foundation, Fredericksburg, Virginia), and further time series and spatial analyses were conducted in R statistical software version 3.3.3 [R Core Team, 2017] and add-on packages.

4.3.6 Statistical Methods

Temporal analysis. Each of the outcomes were aggregated by season and plotted as a function of calendar time to visualize patterns of change over the study period. Random intercept models were used to investigate change in $\mathrm{ID_{CS}}$, $\mathrm{ID_M}$, and HL. The final model for each outcome was chosen because of lowest deviance information criterion and inspection of best fit with observed values.

The final temporal model for the number of cows culled was of the form:

$$\eta_{ij} = \beta_{0j} + \beta_1 Season_{ij} + \beta_2 Milkprice_j + \log(TAR)$$

where $\eta_{ij} = Negative\ binomial(\lambda_{ij}, \theta_{ij})$, β_{0j} was the overall mean number of cows culled, β_1 was a coefficient for season for the i^{th} herd in the j^{th} season centered on 2001, β_2 was the coefficient for the inflation-adjusted milk price in each season, and $\log(TAR)$ was an offset term to scale the model result to the number of culled cows per unit of animal-time. $\beta_{0j} = b_0 + v_{0j}$ where b_{0j} was the overall mean number of cows culled and v_{0j} was a random effect for season of a random walk of order 1 to explain the residual temporal effect of number of cows that were culled [Blangiardo and Cameletti, 2015]. Given a time-ordered vector $z_1 ... z_T$, a random walk of order 1 was such that z_t only depends on the element at z_{t-1} so that the conditional distribution of z_t is $z_t | z_{t-1} \sim Normal(z_{t-1}, \sigma^2)$.

The final temporal models for $\mathrm{ID_M}$ and HL were of the form $ID_{Mij} = \beta_{0j} + \beta_1 Season_{ij}$ and $HL_{ij} = \beta_{0j} + \beta_1 Season_{ij}$, respectively, where the terms were as previously described for $\mathrm{ID_{CS}}$; except that for HL, $HL_{ij} = Normal(\mu_{ij}, \sigma^2)$ and β_1 was a coefficient for season for the i^{th} herd in the j^{th} season centered on 1997, and no offset term was used.

The coefficients for the centered season terms and 95% credible intervals (**CI**) for each outcome were reported to estimate linear change over time, and the fitted estimates for each season plotted along with the observed estimates. The temporal models were fitted with integrated, nested, Laplace approximation methods implemented in the contributed 'R' package 'INLA' [Rue et al., 2009] and described in Blangiardo and Cameletti [2015].

Spatial analysis. We categorized the empirical Bayesian-smoothed SMR for culling and mortality in each polygon in eight seasons at 3 year intervals between 1990 and 2012 and plotted them as different shades of grey in choropleth maps for seasons starting in 1990, 1996, 2005 and 2012. The counts of cows culled or died in each herd-season were plotted in histograms and the appropriate distribution for modeling chosen with the aid of the 'fitdistrplus' package in R [Delignette-Muller and Dutang, 2015]. We investigated autocorrelation in the spatial data by the analysis of standardized residuals from negative binomial models of the $\mathrm{ID_{CS}}$ and $\mathrm{ID_M}$ using aggregated data at the polygon and season level, with all the putative predictor variables included. We conducted global Moran's I tests in eight seasons and plotted correlograms on the model residuals from both 'queen' (sharing at least one point on a boundary), and distance-based (all neighbors within 60 km of the polygon centroid) neighborhood structures in four seasons. We chose 60 km as the cut-point for distance because it enabled polygon centroids up to two polygons distant to be included as neighbors. Overall, Moran's I test was significant ($P < 0.05$) in 52% of combinations, and the interquartile range of Moran's I test statistic was between 0 and 0.1. Correlograms indicated spatial autocorrelation at a spatial lag of one, in two of eight, and four of eight combinations of neighborhood structures and seasons, for culling and mortality, respectively. Because of these findings, we proceeded to spatial regression modeling.

We used intrinsic conditional autoregressive models with exchangeable random effects in a Bayesian framework, also known as Besag-York-Molli models [Besag et al., 1991], to investigate risk factors for and spatial patterns of $\mathrm{ID_{CS}}$ and $\mathrm{ID_M}$. Separate models were fitted for each of eight seasons because the number and location of polygons differed between seasons. For the ith polygon, the number of culls or mortalities, were estimated from a log linear model:

$$\eta_i = \beta_0 + \beta_1 Herd\ size + \beta_2 Change\ herd\ size + \beta_3 Herd\ breed + \beta_4 First\ season\ + \log(TAR) + u_i + v_i$$

and it was assumed that the number of cases (culls or mortalities) had a negative binomial distribution, $y_i \sim NB(\lambda_i, \theta_i)$, the mean was defined in terms of the rate and the expected number of cases, E, $\lambda_i = E_i \rho_i$, and that $log(\rho_i) = \eta_i$. The intercept β_0 estimated the rate in the entire study area, β_1 to β_4 estimated the effects of the categorical variables in the model, $\log(TAR)$ was an offset term to scale the model result to cases per unit of animal-time, and u_i was a spatially structured area-level random effect specified as intrinsic conditional autoregressive, and v_i was the area-specific unstructured exchangeable area-level random effect $v_i \sim Normal(0, \sigma_v^2)$ among the polygons.

To obtain the posterior distribution from a Bayesian model for inferences, it is first necessary to define the parameters for the unknown prior distributions. We evaluated two different priors for the log of the structured effect precision τ_u and log of the unstructured effect precision τ_v which may influence the amount of smoothing of spatial effects to determine the sensitivity of the models to changes in these parameters. First, we used the method of Wakefield [2007] to assume that the residual relative risk had a log t-distribution with 2 degrees of freedom, and that 95% of these risks fell within the interval between 0.5 and 2.0, to obtain a prior for the precision of τ_u and τ_v of Gamma(1, 0.0260). Second, we used the recommendation of Carroll et al. [2015] for the same of Gamma(1, 0.5). We further investigated the sensitivity of the spatial regression models of $\mathrm{ID_{CS}}$ and $\mathrm{ID_M}$ to differences in neighborhood structure (queen or distance-based) and spatial-weighting (row-standardized or binary). In all, we collected results from models combinations of each prior (n = 2), neighborhood structure (n = 2), weighting method (n = 2), outcome (n = 2) and season (n = 8), and chose the combination of the former three that produced models with the least deviance information criterion in the greatest number of combinations to use in our final models. The combination of distance-based neighbors, with row standardized weights and Gamma (1, 0.260) precision of the spatial components provided the least DIC in 96 of the 128 combinations.

The fixed effects in the models were back-transformed from the log to the natural scale and interpreted as IDR. The mean effects of the putative risk factors together with their 95% CI were plotted for each of the seasons analysed to assess their association with $\mathrm{ID_{CS}}$ and $\mathrm{ID_M}$ and variability over time. The plotting points were 'jittered' to avoid over-plotting of symbols and credible intervals, and hence the location on the x-axis (time) appears to differ slightly, even though the analyses were on data in the same season. In all, we presented results from models for culling and mortality, in 8 seasons, or 16 models in total. Risk factors were considered significant when the 95% CI of the IDR did not overlap one or those of another compared factor. We plotted the posterior means of the polygon-specific area-level random effect terms, ζ_i, adjusted for the effects of the risk factors as differently-shaded polygons in choropleth maps in four seasons. Finally, we estimated the proportion of the spatial variance explained by the structural component by simulating a sample from the marginal posterior distributions of τ_u and τ_v. The assumptions of both the temporal and spatial models and presence of outliers were assessed by evaluating the distributions of the probability integral transforms and posterior predictive p-values, and scatterplots of the posterior means of the predictive distributions versus the observed values [Blangiardo and Cameletti, 2015].

4.4 RESULTS

4.4.1 Descriptive Analysis

Over the study period the number of herds in the final data set decreased (8,008 to 6,240), and the mean herd size and the percentage that were located in the SI increased (178 cows to 360 cows and 7.7% to 24.6%, respectively, Figure 4.2). Over the study period the proportion of herds that were in their first season of operation and the mean replacement rate varied between seasons, but the former decreased overall. The proportion of herd breeds that were Holstein-Friesian increased until 1998 and then decreased, while 'Other' breed (mainly crossbreeds of Holstein-Friesian and Jersey) correspondingly increased after 1998, and the proportion of Jersey herds decreased slightly over the entire study period.

4.4.2 Temporal Trends

The $\mathrm{ID_{CS}}$ varied between seasons from a minimum of 14.2 to a maximum of 20.6 cows per 100 cow yr (Figure 4.3), and there was no linear trend in $\mathrm{ID_{CS}}$over time (relative change = 0% per season, 95% CI = -3.6%, 3.8%) after adjustment for the inflation-adjusted price of milk. The $\mathrm{ID_{CS}}$ was associated with the inflation-adjusted price of milk: for each 1 $NZD increase in milk price, the $\mathrm{ID_{CS}}$ changed by a relative -3.1% (95% CI -5.4%, -0.8%). Between 1990 and 2012 the linear trend for $\mathrm{ID_M}$ was stationary 0.8% per season (95% CI = -1.7%, 3.5% per season. The linear trend for HL increased between 1990 and 2003 by a mean of 0.2 mo per season (95% CI = 0.1, 0.2 mo per season).

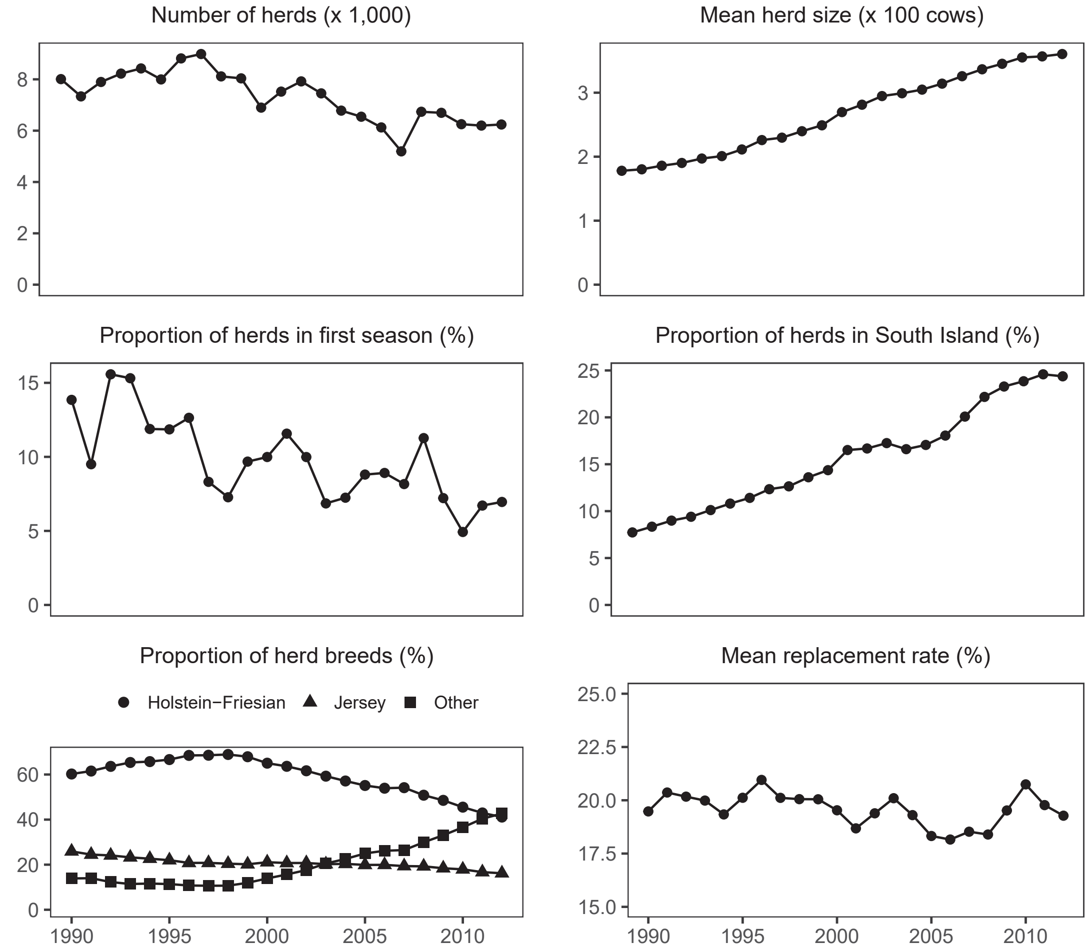


Figure 4.2: Descriptive statistics of seasonal-calving New Zealand dairy herds included in study between 1990 and 2012

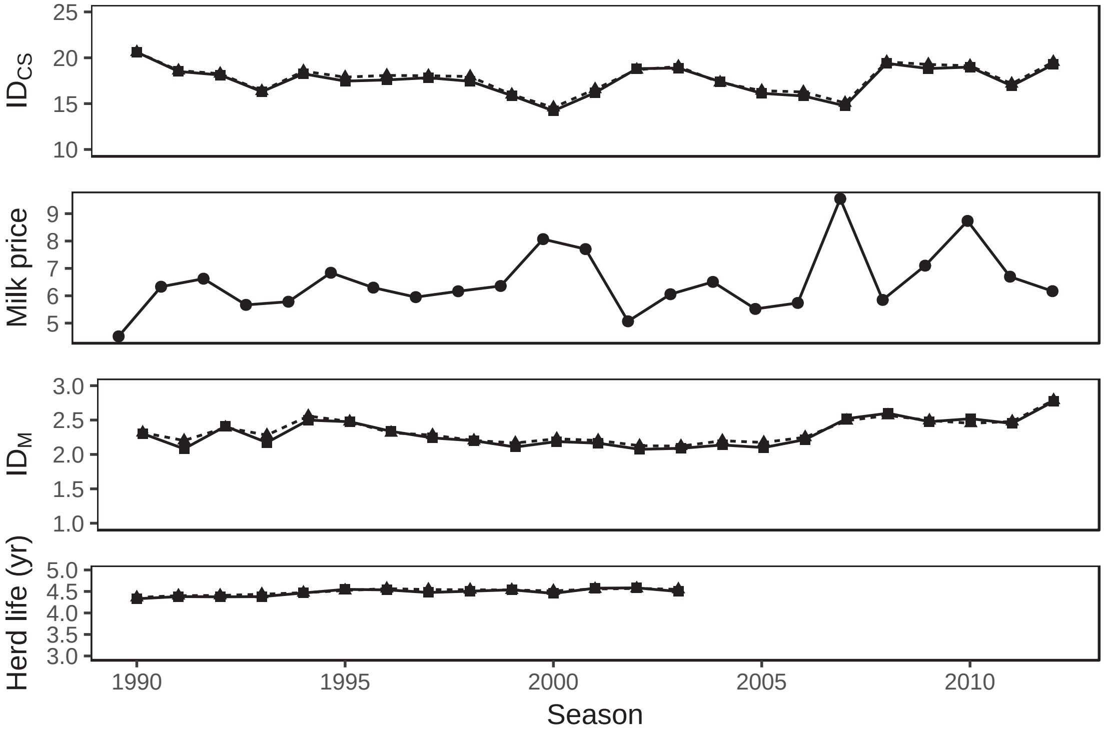


Figure 4.3: Observed (solid line, ■ symbol) and model-fitted (dashed line, ▲ symbol) incidence density (ID, cases per 100 cow yr) of culling (ID_{CS}) and mortality (ID_M), and median length of herd life of cows in seasonal-calving New Zealand dairy herds, and inflation-adjusted milk price, by dairy season between 1990 and 2012

4.4.3 Breed and Herd-Size Related Risk Factors for Culling and Mortality

The upper cut-points for quintiles of herd size increased with time over the study period (Figure 4.4), but those for change in herd size both increased and decreased over time. The lower and upper cut-points for quintile three of change in herd size ranged between -2.5% and 4.6%, respectively. The association of quintile of herd size with $\mathrm{ID_{CS}}$ was weak and inconsistent over the study period for all but quintile five compared with quintile three herd size, which had a mean relative difference of $\mathrm{ID_{CS}}$ of -3.2% (Figure 4.5). However, increased $\mathrm{ID_{CS}}$ was consistently associated with quintiles one and two of change in herd size (mean relative difference = 19.1% and 7.6%, respectively), and conversely, decreased $\mathrm{ID_{CS}}$ was associated with herds of quintiles four and five of change in herd size (mean relative difference = -7% and -14.2%, respectively), compared to herds in the 3rd quintile of change of herd size. Herds in the first season of operation had mean difference in $\mathrm{ID_{CS}}$ of between -4.9% and -13.4% compared with herds that had been operating for more than one season (IDR range 0.95 to 0.87. Predominant herd breed was also associated with $\mathrm{ID_{CS}}$ in all but two seasons. Herds that were predominantly either Jersey or 'Other' breeds had reduced $\mathrm{ID_{CS}}$ compared with Holstein-Friesian herds of a mean relative -6.7% and -3.7%, respectively.

Increased $\mathrm{ID_{M}}$ was associated with herds of quintile one compared to quintile three of size in six of eight seasons (mean relative increase = 7.9%). The direction of association between $\mathrm{ID_{M}}$ and herds of quintile five and quintile three of size reversed direction over the study period. In seasons starting in 1990 and 1993, herds of quintile size five had decreased $\mathrm{ID_{M}}$ compared with quintile three size herds (mean relative difference = -6.7%), but had increased $\mathrm{ID_{M}}$ compared with quintile three size herds in 2008 and 2012 (mean relative difference = 8.7%). Associations between change in herd size and $\mathrm{ID_{M}}$ were generally inconsistent, with the exception of herds of quintile one compared with quintile three change in herd size in seasons between 1990 and 1999, and most recently in 2012, where herds of quintile one (decreasing herd size) had increased $\mathrm{ID_{M}}$ compared with quintile three (steady herd size). Increased $\mathrm{IDR_{M}}$ was associated with herds in their first season of operation compared with those established longer, in seasons between 1990 and 2002, by between relative differences of 6.5% and 15.9%, but not subsequent to 2002. Herds predominantly of Jersey breed had increased $\mathrm{IDR_{M}}$

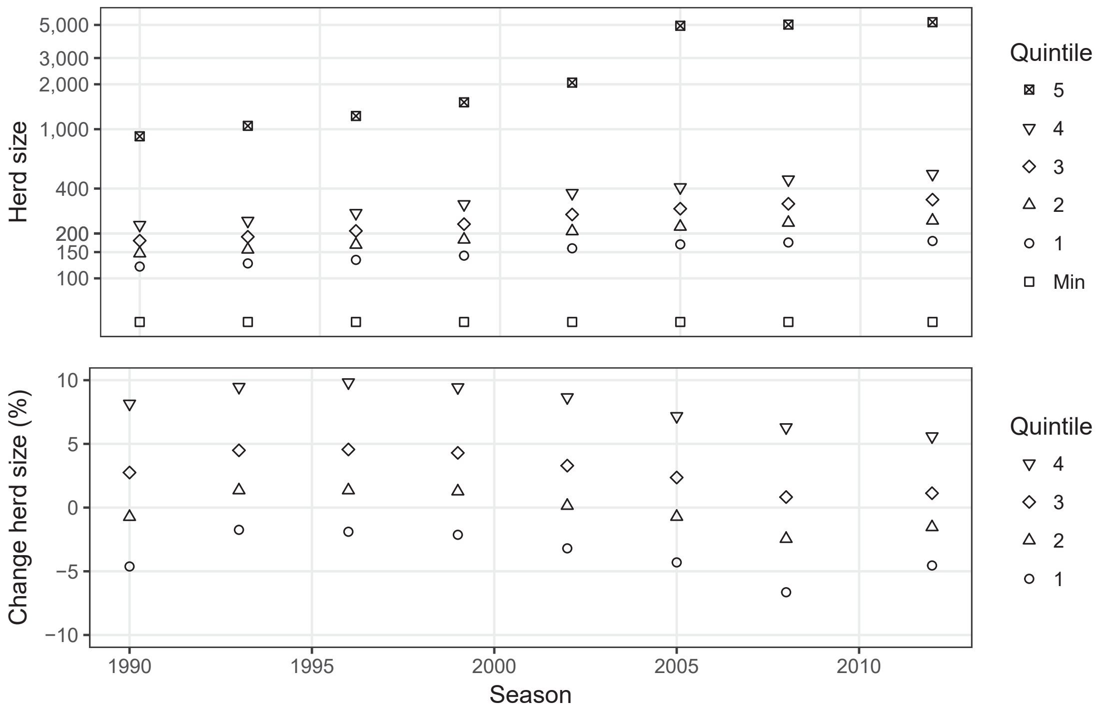


Figure 4.4: Upper cut-points of quintiles of herd size (number of cows calved) and change in herd size in the subsequent season (percent) by year that season commenced in seasonal-calving dairy herds in New Zealand included in study

over the study period compared with Holstein-Friesian herds (relative difference = 9.3%), but Jersey herds were generally not different from herds of 'Other' breeds, and herds of 'Other' breeds did not differ from the Holstein-Friesian herds.

4.4.4 Mapping Incidence of Culling and Mortality

A map of New Zealand Regional Authority areas depicted in Figure 4.6 is provided to orientate the reader. Polygons with empirical Bayes smoothed $\mathrm{ID}_{\mathrm{CS}}$ in the upper quartile were infrequent and located in various regions in different seasons, except in central and norther Waikato and Taranaki (Figures 4.7 to 4.10). No polygon-specific posterior mean relative risk (ζ_i) for culling greater than 1.2 were identified in any of the plots in four seasons, and polygons with $\zeta_i \geq 1$ were frequently located in the West Coast and Southland regions.

With the exception of one polygon in north Taranaki in 1990, empirical Bayes smoothed ID_{M} in the fourth quartile were infrequent and located in regions other than Taranaki, Waikato and Bay of Plenty

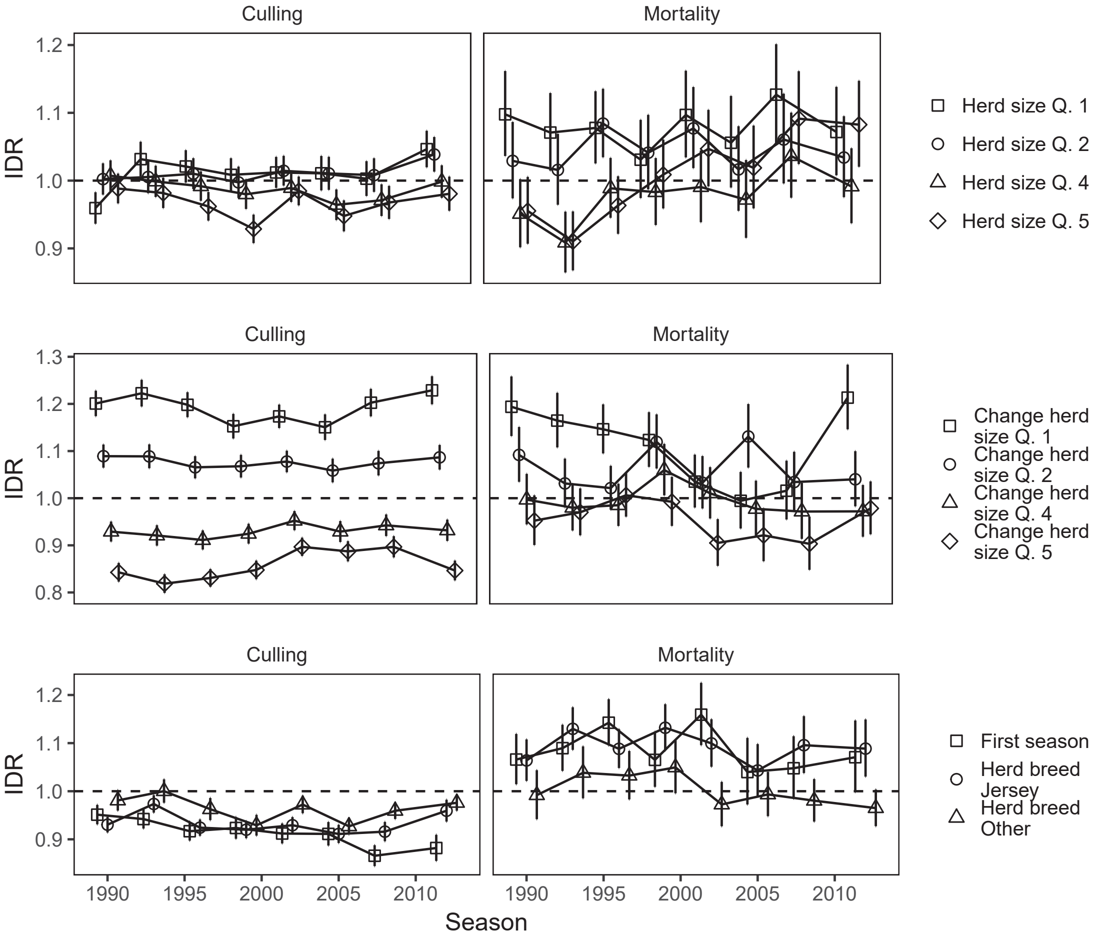


Figure 4.5: Incidence density ratios (IDR) with 95 % credible intervals of the effects of variables in spatial regression models of culling and mortality, compared with a reference level, in New Zealand herds between 1990 and 2012 (reference level: herd in the third quintile of both herd size and change in herd size, in operation for more than 1 season, and predominantly Holstein Friesian breed)

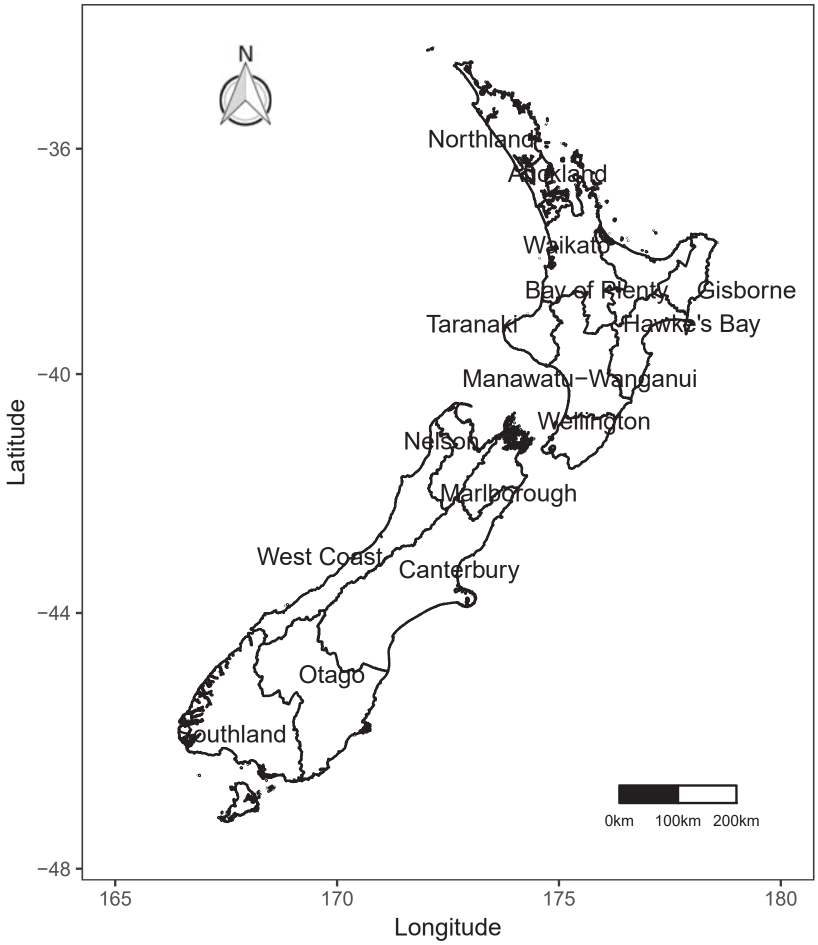


Figure 4.6: Map of New Zealand regional authority boundaries in 2012

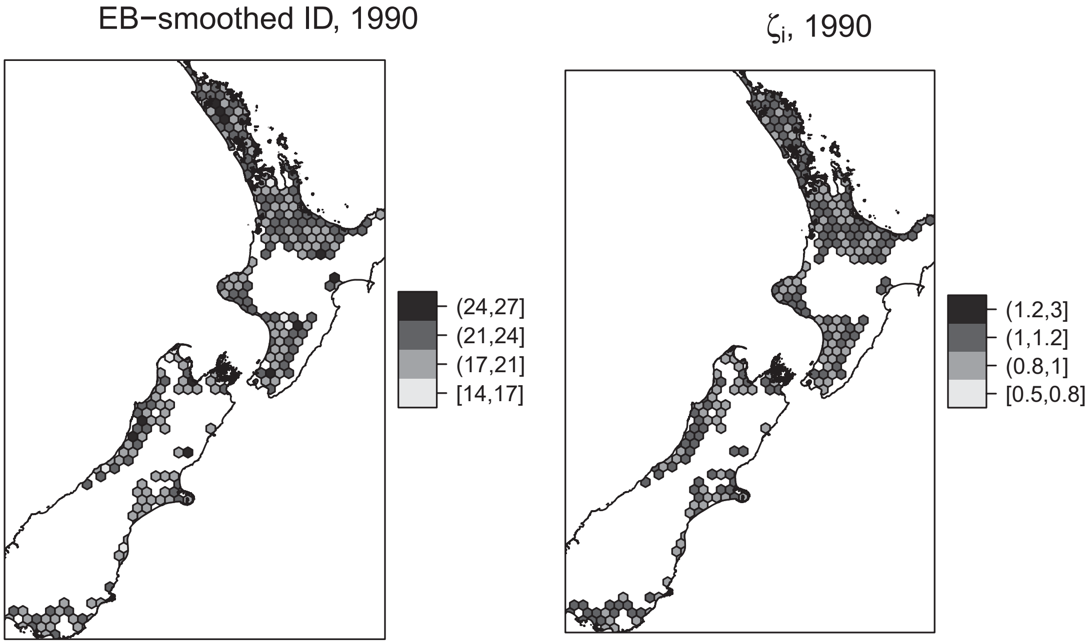


Figure 4.7: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of culling of cows in New Zealand dairy herds in 1990

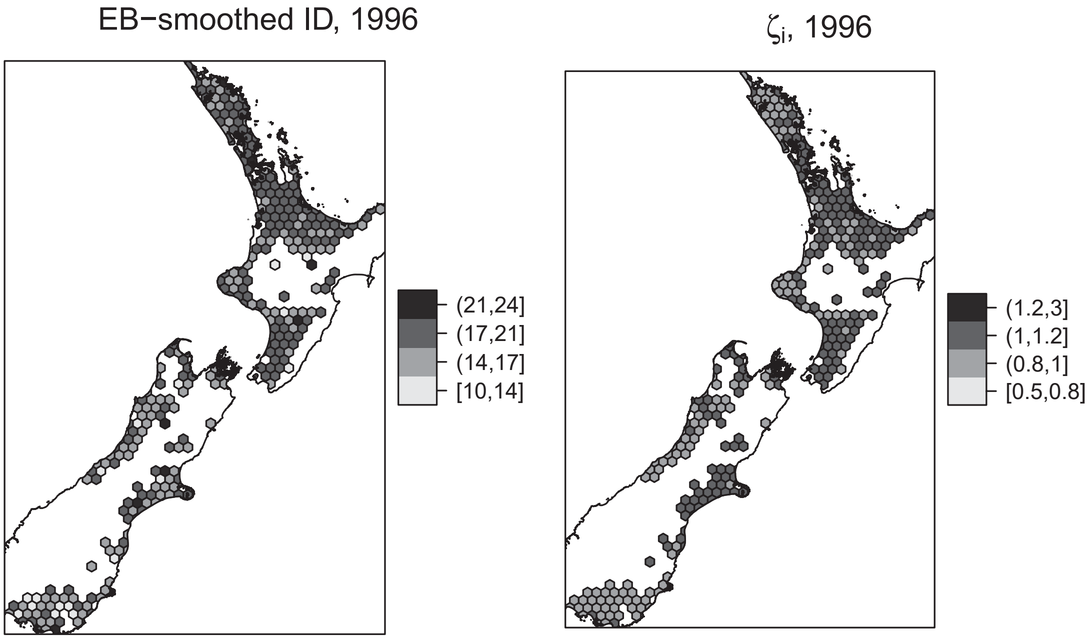


Figure 4.8: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of culling of cows in New Zealand dairy herds in 1996

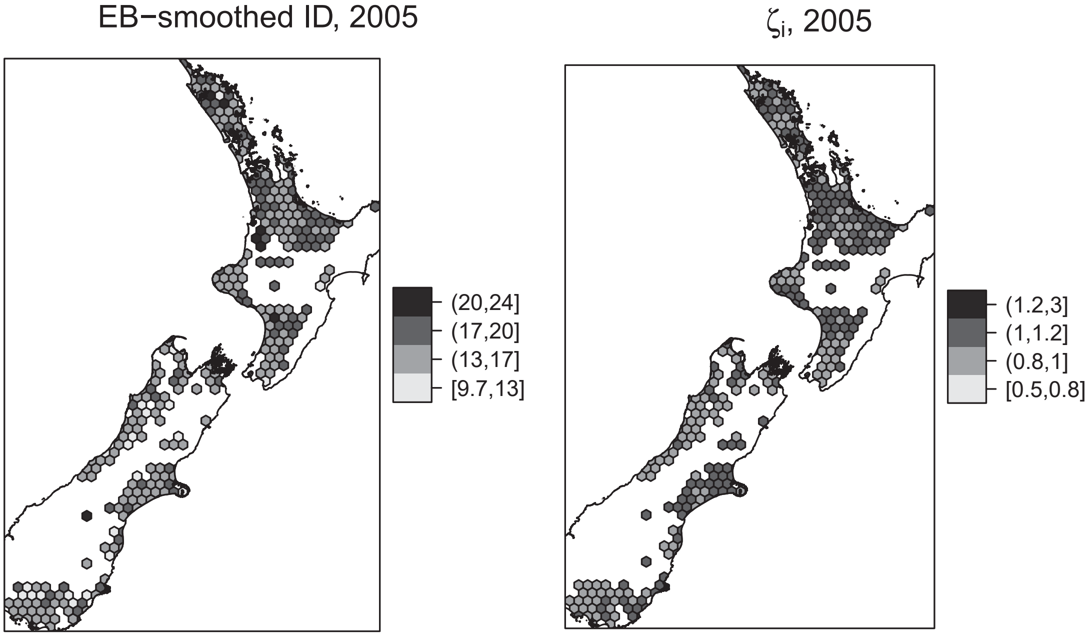


Figure 4.9: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of culling of cows in New Zealand dairy herds in 2005

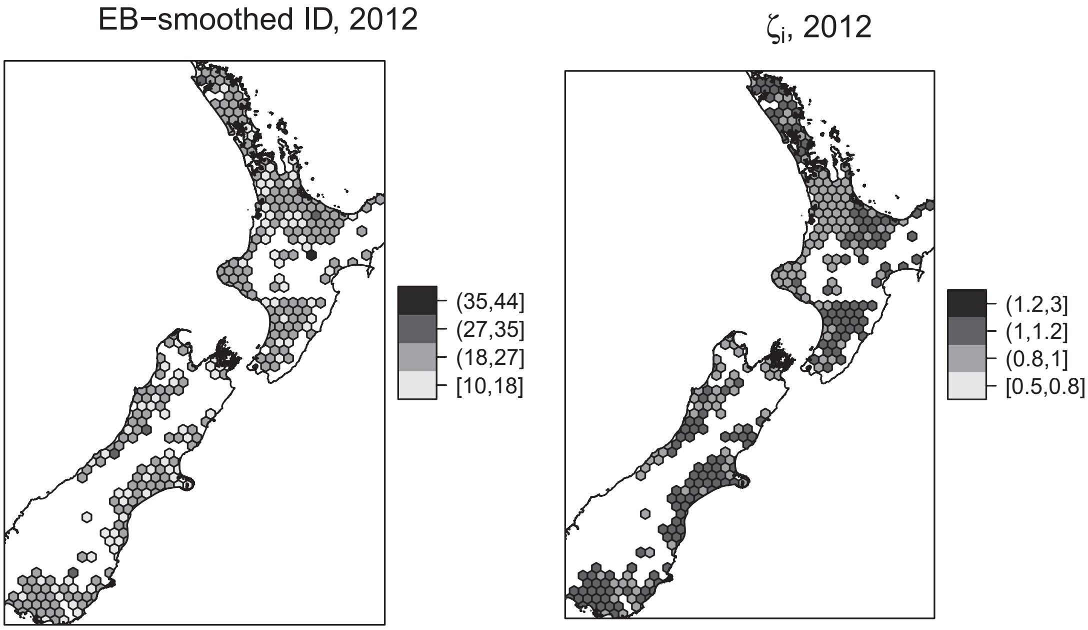
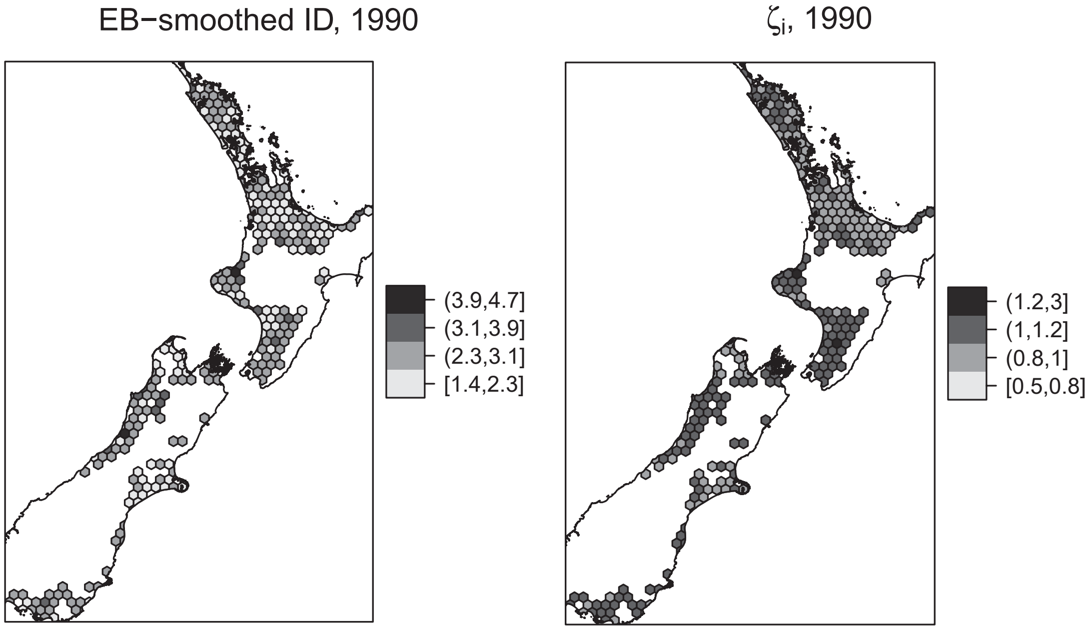


Figure 4.10: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of culling of cows in New Zealand dairy herds in 2012


EB−smoothed ID, 1990

ζ_i, 1990

Figure 4.11: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of mortality of cows in New Zealand dairy herds in 1990

(Figures 4.11 to 4.14). Less than five polygons per season were identified with $\zeta_i > 1.2$) for mortality, and the distribution among regions was similar to that of the empirical Bayes smoothed $\mathrm{ID_M}$. Zero and two polygons with greater than 75% probability of increased relative risk of culling or mortality ($p(\zeta_i) > 1.25$), respectively, were located in the four seasons mapped (not shown).

The minimum, median, and maximum proportion of variance in the spatial regression models for culling attributed to the structured spatial components were 0.3, 0.3 and 0.6, and the same for mortality were 0.3, 0.4 and 0.7, respectively (where a proportion of 0 or 1 indicates no or complete spatial correlation between neighboring polygons, respectively).

4.5 DISCUSSION

This is the first study to define the current incidence, spatial patterns, and trends over two decades of culling and mortality in New Zealand dairy herds. Additionally, and for the first time in seasonal-calving and pasture-grazed herds, we have described herd-level risk factors for $\mathrm{ID_{CS}}$ and $\mathrm{ID_M}$.

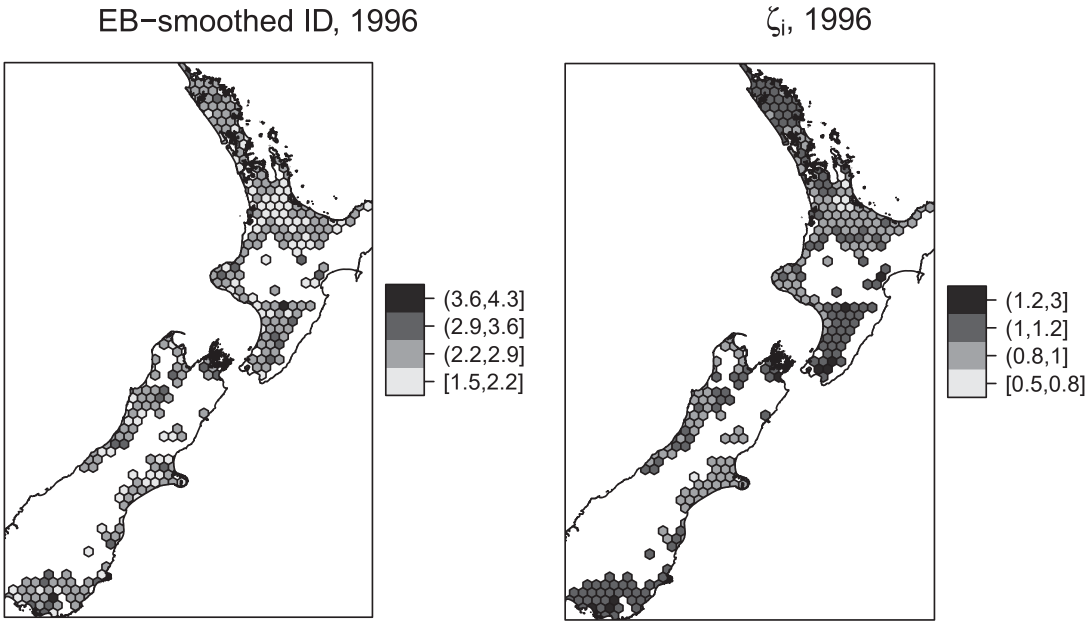


Figure 4.12: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of mortality of cows in New Zealand dairy herds in 1996

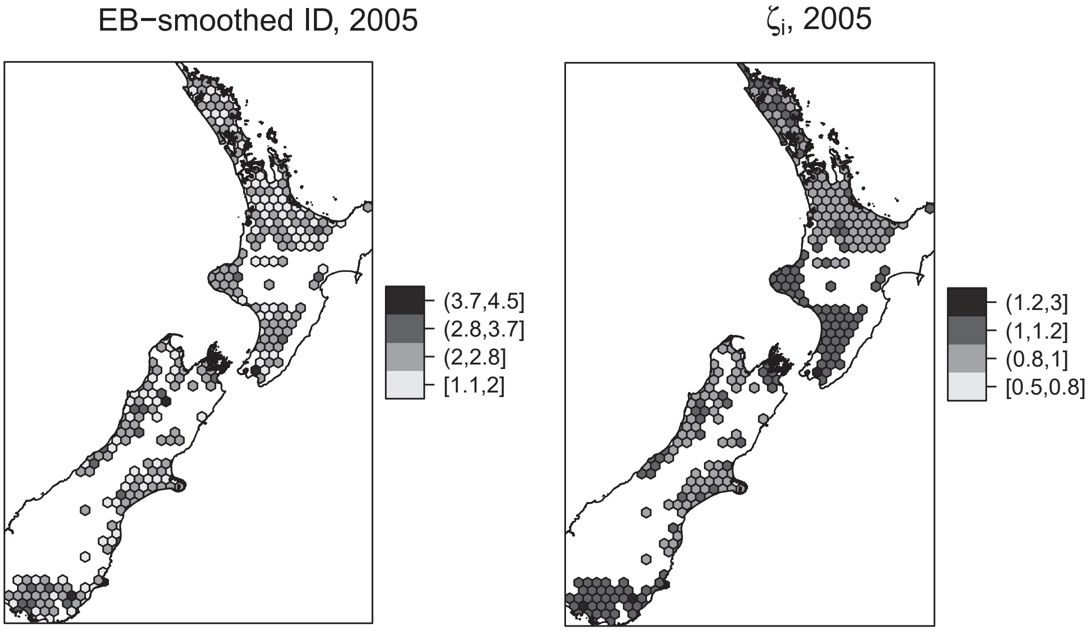


Figure 4.13: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of mortality of cows in New Zealand dairy herds in 2005

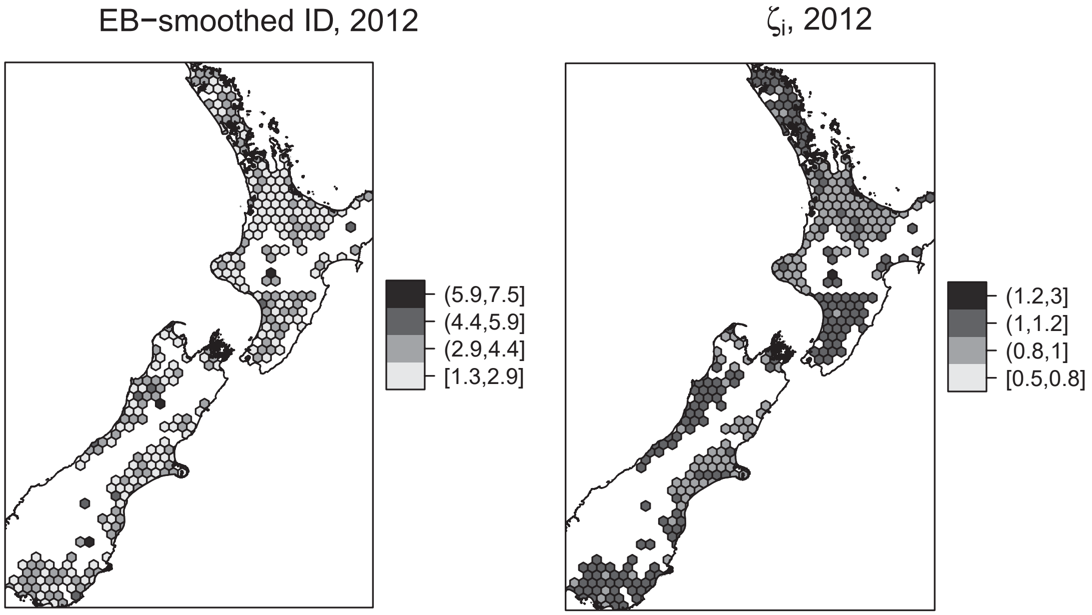


Figure 4.14: Empirical Bayesian (EB) smoothed mean incidence density (ID) and the posterior mean for the relative ID (ζ_i) of mortality of cows in New Zealand dairy herds in 2012

4.5.1 Temporal Trends

Our finding that the $\mathrm{ID}_{\mathrm{CS}}$ has not increased in pasture-grazed herds in New Zealand between 1990 and 2012 is consistent with recent findings from housed herds in the USA [USDA, 2002, 2007] and from a meta-analysis of culling in other international studies by Compton et al. [2017]. However, our findings contrast with those of Maher et al [2008] who reported increased incidence of culling between 2003 and 2006 in seasonal-calving herds in Ireland. One possible reasons for this contrasting finding is that Friesian-Holstein predominate and cross-breeds are uncommon in Ireland [Maher et al., 2008], as in many other countries with modern dairy industries, whereas crossbred cows predominate in New Zealand. The cyclical pattern of $\mathrm{ID}_{\mathrm{CS}}$ over time we report in the current study was in part explained by the negative association between $\mathrm{ID}_{\mathrm{CS}}$ and the price farmers received for milk in the same season. It is likely that increased milk prices encouraged farmers to retain cows that would have otherwise been culled, in anticipation of improved economic returns if they were retained longer in the herd. Conversely, in seasons of reduced milk prices, farmers culled or sold more cows to control fixed costs associated with cows in anticipation of reduced income. Knowledge of the association between milk price and culling further supports the assertion that culling is primarily a result of economic decision-making by farmers to improve their financial returns [Fetrow et al., 2006] and results from a complex interaction of external, farm-, and cow-level factors.

Our finding that the $\mathrm{ID_M}$ has not increased in New Zealand dairy herds between 1990 and 2012 contrasts with those of studies from other modern dairy industries [Thomsen et al., 2004, Alvasen et al., 2012, Shahid et al., 2015]. This is suprising, because increased herd size has been associated with increased incidence of mortality in those countries, but $\mathrm{ID_M}$ has not similarly increased over time in New Zealand along with increased mean herd size. One possible reason for this difference is that New Zealand dairy herds are pasture-grazed, whereas most other modern dairy industries, with the exception of Ireland and Australia, have housed or semi-housed systems. However, pasture-grazing alone may not explain all the difference between trends in mortality among modern dairy countries, because Maher et al [Maher et al., 2008] reported that the incidence of mortality in Irish dairy herds had increased between 2003 and 2006 from 3% to 4%. Another possible reason for the difference in temporal trends of incidence of mortality between New Zealand and other countries with modern dairy industries may be due to differences in the genetics of the cow populations. As reported in this study, the composition of breeds in New Zealand dairy herds has moved strongly away from Holstein-Friesian towards cows of other breeds (mainly crossbreds of Holstein-Friesian and Jersey), which have been reported to have decreased incidence of mortality compared with cows of either pure breed [Pinedo et al., 2014].

The length of HL of New Zealand cows between 1990 and 2003 followed a small but increasing linear trend over time. This may be explained by the sum of contributions over the same period and subsequent seasons from culling and mortality. It was not possible to disentangle the contribution of each factor because of the few years of data, but reductions in $\mathrm{ID_{CS}}$ in the 1990s apparent in the temporal plot may have been sufficient to account for the small positive trend in HL we estimated. Our estimate of mean HL of New Zealand cows between 1990 and 2003 (4.5 yr) is greater than that reported by others, for example Ahlman et al [2011, 3.1 yr] and Hare et al [2006, 2.7 to 3.6 yr]. This difference is explained by the greater incidence of especially culling [USDA, 2007], but also mortality [USDA, 2007, Strandberg and Emanuelson, 2016] reported from these countries compared with New Zealand, which of course reduce HL. Herd life reflects the combined incidence of culling and mortality over an extended number of seasons following the first calving. Therefore, changes in measured herd life for a particular cohort of primparous heifers may not be available until several years after changes in culling and mortality occur, and a lag period has passed to allow the cows an opportunity to express that measure. Although the estimation of herd life may not provide timely information for decision-making, it does however provide information that is easy to communicate and that is more stable over time than especially the incidence of culling, and to a lesser extent, of mortality. We recommend that herd life be used to monitor long-term changes in the survival of cows and the age structure of dairy herds, but nevertheless favor lactational incidence risk or density of culling and mortality as key performance indicators for farmers.

4.5.2 Breed and Herd-Size Related Risk Factors for Culling and Mortality

Herd size. We detected generally weak and inconsistent associations between quintile of herd size and $\mathrm{ID_{CS}}$ over the study period after adjustment for other factors included in the spatial regression models. Herds of increasing quintile herd size generally had numerically reduced $\mathrm{ID_{CS}}$, but any differences were generally not significant, except herds of size quintile 5 had reduced $\mathrm{ID_{CS}}$ compared with quintile 3 size herds in four of the eight seasons modeled (maximum relative change in $\mathrm{ID_{CS}}$ = -7.1%). One possible explanation for this finding is that herds of quintile 5 size were unable to rear or purchase sufficient replacements to cull cows with disorders that would otherwise have been culled in herds with more replacements available, but we did not test this hypothesis.

We similarly detected that herds of greater quintile of herd size generally had reduced $\mathrm{ID_M}$ compared with herds of quintile three size. In six of the eight seasons, herds of quintile one size had greater $\mathrm{ID_M}$ than herds of quintile three size (overall mean relative difference in eight seasons = 4.6%). However, the direction of association between herds of each quintile and $\mathrm{ID_M}$ over the time was not consistent for herds of all quintile sizes. Herds of quintile size five had reduced $\mathrm{ID_M}$ in the 1990 and 1993, but increased $\mathrm{ID_M}$ in 2008 and 2012 compared with herds of quintile three size. Our data suggests that herds of the largest quintile of herd size reached a 'tipping point' in the mid 1990s that reduced the effectiveness of their manangement to control mortality. Our findings are in partial agreement with those of others [Thomsen et al., 2006, Alvasen et al., 2012, Shahid et al., 2015] who reported increased risk of mortality of cows with increasing herd size, except that our finding only relates to the largest quintile of herd size, whilst their findings were of linear increases of incidence of mortality associated with increased herd size. These cited authors have proposed that this association is because as herd size increased there was decreased time available per cow to diagnose and care for cows, and a consequent increase in incidence of mortality. The same reason may also be a contributing factor in New Zealand, where the number of cows per full time labour equivalent increased from 83 to 142 over the study period [Anonymous, 2013b]. Further information on changes in the workforce on dairy farms were provided by Taylor et al. [2009], who reported that the number of non-family staff on dairy farms had more than trebled in the preceding 20 yr. These staff are more likely to be employed in the largest herds with the greatest needs for non-family labour. Therefore, reduced experience and skills of staff, in addition to reduced time available for individual cow management, may together be associated with increased $\mathrm{ID_M}$ in the largest herds in recent years. On-farm investigations of these herd size-specific factors are needed, in addition to further epidemiologic studies. Together, these may reveal possible reasons for this changing pattern within pasture-grazed herds of different sizes, and reasons for the differences in pasture-grazed compared with herds in partial or fully-housed systems. Our finding is important because there is no indication that the trend of increasing herd size in New Zealand is about to halt, and therefore a risk exists that national $\mathrm{ID_M}$ may increase, with consequent adverse financial and animal welfare consequences.

Change in herd size. Our findings clearly show that the $\mathrm{ID_{CS}}$ is negatively associated with change in herd size in the subsequent season. This finding is in agreeement with Faust et al [2001] who reported that farmers in a phase of herd expansion frequently made culling decisions under financial pressure to retain cows with disorders, which was more profitable than purchase of replacements. An explanation for our finding that increased $\mathrm{ID_M}$ was associated with herds in the first compared with the third quintile of change in herd size is less intuitive. One explanation may be that decreasing herd size may be a result of other factors associated with poor farm performance, for example poor animal husbandry skills, that also increased $\mathrm{ID_M}$. However, this finding occurred in only five of the eight seasons modeled, and hence we give it little emphasis.

Herds in first season of operation. Herds in their first season of operation had consistently reduced $\mathrm{ID_{CS}}$ compared with herds operating for more than one season. A possible reason for this finding is that herds in their first season of operation have additional constraints on expenditure for rearing replacements compared with already-established herds, and therefore, cull fewer cows to meet their targeted herd size. Our finding that $\mathrm{ID_M}$ was generally greater in herds in their first season of operation suggests that cow health and welfare in such herds is at increased risk. This may be because of the presence of new or less experienced staff, unfamiliarity with farm-specific management needs, or even lapsed biosecurity measures or purchase of cows in poor body condition when a new herd was formed that increased the risk of fatal disorders. The proportion of newly-established herds has decreased over time, which may be associated with a decrease in the proportion of share-milking business structures where the milk receipts are shared between the herd owner and land owner [Anonymous, 1991, 2013c], but there were still between approximately 5% to 16% of herds in recent seasons that were newly-established. These herds may not be common overall, but they are readily identified through professional and social contacts with the farming community, and therefore, may easily be targeted for increased support or monitoring by advisors and veterinarians.

Predominant herd breed. We detected relatively weak associations between predominant herd breed and $\mathrm{ID_{CS}}$: herds predominantly of Holstein-Friesian breed cows had increased $\mathrm{ID_{CS}}$ compared with Jersey or 'other' breed herds. This may be explained by the adverse effect of North American Holstein-Friesian genetics on the interval from calving to conception of cows in pasture-grazed New Zealand herds [Harris and Kolver, 2001]. This is because cows that fail to conceive within the limited breeding programme required in a seasonal calving system are most frequently culled. However, we observed a clearer association between herd breed and $\mathrm{ID_M}$ and in the opposite direction than between herd breed and $\mathrm{ID_{CS}}$; herds of Jersey breed had greater $\mathrm{ID_M}$ compared to herds of both Holstein-Friesian and 'other' breeds. Others have reported increased risk of mortality in herds of Holstein-Friesian compared with a variety of other breed [Thomsen et al., 2006, Raboisson et al., 2011, Shahid et al., 2015], but Pinedo et al. [2014] reported increased incidence of mortality in Jersey compared with Holstein cows, which in turn were greater than Holstein-Jersey crossbreds. A possible explanation of our finding may be related to the increased risk of metabolic disorders in early lactation, such as hypocalcaemia in Jersey compared to Holstein-Friesian cows [Lean et al., 2006, Pinedo et al., 2014] and failure of feed management programs in the transition period of pasture-grazed herds to adequately manage calcium metabolism for this breed. Nevertheless, Jersey herds are a minority in the population (16.2% in our study in 2012), and hence the population impact of this small increase in $\mathrm{ID_M}$ is likely small.

4.5.3 Mapping Incidence of Culling and Mortality

Results from mapping of incidence of culling and mortality are particularly relevant for investigation and control programs. The maps of empirical Bayes-smoothed $\mathrm{ID_{CS}}$ in each season revealed few polygons in the upper quartile of ID, and further maps indicated no herds with mean posterior relative risk of culling greater than 20% above or below the population mean. Hence, after considering the effects of herd size, change in herd size, whether or not the herd is in the first year of operation, and predominant herd breed, the $\mathrm{ID_{CS}}$ varied by no more than 20% about the population mean. This finding indidcates there is little difference in culling policies between dairy farms in different areas of New Zealand. Similarly the empirical Bayes-smoothed maps of $\mathrm{ID_M}$ indicated few polygons in the upper quartile of ID, but in contrast with culling, between one and five polygons with mean relative risk of mortality $> 20\%$ above the population mean were located in each season. These 'increased risk' polygons were located in different locations, including the Southland and Wellington regions in two seasons, but never in the traditional dairy regions of the Waikato and Bay of Plenty. However, the number of these polygons and seasons analyzed were too few to make inferences about specific locations and $\mathrm{ID_M}$. Nevertheless, the spatial patterns of $\mathrm{ID_M}$ were more heterogenous than those of $\mathrm{ID_{CS}}$. The reason for this may be that the $\mathrm{ID_M}$ is not managed by policies generally applied in seasonal-calving, pasture-grazed herds, but rather is affected by the management skills of individual farmers that interact with a wide range of geographic and climatic conditions that exist in New Zealand dairy regions. We detected that the proportion of variance in $\mathrm{ID}_{\mathrm{CS}}$ and ID_{M} attributed to the spatial proximity of herds was low, which means that national, rather than region-specific solutions, are justified.

4.5.4 Data Quality

The data for this study were retrieved from an electronic registry, and hence our findings have been at risk of bias because of misclassification and under-reporting [Emanuelson and Egenvall, 2014]. If any, the effect of the latter poses probably the greatest risk to our findings. We excluded herds from analysis that had $> 5\%$ of cows that had unknown fates after 30 mo as a means of reducing this risk, but we acknowledge that incidence was potentially underestimated. However, no data currently exists which might be used to adjust our estimates. Although our original data were close to a census of the New Zealand dairy herd, the risk of selection bias affecting our findings cannot be ignored either because we excluded a relatively large proportion (43.5%) of data from our study. Most records were removed because they exceeded our threshold for percentage of cows lost to follow-up, and a lesser percentage were excluded because of likely misclassification of fate of removal (indicated by implausibly high incidence of culling, sale or mortality for herds not in their final season of operation). However, the spatial distribution of the study herds was consistent with the known distribution of herds in the New Zealand industry. Notwithstanding these potential shortcomings, we have taken reasonable steps to balance the needs of data quality with using a representative sample of the target population by excluding only implausible or non-representative records.

4.5.5 General Discussion

Our study has revealed relationships between culling or mortality, and herd-level risk factors that may be used by farmers, their advisors, scientists and policy makers, to target control and investigation programs that aim to improve the welfare and productive life of New Zealand dairy cows. Increase in the size of dairy farms and expansion into non-traditional regions between the years of 1990 and 2012 has challenged management systems to adapt in ways that control non-production culling and mortality of cows. In the main, our findings indicate that these challenges have been successfully met, but our data indicates that risks still exist, particularly in the largest dairy herds with respect to mortality. There has been growing attention given by scientists and the public to the impact of expansion and intensification of dairy farms on ecosystems. However, the effects of these changes on cow management and farm systems have not been described and their investigation may provide important insights. We recommend that this deficit of knowledge be redressed to provide effective programs to control culling, and particularly mortality.

4.6 ACKNOWLEDGEMENTS

We thank New Zealand dairy farmers through DairyNZ Inc. (Project number RD1405) and the Ministry of Business, Innovation and Employment through the research partnership “Pillars of a Competitive and Responsible Dairy System: Improved Longevity and Reproductive Performance” (Contract number DRCX1302) for funding this work.

Chapter 5

Competing risks analysis for culling and mortality of New Zealand dairy cows

5.1 ABSTRACT

We investigated cow-level risk factors of disorders and breed, for culling and mortality in pasture-grazed, seasonal-calving dairy herds from four regions in New Zealand over two production seasons. We used data from a previous prospective study that consisted of electronic records of herd and cow identification, demographic, reproductive, and, where available, animal health and milk production test data. Additionally, on-farm paper records of diagnoses and treatments of disorders were retrieved to augment the electronic data. We selected data for analysis from herds that were production-tested in each season, and had culling and animal health records, to create a final data set of records from 65 herds, 123 herd-seasons and 70,964 cow lactations. Culled cows were defined as those sold for slaughter or dairy purposes, and mortalities as cows that either died unassisted or that were euthanized on-farm. Our analysis used the first occurrence in a lactation of the most frequently-recorded, modifiable disorders, and, additionally, breed of cow, as risk factors. We estimated hazard ratios for culling ($\mathbf{HR_c}$) or mortality ($\mathbf{HR_m}$), or both combined, for risk factors with competing risks Cox proportional hazards models, shared frailties and time-dependent covariates to account for the possibility of cow removal because of either culling or mortality, the clustering of cows within herd-seasons, and, changing values of covariates over time, respectively. An individual cow lactation was the unit of measurement.

In both primiparous (2 yr old) and multiparous (> 2 yr old) cows, calving difficulty and treatment for a calving difficulty were each associated with increased HR_c and HR_m, and clinical mastitis was associated with increased HR_c but not HR_m. Early and late uterine infection ($<$ 14 d and $\geq$ 14 d post-calving, respectively) and metabolic disease were only associated with increased HR_c and HR_m in multiparous cows. Lameness was not associated with either outcome in either age group. Holstein-Friesian breed was associated with increased HR_c but not HR_m in multiparous cows, but breed was not associated with either outcome in primiparous cows. Overall, this study indicates that programs to reduce mortality and non-production related culling of cows in pasture-grazed, seasonal-calving herds need to improve animal health in the transition period as well as genetic merit for survival.

Keywords: multiple risks, survival analysis, pasture-grazed

5.2 INTRODUCTION

Culling and mortality of dairy cows have important economic and welfare implications for the farmer and animal, respectively. Orpin and Esslemont [2010] reported that the costs attributed to culling or mortality in the United Kingdom were between UK£1,200 and £3,500 per case and Liang et al. [2017] estimated that culling and mortality contributed between 5% and 22% of the total costs of common health disorders. Lopez-Villalobos and Holmes [2010] used a computer simulation model of pasture-grazing seasonal-calving systems to show that net economic returns on the average New Zealand dairy farm in 2009 could be increased by 7% per hectare, if culling and mortality were reduced from 19% to 15% per season. Furthermore, high and sustained rates of culling, and, in particular, mortality, are indicators of poor welfare status in dairy animals [de Vries et al., 2011], which concerns farmers, consumers and animal welfare advocates [Hemsworth et al., 1995]. Hence, programs to reduce culling and mortality rates will contribute to the sustainability of dairy industries.

Preventive animal health programs rely on evidence from randomised controlled intervention studies, and population-based observational studies to determine risk factors for the target disorder. Many reports are available from the international literature on factors associated with the risk of culling in dairy cows, as reviewed by Beaudeau et al. [1993; 2000]. Those reviews and more recent reports consistently indicate that cows with reproductive failure, mastitis, and lameness or trauma, have the greatest risks of culling, although their relative ranking varied between studies. Farmer-reported reasons for mortality were more varied, but included accidents, mastitis, and disorders related to calving and the digestive, locomotory, and metabolic systems [reviewed by Thomsen and Houe, 2006]. However, farmers are likely to report the disorders they observed closest to cow removal as the reason for culling or mortality, but the removal event may, in fact, have been associated with other preceding factors. Additionally, farmers may not use standardized definitions for the removal codes they record. For these reasons, analysis of farmer-reported reasons alone is not sufficient to evaluate risk factors for culling and mortality, and multivariable regression methods that consider the complex of possible preceding factors are preferred [Beaudeau et al., 2000].

Most studies of risk factors for culling and mortality in cows were undertaken in countries with management systems and cow genetics different from those in the pasture-grazing, seasonal-calving system, common in New Zealand, Australia, Ireland and other parts of Europe. For example, most countries with modern dairy industries have continuous-calving, housed systems where the inter-calving interval of cows frequently exceeds the 365-d average of New Zealand cows, and where cows consequently have longer breeding periods. Hence, risk factors that reduce the probability of conception in the short term, but that would eventually resolve, may be critically important in seasonal-calving systems but of lesser importance in continuous-calving systems. We reasoned that risk factors for culling and mortality and the strength of their associations might vary between dairy farming systems as has been previously suggested [Beaudeau et al., 1993], and believed it was important to investigate them for the first time in pasture-grazed, seasonal-calving herds.

Therefore, the main aim of this study was to evaluate modifiable risk factors for culling and mortality of cows in pasture-grazed, seasonal-calving herds in New Zealand to provide information for animal health management programs.

5.3 MATERIALS AND METHODS

5.3.1 Definitions and Data Management

Electronic records for the study herds from June 2008 to May 2012 were previously retrieved from LIC (Hamilton, New Zealand) as part of the National Herd Fertility Study [Brownlie et al., 2011, 2014]. The National Herd Fertility Study described herd reproductive performance and management, and investigated the effect of a farmer-led management intervention on 6-week in-calf rate in dairy herds from four regions (Waikato, Taranaki, South Canterbury, North Otago) in New Zealand. These data included the 46 legislated fields from the New Zealand Dairy Industry Core Database (Dairy Industry Regulations 2001): a unique animal identifier, demographic information on date of birth and breed, date of entry into a herd, date of and fate and reason for exit from a herd, data on calving and breeding events, and where available, results from milk production tests. Additionally, electronic records of animal diagnosis and treatments and the date on which they occurred, were extracted from the same source. These were augmented with the same type of data retrieved from on-farm records by the investigator of that study over two dairy seasons commencing in 2009 and 2010. It was mandatory for farmers to record either in on-farm records or electronically, the cow identification and date of any antibiotic or other treatments that required a withholding period of animal products for human consumption.

We defined culled cows as removed from the herd directly to slaughter or sold for dairy purposes, and mortalities as those that died unassisted or that were humanely euthanized on-farm. The start date for a dairy season varied among herds and was defined as the date 130 d prior to the start of the breeding program for that season [Brownlie et al., 2011]. A dairy season was defined as the interval between the start of two subsequent seasons, and was on average 365 d of duration. A lactation was defined as the time period of each cow between the day it calved and it was then either culled, died, or was right-censored. A cow was right-censored if it calved and began a new lactation, or was temporarily moved off the farm, or was lost to follow-up at a maximum of 36 mo after calving or at the last date that electronic data were collected. The unit of analysis was a cow-lactation. A cow could have only one lactation per season, and only lactations of cows that calved on a study farm were considered.

The age of cows at the start of a lactation was categorized as ‘2’, ‘3-4, ’5-7’, or ‘8+’ yr and the breed of cow was categorized as Holstein-Friesian or Jersey, when $> \frac{12}{16}$ of its ancestry was of that breed, otherwise it was categorized as “Crossbred”. A measure of genetic merit for milk production was not available from the electronic records, but a phenotypic measure for milk production potential was derived from the individual herd and age-standardized milk production from the previous lactation. Milk production data for the lactation of each cow (milksolids, MS = kg milk fat + kg milk protein) were grouped by age category, herd and season (age-herd-season), and the standardized MS production calculated as the individual cow MS less the mean age-herd-season MS, divided by the standard deviation of the age-herd-season MS. A variable for “calving difficulty” was derived from farmer-recorded codes for calving assistance (whose possible codes were ‘none’, ‘minor’ or ‘major’) and records of calf status at birth (alive or dead) because only approximately 50% of calving assistance codes were complete, but status of calf at birth was almost completely recorded, after the method used by Bicalho et al. [2007]. A cow with a record of either minor or major assistance at calving, or a dead calf, or both, was coded as having had calving difficulty, otherwise not. A somatic cell count (**SCC**) of $>$ 120,000 or $>$ 150,000 cells/ml of milk from a production test for primiparous cows and multiparous cows, respectively, was categorized as increased and indicated intramammary infection [Holdaway et al., 1996a].

We analyzed the first documented case of frequently recorded cow disorders coded by the dairy farmer in electronic records or transcribed from on-farm treatment records. The disorders were classified as: 1) ‘post-calving treatment’ which included antibiotic or anti-inflammatory treatment, or both, for calving-related trauma or infection; 2) ‘metabolic disease’, which included milk fever or hypomagnesemia; 3) ‘mastitis’ which included cows with clinical signs of abnormal milk or swollen and painful udders or both symptoms; 4) lameness; and 5) ‘uterine infection’ (including retained fetal membranes). Uterine infections were classified as ‘early’ or ‘late’ if they were < 14 d or ≥ 14 d following calving, respectively. This cut-point was used as it was common practice to use that time interval to select cows with purulent vaginal discharge for intra-uterine antibiotic treatment [McDougall et al., 2013]. The definitions for

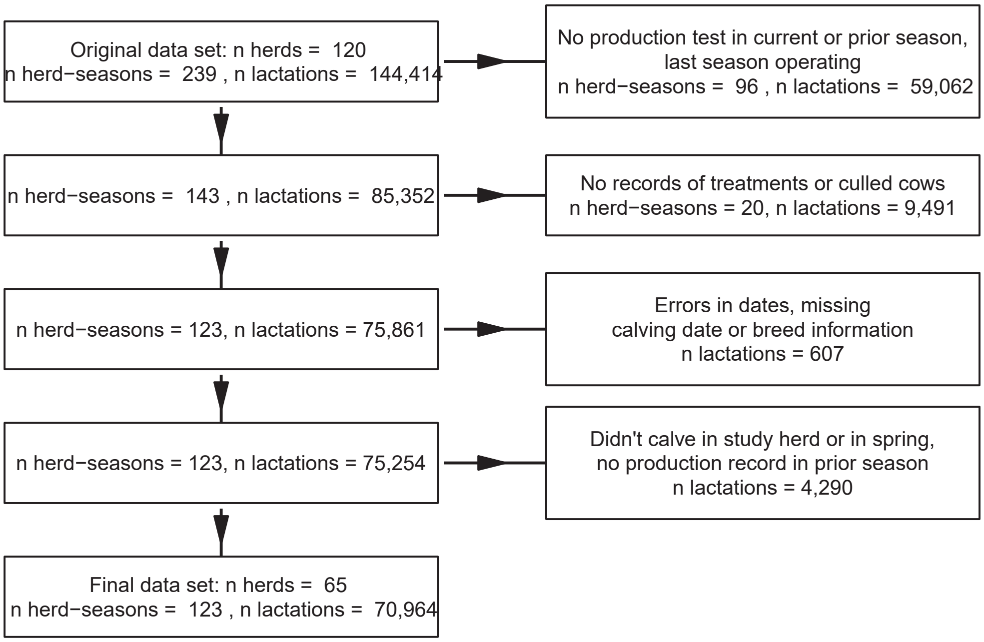


Figure 5.1: Flow chart of the number and reasons why records were excluded from the initial data set to create the final data set for analysis of risk factors for culling and mortality of cows from 65 herds over two seasons from four regions of New Zealand

diagnosis for each disorder were those used by each farmer.

Herd size was defined as the number of cows that calved on the farm in each dairy season and herd breed was categorized as the predominant breed of cows in the herd-season. The herd lactational incidence risk for the percentage of culling and mortality were calculated as the number of cows that were culled or died on-farm, respectively, divided by the herd size, and multiplied by 100. The percentage change in herd size was calculated as the herd size in the current season less the herd size in the previous season, divided by the herd size in the previous season, multiplied by 100; and the replacement percentage was calculated as the number of primiparous cows in the herd divided by the herd size, multiplied by 100. An explanation of the number and reason why records were excluded from the final data set are depicted in Figure 5.1.

Table 5.1: Example of arrangement of data[1] for estimation of hazard ratios of culling or mortality of cows from 65 pasture-grazed, seasonal-calving herds from four regions of New Zealand

Herd-season	Cow	Breed	Mastitis	Incr. SCC	Time start	Time stop	Time step	Group	Status
1	1092668	Holstein-Friesian	0	0	0	74	1	culled	0
1	1092668	Holstein-Friesian	0	1	74	200	1	culled	0
1	1092668	Holstein-Friesian	0	1	200	381	2	culled	0
2	1034473	Crossbred	0	0	0	1	1	culled	0
2	1034473	Crossbred	1	0	1	52	1	culled	0
2	1034473	Crossbred	1	1	52	200	1	culled	0
2	1034473	Crossbred	1	1	200	251	2	culled	1
1	1092668	Holstein-Friesian	0	0	0	74	1	died	0
1	1092668	Holstein-Friesian	0	1	74	200	1	died	0
1	1092668	Holstein-Friesian	0	1	200	381	2	died	0
2	1034473	Crossbred	0	0	0	1	1	died	0
2	1034473	Crossbred	1	0	1	52	1	died	0
2	1034473	Crossbred	1	1	52	200	1	died	0
2	1034473	Crossbred	1	1	200	251	2	died	0

[1] Mastitis = clinical mastitis status (0 = no, 1 = yes), Time start and Time stop = the number of days from calving at the start and end of the time interval, respectively, Group = the copy of records used to stratify the analysis in the Cox proportional hazards model, Status = the event status for the cow at the end of the time interval (0 = no event of type in group occurred or censored, 1 = event of type in group occurred) Interpretation of this simplified example of two primiparous cows and only two covariates: Cow ID 1092668 had a first record of increased somatic cell (SCC) count at 74 d after calving, and was censored at 381 d after calving, whereas, cow ID 1034473 had a first case of clinical mastitis at 1 d post-calving, a first case of increased SCC at 200 d post-calving, and was culled at 251 d post-calving

5.3.2 Statistical methods

Data preparation for analysis. The baseline data set consisted of one row of data per lactation that included identification and outcome variables, and variables that did not vary throughout the lactation, for example, breed of cow. Data sets of cow disorders and SCC test results were combined with the baseline data and unique time-dependent covariates created for each variable for each cow-lactation. Finally the data set was duplicated with a variable created for each set that defined the strata for each type of removal (culled or died) and these were stacked for type-specific relative hazards regression analysis [Lunn and McNeil, 1995]. An example of the structure of the data set with a limited number of the available covariates is shown in Table 5.1.

Descriptive statistics. We calculated descriptive statistics for the study herds, and the lactational incidence risk of the putative risk factors and of culling and mortality. The cumulative incidences of culling and mortality, accounting for competing risks were plotted together. The cumulative incidence in a competing risks setting is interpreted as the probability of cows experiencing an event of type k before time t and before the occurrence of other events [Austin et al., 2016]. It does not necessarily approach one with sufficient follow-up time because of the occurrence of competing events that prevent the other events from occurring and because of censoring.

Regression models. We created a causal diagram (or directed acyclic graph, Figure 5.2) that described the postulted causal relationships between the exposure variables available in the study, and between them and the outcome variable, based on our biological understanding and previously published diagrams [Erb et al., 1985, Grohn et al., 1990]. Three of the exposure variables were considered potential confounders (age group, breed, and standardized milk production) and included in each model, and one was unobserved (reproductive failure) but included to depict an important but unmodeled pathway. This graph considered milk production and reproductive status in the current lactation to be intervening variables between the putative risk factors and the main outcomes because they may have been directly affected by them, and themselves affect the type-specific hazard of culling or mortality. Individual regression models were constructed for each exposure variable, and separately for primiparous and multiparous cows. We created minimal sufficient adjustment sets of covariates for each model by use of the on-line software tool 'Daggity' [Textor et al., 2011] that appropriately controlled confounding of the association between the exposure variable of interest and the outcome, and that estimated the total causal effects of each exposure variable [Dohoo et al., 2009].

We used survival analysis methods because they account for the time at risk of right-censored cows. We included random effect terms because of the clustering of cows within herd-seasons, a competing-risks analysis because cows could be removed from herds for two reasons (culling or death), and time-dependent covariate because of possibly changing covariate values of individual cows over time.

Notation for a Cox proportional hazards model that includes a random effect term with a gamma distribution shared by all cows within a herd-season is

$$h_{ij}(t) = h_0(t)\exp(\beta\mathbf{X}_{ij} + \alpha_j)$$

where $h_{ij}(t)$ is the hazard for the i^{th} individual in the j^{th} herd-season at time t, $h_0(t)$ is the baseline hazard at time t, $\beta\mathbf{X}_{ij}$ are the coefficients multiplied by the linear predictor, and α_j denotes the random effect associated with the j^{th} cluster. The data set included cows and herds with two lactations, but

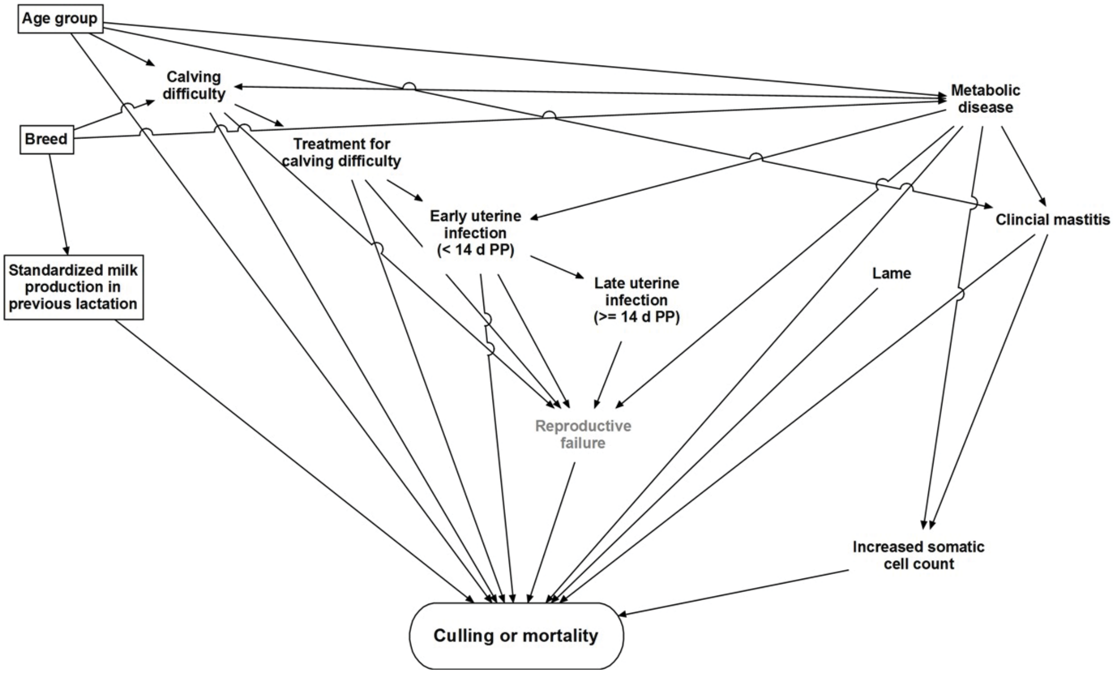


Figure 5.2: Cauasl diagram showing postulated paths linking variables related to the occurrence of culling and mortality of cows from 65 herds over two seasons from four regions of New Zealand

these potential correlations were not accounted for in the model because we considered their impact to be small because there were a mean of less than two repeated measures at each of these levels.

Survival regression modeling where more than one type of 'failure' can occur (competing risks) setting was undertaken with 'cause-specific hazard models' that are suited for etiological or risk factor analysis [Lau et al., 2009]. Epidemiologists in human health settings would use the term 'cause' to describe the type of competing event in this study (either culling or mortality), whereas veterinarians or farmers would more commonly use the word 'type' to describe the fate of animal at exit from the herd. To reduce confusion for the intended audience of this article, where possible we have either dropped the word 'cause' or replaced it with 'type'.

The notation for the type-specific relative hazard model is

$$h_k(t) = h_{0k}(t)exp(\beta_k\mathbf{X})$$

where $h_k(t)$ is the type specific hazard at time t for the k^{th} event, $h_{0k}(t)$ is the arbitrary baseline type-specific hazard for type k at time t, and $\beta_k\mathbf{X}$ are the corresponding regression coefficients for each type multiplied by the linear predictor. The type-specific hazard ratio is interpreted as the relative change in the type-specific hazard for the k^{th} event corresponding to a 1-unit increase in the corresponding covariate [Lau et al., 2009].

Finally, time-dependent covariates were added to incorporate covariates whose values changed at steps in time as denoted by

$$h(t) = h_0(t)exp(\beta X(t))$$

(Hosmer and Lemeshow [1998]) where $\beta\mathbf{X}(t)$ is the vector of coefficients multiplied by the linear predictor at time t.

Our models combined features of each of the previous model types, denoted as

$$h_{ijk}(t) = h_0(t)\exp(\beta_k\mathbf{X}_{ij}(t) + \alpha_j)$$

where $h_{ijk}(t)$ is the hazard for the i^{th} cow in the j^{th} herd for the k^{th} type, $h_0(t)$ is the baseline hazard, $\beta_k\mathbf{X}_{ij}(t)$ is the vector of coefficients for the k^th type multiplied by the linear predictor at time t and α_j is the frailty term for the j^{th} herd.

A series of regression models were built from the minimal sufficient adjustment set for each exposure variable, together with the exposure variable itself, but we only reported the results of the latter. For each model we also investigated the interaction between the exposure and the type of removal to determine if the hazard varied by type. This was done by adding an interaction term between the exposure and the strata term for each type of removal, and if significant, the interaction term was retained. The coefficients and variance-covariance matrices for these interaction models were used to estimate the type-specific hazard ratios for the interaction terms and their 95% confidence intervals [Hosmer and Lemeshow, 1998]. The proportional hazards assumption was evaluated by plotting scaled Schoenfeld residuals for each covariate against time and testing whether the time-dependent coefficient for the covariate had a slope significantly different from zero [Grambsch and Therneau, 1994]. Where the proportional hazards assumption was violated, further time-dependent covariates were created by use of the ‘survsplit’ function and an interaction term with the exposure added to the model. Minor departures from the proportional hazards assumption were permitted to improve interpretation of the model. The HR and their 95% confidence intervals for the exposures in each model were displayed in forest plots. The size of the point estimates were proportional to their precision, and where the 95% confidence interval for the estimate overlapped the hazard ratio of one on the x-axis, the variable was considered not significant. The outcome variables from our models were type-specific hazard ratios for culling ($\mathbf{HR_c}$) and mortality ($\mathbf{HR_m}$). Separate models were fit for primiparous and multiparous cows because the primiparous cows did not have an adjustment variable for standardized milk production, and because among them metabolic diseases were so rare that this exposure was not considered.

Statistical software. Data were managed in a Microsoft SQL Server database (version 2008, Redmond, Washington) and data were analysed with R statistical software (Version 3.4.1, R Foundation for Statistical Computing, Vienna, Austria). We used the add-on R package 'survival' [Therneau and Grambsch, 2000, Therneau, 2015b] for survival analysis methods and the 'forestplot' package [Gordon and Lumley, 2017] to display the model results.

5.4 RESULTS

5.4.1 Descriptive Analysis

More herds were enrolled from the North Island regions of Waikato and Taranaki than the South Island regions of South Canterbury and North Otago, and the predominant herd breed was Holstein-Friesian and Jersey crossbred (Table 5.2).

The lactational incidence risk of modifiable risk factors varied little between the two age groups, with the exception of clinical metabolic disease (rare in primiparous cows), and increased SCC (greater in multiparous cows, Table 5.3). Additionally, cows in the older age group had an almost two-fold increased lactational incidence risk of culling.

The interval within 30 d post-calving had the greatest number of first cases of each disorder, except for lameness and increased somatic cell count, where the first cases were more dispersed in lactation, and the latter were grouped around milk production test dates (Figure 5.3).

A plot of the type-specific cumulative incidence functions indicated a greater probability of removal from the herd due to either culling or mortality for multiparous compared with primiparous cows after

Table 5.2: Summary descriptive statistics of 123 herd-seasons[1] from 65 pasture-grazed, seasonal-calving herds from four regions of New Zealand herds analyzed in a study to investigate risk factors for culling and mortality of cows

	n (% or SD or IQR)
	N=123
Region:	
Waikato	39 (31.7%)
Taranaki	30 (24.4%)
South Canterbury	29 (23.6%)
North Otago	25 (20.3%)
Herd size	500 [284;816]
Herd breed:	
Crossbred	80 (65.0%)
Holstein-Friesian	32 (26.0%)
Jersey	11 (8.9%)
Mean milk yield (l)	4209 (977)
Mean per cow milk solids production (kg fat + protein)	363 (76)
Culling incidence risk (% per lactation)	19.1 [16.8;22.3]
Mortality incidence risk (% per lactation)	1.7 [1.1;2.6]
Herd size change (%)	0.7 [-2.1;3.0]
Replacement rate (%)	21.9 [19.3;24.2]

[1] Percentage of categorical variable, standard deviation of normal variable, interquartile range of non-normal variable, Herd size = number of cows calved in a dairy season, Herd breed = predominant breed of cows in herd, Herd size change = relative change from previous season, Replacement rate = percentage of primiparous cows in dairy herd

Table 5.3: Descriptive statistics[1] and lactational incidence risk (grouped by age of cows, from 64,093 cows in 65 seasonal-calving herds from four regions of New Zealand used in analysis of risk factors for culling and mortality

	Primiparous	Multiparous
	N=15995	N=54969
Age category:		
2 yr	15995 (100.0%)	0 (0.0%)
3-4 yr	0 (0.0%)	22742 (41.4%)
5-7 yr	0 (0.0%)	21032 (38.3%)
8+ yr	0 (0.0%)	11195 (20.4%)
Breed category:		
Crossbred	9773 (61.1%)	31195 (56.8%)
Holstein-Friesian	4684 (29.3%)	17234 (31.4%)
Jersey	1538 (9.6%)	6540 (11.9%)
Difficult calving	1453 (9.1%)	6865 (12.5%)
Metabolic disease	7 (<0.1%)	427 (0.8%)
Post-calving problem	84 (0.5%)	189 (0.3%)
Uterine infection (< 14 d)	208 (1.3%)	794 (1.4%)
Uterine infection (14+ d)	427 (2.7%)	1018 (1.9%)
Mastitis	1885 (11.8%)	7565 (13.8%)
Lameness	452 (2.8%)	1966 (3.6%)
Increased somatic cell count	5907 (36.9%)	26444 (48.1%)
Culling	1987 (12.4%)	11927 (21.7%)
Mortality	266 (1.7%)	1158 (2.1%)

[1] Percentage of categorical variable, standard deviation of normal variables, interquartile range of non-normal variables Herd size = number of cows calved in a dairy season, Herd breed = predominant breed of cows in herd, Herd size change = relative change from previous season, Replacement rate = percentage of primiparous cows in dairy herd

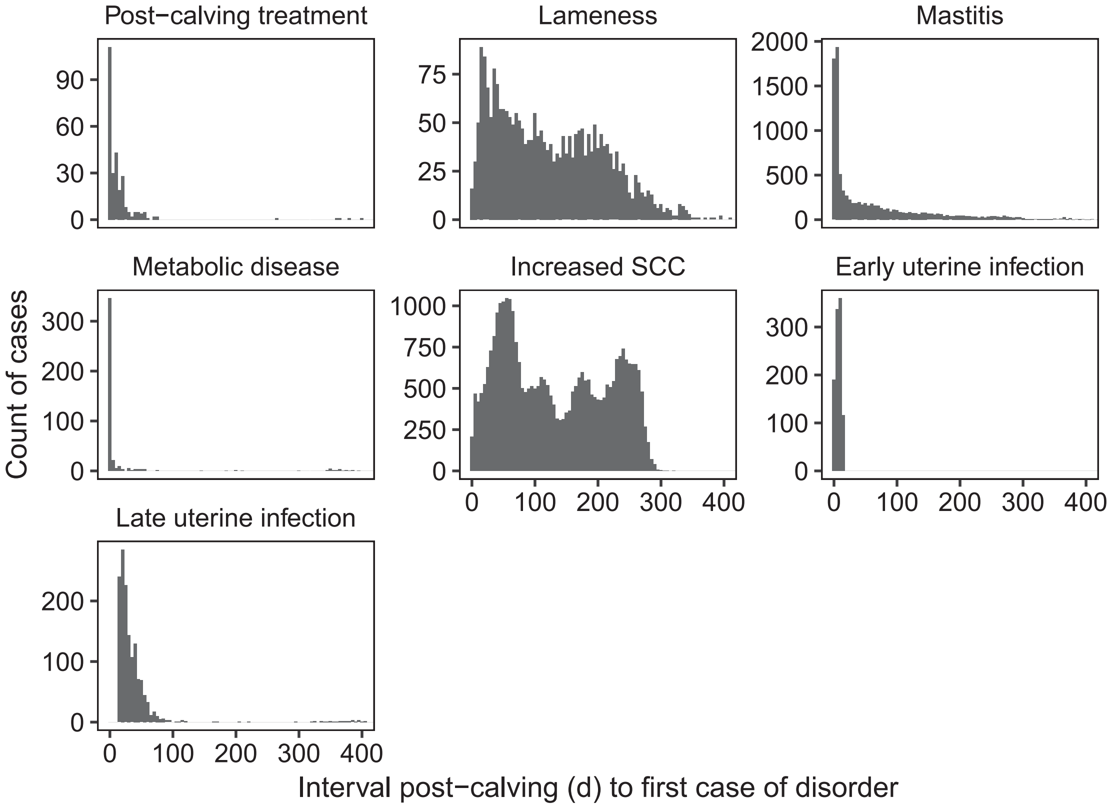


Figure 5.3: Distribution of intervals within 400 d post-calving to first cases of disorders investigated as risk factors for culling and mortality among cows from 65 pasture-grazed, seasonal-calving herds over two seasons from four regions of New Zealand. (Post-calving treatment = farmer-recorded treatment for severe calving-related problem, Metabolic disease = milk fever or hypomagnesemia, Increased SCC = increased somatic cell count indicating intramammary infection, Early and late uterine infection = treatment with antibiotics for uterine infection or retained fetal membranes within 14 d (early) or 14 d or more (late) post-calving)

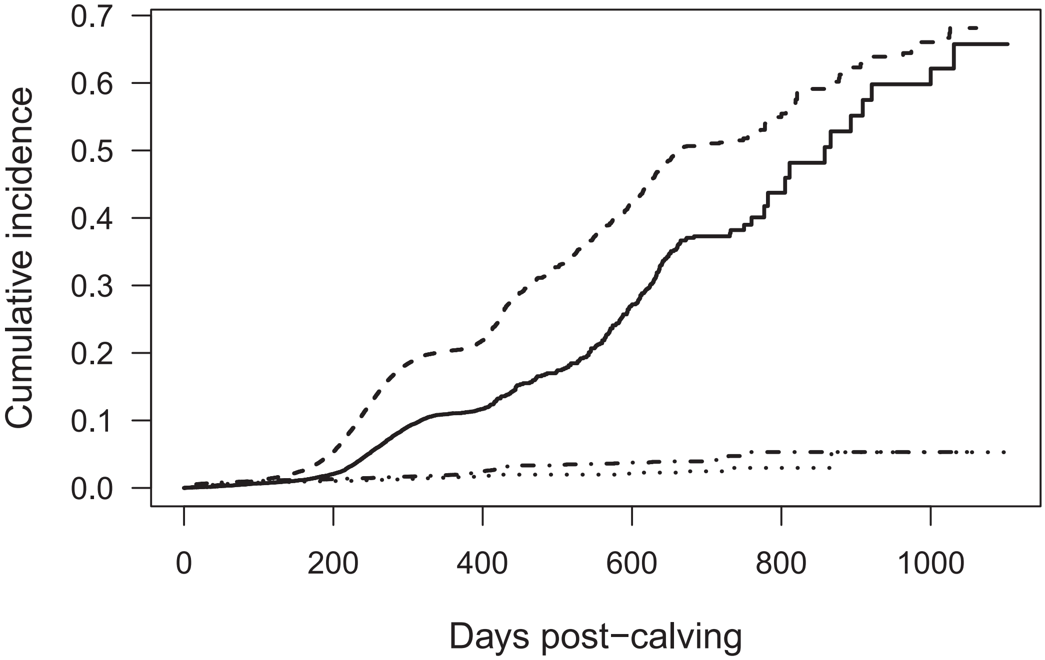


Figure 5.4: Cumulative incidence of removal from herd due to culling (primiparous cows = solid line, multiparous cows = dashes) or mortality (primiparous cow = dotted, multiparous cow = dash-dot) from competing risks analysis of cows from 65 pasture-grazed, seasonal-calving herds over two seasons from four regions of New Zealand

approximately 200 d post-calving (Figure 5.4, pointwise-confidence intervals not shown).

5.4.2 Hazard Ratios for Culling and Mortality

Primiparous cows. Both calving difficulty and post-calving treatment were associated with increased rates of both culling and mortality (1.5 and 1.9-fold increases, respectively, Figure 5.5). One or more first cases of increased SCC, and uterine infection both less than or after 14 d post-partum, were associated with increased rates of culling or mortality, but first cases of mastitis were only associated with increased rate of culling (and not mortality). First cases of lameness were not associated with either culling or mortality.

Multiparous cows. The associations between calving difficulty, and first cases of mastitis and increased SCC, differed for each of the competing outcomes, and for the udder health disorders, by

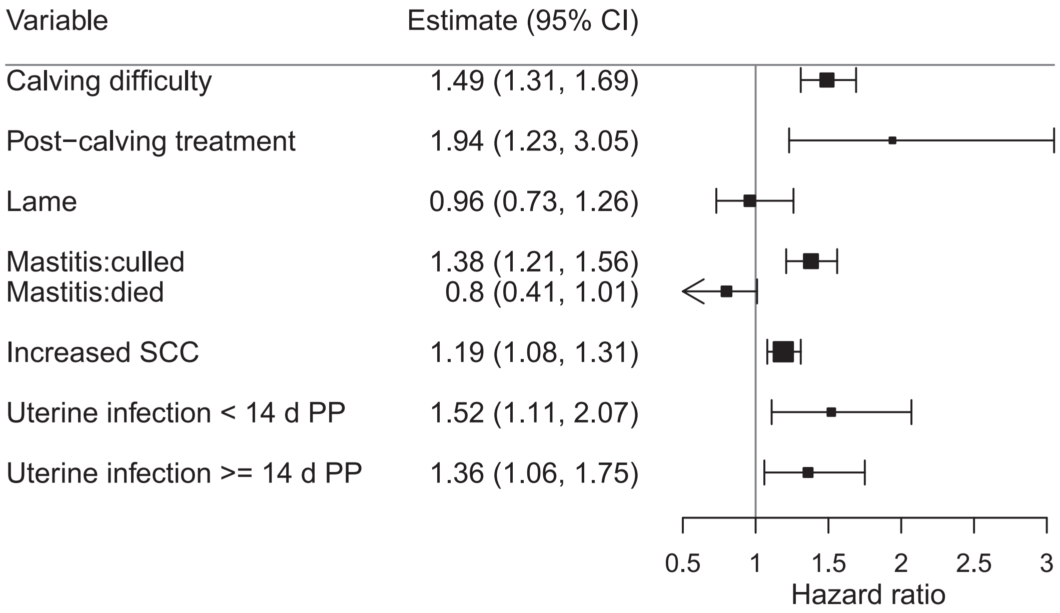


Figure 5.5: Results from multivariable competing risks analysis of the associations between risk factors and the hazard ratios of culling and mortality of primiparous cows from 65 pasture-grazed, seasonal-calving herds over two seasons from four regions of New Zealand

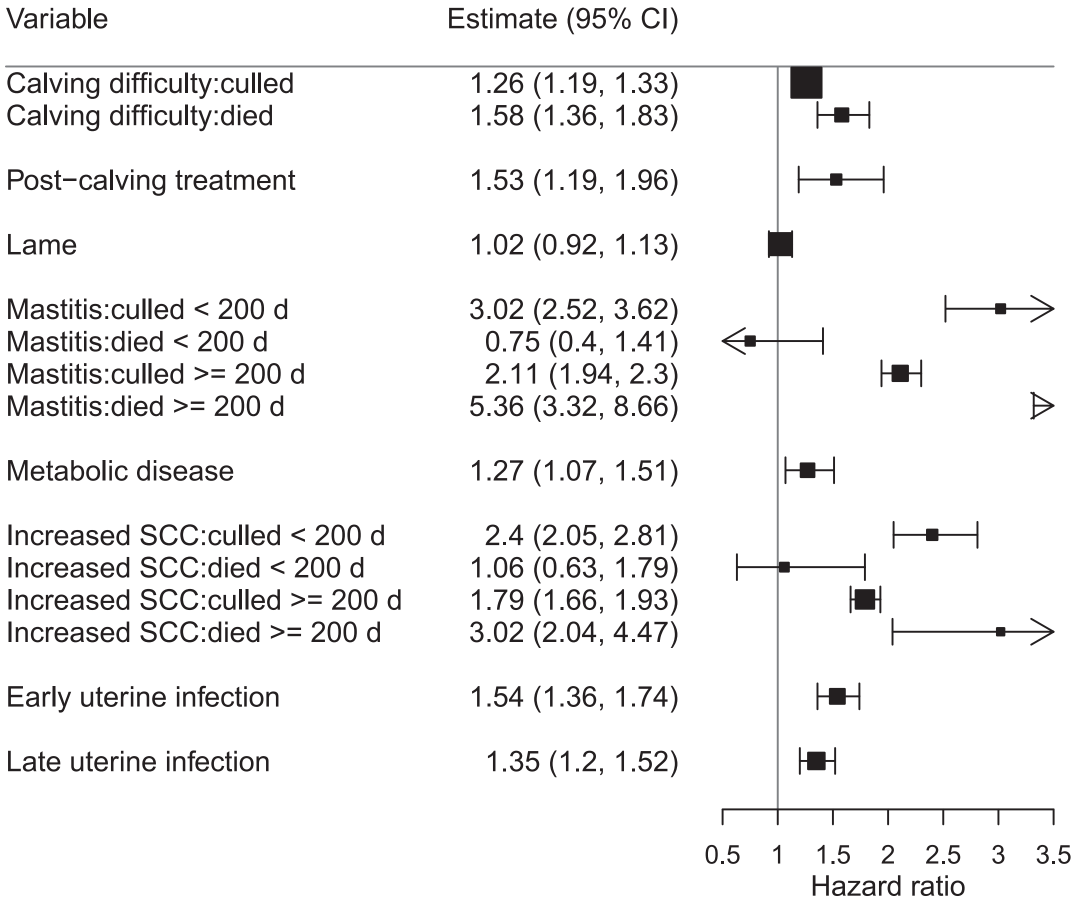
time after the first case (Figure 5.6). For example, calving difficulty increased the $\mathrm{HR_m}$ more than the $\mathrm{HR_c}$, and the first case of mastitis increased both the $\mathrm{HR_c}$ and $\mathrm{HR_m} \geq 200$ d following the first case, but only increased the $\mathrm{HR_c}$, but not the $\mathrm{HR_m}$, < 200 d following the first case. The first case of lameness was not associated with either $\mathrm{HR_c}$ or $\mathrm{HR_m}$.

5.5 DISCUSSION

This is the first study to investigate risk factors for culling and mortality in cows in pasture-grazed, seasonal-calving cows. Previous studies in New Zealand have investigated risk factors associated with a range of disorders, such as purulent vaginal discharge [McDougall, 2001a, McDougall et al., 2007b] and clinical mastitis [Bates and Dohoo, 2016], but we could find no reports of their associations with culling and mortality. Our findings provide information on additional associations with these disorders, that have economic and animal welfare consequences, and can inform control programs to reduce mortality and non-production related culling.

5.5.1 Calving Difficulty and Post-Calving Treatment

Dystocia, measured by calving ease or assistance scores and the stillbirth of calves, has frequently been associated with an increased risk of culling [Beaudeau et al., 2000] and as a common farmer-reported cause of mortality [Thomsen and Houe, 2006]. Our results are similar to those reported previously for cows managed in housed systems. Using a multivariable model that accounted for competing risks, we estimated that the total effect of a record of a dead calf or assisted calving, or both, was to increase the risk of culling and mortality by 1.5-fold in primiparous cows. In multiparous cows, however, we detected that animals with recorded calving difficulty had greater increase in the relative hazard of mortality on-farm compared with culling (1.6 vs 1.3-fold increase), although culling was likely a much more likely outcome because the baseline hazard was greater. Alvasen et al. [2014a] reported that dystocia and still birth in Swedish primiparous cows increased the hazard of mortality by 2.1 and 1.4-fold, respectively, and by 1.5 and 1.2-fold, respectively in multiparous cows. Other authors have not differentiated between age of cow, but de Vries et al. [2010] and Haine et al. [2017] have also reported



Variable	Estimate (95% CI)
Calving difficulty:culled	1.26 (1.19, 1.33)
Calving difficulty:died	1.58 (1.36, 1.83)
Post−calving treatment	1.53 (1.19, 1.96)
Lame	1.02 (0.92, 1.13)
Mastitis:culled < 200 d	3.02 (2.52, 3.62)
Mastitis:died < 200 d	0.75 (0.4, 1.41)
Mastitis:culled >= 200 d	2.11 (1.94, 2.3)
Mastitis:died >= 200 d	5.36 (3.32, 8.66)
Metabolic disease	1.27 (1.07, 1.51)
Increased SCC:culled < 200 d	2.4 (2.05, 2.81)
Increased SCC:died < 200 d	1.06 (0.63, 1.79)
Increased SCC:culled >= 200 d	1.79 (1.66, 1.93)
Increased SCC:died >= 200 d	3.02 (2.04, 4.47)
Early uterine infection	1.54 (1.36, 1.74)
Late uterine infection	1.35 (1.2, 1.52)

Figure 5.6: Results from multivariable competing risks analysis of the associations between risk factors and the hazard ratios of culling and mortality of multiparous cows from 65 pasture-grazed, seasonal-calving herds over two seasons from four regions of New Zealand

increased risk of both culling and mortality following dsytocia (up to 2.0-fold increased hazard and 1.6-fold increased odds, respectively). Judging by the similar strengths of association, it appears that the mechanism by which dystocia affects culling and mortality is through similar mechanisms across different management systems.

The total causal pathway of dystocia on increased risk of mortality is self-evident, whereas the increased risk of culling is likely indirect through impaired reproductive performance as a result of uterine infection and metabolic disorders, and through reduced milk production [Erb et al., 1985, Heuer et al., 1999]. In addition, we included post-calving treatments as a separate measure in our study. Farmers recorded post-calving treatments separately from dystocia and it was likely that they documented these treatments more accurately than stillbirth or calving ease because it was mandatory to record treatments with meat or milk withholding periods, such as for use of antibiotics and anti-inflammatory drugs. As such, a record of post-calving treatment is likely to reflect more severe forms of dystocia that caused significant trauma, such as cervical or vaginal laceration or obstetric paralysis. Accordingly, post-calving treatment for calving difficulty was associated with a 1.9- and 1.5-fold increased rate of culling and mortality in primiparous and multiparous cows, respectively. Overall, our findings support the recommendations of the previously-cited authors for farmers to improve calving management by providing timely and appropriate intervention to reduce the incidence or severity of dystocia, and for dairy cattle breeders to seek genetic solutions to improve calving ease.

5.5.2 Mastitis and Increased SCC

Mastitis in dairy cows is commonly associated with increased risk of culling [Beaudeau et al., 2000]. We also report a positive association between clinical mastitis and culling in primiparous cows, and in multiparous cows both before and following 200 d after the first case (1.4, 3 and 2.1-fold, respectively). The estimates for multiparous cows were similar to those reported in previous studies, for example, Bar et al. [2008] reported that mastitis increased the odds of culling in multiparous cows 3.4-fold, and Hertl et al. [2011] reported increased rates of culling ranging from 1.2 up to 16.5-fold depending on the age of cow, the number of previous cases and the causative organism. The association between mastitis and $\mathrm{HR_c}$ was weaker in primiparous compared to multiparous cows, possibly because farmers know that mastitis cure rates are generally greater in the younger age group and they are more willing to attempt treatment.

We did not detect any association between mastitis and $\mathrm{HR_m} < 200$ d following the first case in multiparous cows, but several others have reported incresed rates of mortality in cows associated with mastitis. Alvasen et al. [2014a] reported a 1.4 to 1.7-fold increase in hazard depending on age of cow, and Hertl et al. [2011] reported significantly increased rates of mortality only for cases where gram-negative bacteria were isolated. We also detected an increased $\mathrm{HR_m} \geq 200$ d following the first case of mastitis in multiparous cows. We attribute this increased $\mathrm{HR_m}$ (5.4) to deaths occurring in carry-over cows (not milked in one season because they were not pregant in the previous season) in late pregnancy (apparent from approximately 700 d post-partum), but the proportion of cows in this category (2%) and therefore population impact was negligible. The biologic reason for this finding is unclear, but may be related to persistent intramammary infection, although the farmer-reported causes of death were not informative. Overall, the increased risk of mortality due to clinical mastitis appear to be less in the present study where cows were managed in a pasture-based, seasonal-calving system compared with cows in housed systems. One likely reason for the difference between our findings and those of the cited authors are the divergent relative frequencies of causative organisms found in the different dairy systems. Previously cited reports were from confinement dairy systems where gram-negative bacteria are isolated more frequently from cases of mastitis [Bar et al., 2008, Hertl et al., 2011] compared with pasture-grazed systems where gram-positive organisms predominate and gram-negative bacteria are uncommon [McDougall et al., 2007a]. It is well known that the immune response of cows varies with pathogen type [Schukken et al., 2011] and that mastitis caused by gram-negative bacteria is more likely to result in death than those caused by gram-positive bacteria. Nevertheless, clinical mastitis was the most frequently reported disorder requiring treatment in the current study, and, therefore, its strong adverse associations with culling are likely to have an important impact at the herd level.

Subclinical mastitis or intramammary infection, as indicated by increased SCC at herd testing, was more strongly associated with the rate of culling both before and after 200 d following the first case in multiparous compared with primiparous cows (2.4 and 1.8 compared with 1.2-fold increase in rate, respectively), possibly for the same reasons as discussed for clinical mastitis. Our findings are in general agreement with the limited reports of the association between increased SCC and risk of culling. Beaudeau et al. [2000] reported that increased SCC was associated with up to 1.7-fold increased risk of culling throughout the lactation across all ages of cows combined. Similarly to our finding in primiparous cows, Archer et al. [2013] reported a 5% increase in the odds of culling in the next 50-d interval for each natural log increase in SCC in the first month of lactation, and de Vliegher et al. [2005] reported a 10% increased hazard of culling in the first lactation for the same risk factor. As for cows with mastitis, we also detected an increased rate of mortality $\geq$ 200 d following the first case of increased SCC in a small number of cows, and because the pattern of mortalities was similar to that previously described, we speculate a similar cause and population impact. Farmers may cull cows with increased SCC to ensure they are paid premium milk prices and to improve the efficiency of milk production by reducing the prevalence of subclinical mastitis. In a similar manner to clinical mastitis, the high incidence of increased SCC and moderate increase in rate of culling associated with this factor suggests it may have an important impact on non-production culling in herds. Therefore, management strategies to control intramammary infections and mastitis are likely to both improve animal health and welfare and reduce the incidence of mastitis-related culling.

5.5.3 Metabolic Disease

The incidence of metabolic disease (mainly milk fever) increases with the age of the cow [DeGaris and Lean, 2008], which was evident in our study because metabolic disease was rare in primiparous cows. Metabolic disease in multiparous cows was associated with a 1.3-fold increase in the rate of culling and mortality. The strength of association between metabolic diseases and culling or mortality reported previously varies: Alvasen et al. [2014a] reported that metabolic disease and milk fever increased the hazard of mortality by 3.6 and 8.2-fold, depending on the disorder and cow age, whereas, Grohn et al. [1998] and Haine et al. [2017] reported an increase in hazard of 2.1-fold and odds of 1.9-fold, respectively, of culling and mortality associated with milk fever. This heterogeneity was also reported in the review of Beaudeau et al. [2000] who found inconsistent associations between metabolic disease and culling. Possible reasons for the different strength of associations among studies include variations in the definitions for the disorders and statistical methodology. The direct causal pathway of milk fever to mortality is obvious, and others have reported that hypocalcaemia is a risk factor for culling [Erb et al., 1985, Heuer et al., 1999]. The incidence of clinical milk fever in New Zealand herds has been reported to vary between 2% and 4% [Roche, 2004], although the reported incidence in our study was less than half of that. It is possible that metabolic disease was underreported in our study because it was not mandatory to record animal treatments which had no withholding periods for products for human consumption, and therefore non-differential misclassification of cases would have biased the association we estimated towards null. However, the incidence of subclinical hypocalcemia in pasture-grazed, seasonal calving systems may be as much as 10 times that of the clinical disorder, as reported by Roberts and McDougall [2016], and the total impact of the two combined may be greater than we estimated. Both clinical and subclinical metabolic diseases are associated with greater risk of other post-calving disorders such as mastitis and uterine infections, and hence animal health programs that control both forms of the disorder would likely have greater benefits for cow health and longevity.

5.5.4 Early Uterine Infection

The total causal effects of early uterine infection (including retained fetal membranes) within 14 d of calving on the $\mathrm{HR_c}$ and $\mathrm{HR_m}$ were similar in both primiparous and multiparous cows (1.5 and 1.5-fold increases, respectively). Others have reported no significant associations between metritis and culling or mortality [Grohn et al., 1998, Dubuc et al., 2011], and Beaudeau et al. [2000] reported in their review that associations between metritis and culling were inconsistent among different studies. Differences between the studies in the definitions of early uterine infection or metritis may be one explanation for these inconsistencies. However, our findings indicate that strategies that reduce the incidence of early uterine infections through improved management of the close-up and calving cow are likely to decrease mortality and non-production culling.

5.5.5 Late Uterine Infection

In both primiparous and multiparous cows, late uterine infection (from 14 d post-calving onwards) was associated with a 1.4 and 1.4-fold increased rate of both culling and mortality, respectively. Our result is similar to that of Beaudeau et al. [1995], who reported a 1.4 fold increase in the hazard of culling and mortality in cows with “late metritis” compared with those without this health disorder. Dubuc et al. [2011], however, reported no association between either cytological endometritis or purulent vaginal discharge measured 35 and 56 d post-calving, and the hazard of culling and mortality. Reasons for these inconsistent findings may again include differences in how the disorders were defined, but also because of differences in the dairy management systems the studies were conducted in. In the current study, cows were farmed in seasonal-calving systems where a prolonged post-partum anovular period is an important risk factor for non-pregnancy and culling [Rhodes et al., 2003]; whereas cows in continuous-calving systems may have extended periods of breeding, typically greater than in the seasonal-calving systems. Dubuc et al. [2012] reported that cytological endometritis was associated with prolonged postpartum anovulation, and McDougall et al. [2007b] reported that purulent vaginal discharge from 14 d post-partum onwards, was associated with reduced submission and pregnancy rates in seasonal-calving cows. Hence, it is possible that cows with these disorders do not have sufficient time to self-cure and conceive in seasonal-calving compared with continuous-calving systems, and they are, therefore, culled at increased rates.

5.5.6 Lameness

We found no total causal effect of lameness on the $\mathrm{HR_c}$ or $\mathrm{HR_m}$, in either primiparous or multiparous cows. The reports of associations between lameness and culling or mortality vary. In their review, Beaudeau et al. [2000] reported inconsitent associations between lameness and culling, from no increase up to a 6.0-fold increase in the risk of culling, and, more recently Alvasen et al. [2014a] reported a 1.7 to 2.2-fold increased hazard of mortality associated with lameness. Several reasons could explain the contrast between our findings and those of others, including differences in the definition or the types of lameness. For example, white line disease and sole injuries predominate in pasture-grazed cows

[Lawrence et al., 2011], whereas housed cows suffer additionally from other severe forms of lameness, such as sole ulcers [Bicalho and Oikonomou, 2013]. A further reason is that in the current study, cases of lameness were either not recorded because it was not mandatory if treatment did not require a milk or meat withholding period, or not diagnosed by farmers. Fabian et al.[2014] indicated that the prevalence of lameness was four-times greater than estimated by farmers, which suggests that this disorder may have a greater effect on the longevity of cows in New Zealand dairy herds than our findings suggested, and that further studies are needed to investigate their relationship.

5.5.7 General Discussion

We used a combination of statistical methods to account for four important features of our data. First, not every cow in our study completed their follow-up period by calving again because they were right-censored due to loss to follow-up, and this was appropriately managed using survival analysis techniques [Beaudeau et al., 2000]. Second, our data on individual lactations were clustered within herd-seasons, So, we used a single shared frailty term [Therneau and Grambsch, 2000] to account for the resulting lack of independence between cows within herd-seasons. Third, we needed to account for the fact that once a cow calved, in addition to censoring, it could be removed from follow-up because it was culled or died, an event which would alter the probability of the alternate event occurring. This situation is known as 'competing' or 'multiple risks' [Scrucca et al., 2007]. Failure to account for this situation with the use of standard survival analysis methods that assume only one possible type of failure is inappropriate, will over-estimate Kaplan-Meier estimates of the hazards of failure [Scrucca et al., 2007] and violates the assumption required in Cox proportional hazards models that failure and censoring are independent. We wanted to preserve culling and mortality as different outcomes because they have different economic and welfare consequences, and because we believed that the risk factors we aimed to investigate could have different associations with either outcome. Survival regression modeling where more than one type of 'failure' can occur (competing risks) setting is commonly undertaken using either 'cause-specific hazard models', that are suited for aetiological or risk factor analysis, or 'subdistribution hazards models', which are more suited to answer questions about the cumulative incidence of different types of failure in individuals over time [Lau et al., 2009]. We chose the former method as it directly answered the study aim, and because statistical methods for the second option are less well developed, especially for complex data. Finally, the status of some of the putative risk factors we aimed to investigate changed throughout the lactation, which required the used time-dependent covariates [Therneau and Grambsch, 2000]. We combined these statistical methods to obtain valid estimates that would achieve the aims of our study. Future advances in statistical methodology may enable the estimation of the cumulative incidence of different types of failure in competing risks analysis with more complex data sets, which would benefit the design of control programs. In addition, our use of a directed acyclic graph and minimal sufficient adjustment sets provided estimates of the total causal effects of our exposures of interest, which are of most interest for decision-making, in models which minimised bias due to confounding from other covariates.

However, there were several other likely sources of bias in our study that may have affected our findings. The disorders that formed variables in our study, except for increased SCC, were diagnosed by farmers. Therefore, the definitions they used to classify cases and their ability to detect cases would be expected to differ between herds, and as already mentioned, farmers were not required to record all disorders. Hence, the estimates of incidence of some diseases and their associations with culling may be underestimated, especially for those not usually treated with antibiotics. If cases were missing and misclassification occurred at random, then the study results would most likely be biased towards no association and our estimates would be conservative. Additionally, the results of the current study were based on a convenience sample of well-recorded and production-tested herds that may not be representative of the wider population of dairy herds in New Zealand. However, although the incidence of disorders may not be representative of the national herd, the causal pathways leading to culling and mortality are not likely to differ greatly because the study herds were still commercial operations with similar cow genetics.

We previously reported from the same data set, relatively high incidence rates of mortality in the peripartum period compared with the rest of the lactation, increasing rates of culling starting in mid-lactation, and that the most frequent exit code for culling was non-pregnancy (Chapter 3). In the current study we determined that the the most frequently-treated disorders associated with culling and mortality, typically first occurred in the early postpartum period. Together, these findings agree with those of McDougall [2001b] and Ribeiro et al. [2013], that periparturient diseases are common in seasonal-calving pasture-grazed dairy cows and adversely affect reproductive performance and increase the rate of culling. Once more, the critical importance of the transition period in the production cycle of dairy cows is emphasized, especially in herds with compact seasonal-calving spreads, where the opportunity to positively influence the trajectory of the lactations for the next milking herd occurs in a period of only one to two months, once a year. Despite the importance of this period, the effect of different management practices on pasture-grazed, seasonal-calving dairy herds over the transition period on the incidence of peripartum diseas and associated incidences of culling and mortality remains unclear. Improved understanding of the management, husbandry and nutrition of cows over this period may provide further opportunities to improve animal health and reproductive performance and reduce mortality and non-production culling.

5.6 ACKNOWLEDGEMENTS

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Chapter 6

Evaluation of electronic records of cows removed from a sample of New Zealand dairy herds

6.1 ABSTRACT

Our primary aim was to evaluate farmer-reported electronic records of cow removals in the New Zealand National Dairy Herd Animal Database (**EDB**) when compared with paper-based on-farm records (**OFR**). We also aimed to investigate factors associated with incomplete or incorrect EDB records and any threat of bias to results that might arise from their analysis. We defined completeness as the percentage of cows and causes of removal that where present in OFR, that were also present in the EDB, and correctness as the percentage of fates (i.e. culled for slaughter, sold for dairying, or died on farm) and causes of fates in the EDB that were the same as those where present in OFR. The seasonal incidence risk ($\mathbf{IR_S}$, for 12 mo period in annual management cycle) of each fate were calculated from only the records in the EDB (the crude estimate), and then again by including cows recorded as removed in OFR that were not included in the EDB (the adjusted estimate). We used logistic and multinomial regression models to investigate factors associated with completeness and correctness of OFR, respectively. We retrieved data from a non-random sample of 33 seasonal-calving, pasture-grazed herds and 35,524 cow-seasons over two dairy seasons starting in 2014 and 2015, from two regions of New Zealand. Overall, 23.6% of all removed cows were recorded in both the EDB and in the OFR. Because of the non-random selection of herds and small proportion of records available for comparison, we could only make inferences from herds that provided OFR and for those removals recorded in them. The overall mean crude $\mathrm{IR_S}$ and difference when missing records were included (adjusted minus crude $\mathrm{IR_S}$ in parentheses), of culling, sale and mortality were 15.6 (1.1), 4.6 (0.3) and 2.9 (0.3) % per season, respectively. However, the underestimate of $\mathrm{IR_S}$ varied by as much as 8.2% in individual herds. The odds of a missing fate record in the EDB were greater for cows that died on-farm in late season compared with cows that were culled early in the season, and sold cows had greater odds of a missing cause of removal compared with cows that were culled. Both cows that were sold compared with cows that were culled, and cows that were culled in the earlier compared with the latter half of the season when most cows were culled, were more likely to have an incorrect fate in the EDB. We concluded that the biases in the estimates of the $\mathrm{IR_S}$ of culling, sale and mortality were probably small across all the study herds, but could be considerable in individual herds, where caution should be used in their interpretation. Furthermore, because the records of the fate of removed cows in the EDB were neither incomplete nor incorrect randomly, results from their analysis could be biased and should be interpreted cautiously.

Key words: cow removal, mortality, culling, completeness, correctness, validation

6.2 INTRODUCTION

Cows are removed from dairy herds because of culling directly to slaughter, sale for further dairy purposes, or on-farm mortality. These removals, especially in young cows and in early lactation, have significant financial consequences because of lost potential milk production and additional costs to rear or purchase replacement animals to maintain herd size [Rogers et al., 1988]. Furthermore, on-farm mortality, and the clinical disease that cause cows to be culled or sold, reflect poorly on animal welfare for the affected cows [de Vries et al., 2014] and are of concern to both farmers and the public. Therefore, it is important to use unbiased (without systematic error) estimates of incidence of these important outcomes [Dohoo et al., 2009] as a basis for decision-making, or at least to be aware of these issues when interpreting study results.

The most efficient means to gather data to estimate the incidence risk (**IR**) of culling, sale or mortality of cows is to retrieve herd records from registries or electronic databases (**EDB**). The National Dairy Herd Animal Database, (LIC, Hamilton) stores such records for most New Zealand dairy cows. This EDB was designed primarily to store records of calving and breeding events, and the results of milk production testing, for the purpose of selecting sires. To maintain an accurate livestock inventory, farmers record the date and fate of removed cows (i.e. culled for slaughter, sold for dairying, or died on farm), and optionally, a reason for their removal. Such records, which were not collected with the specific research question in mind, are termed ‘secondary data’ [Emanuelson and Egenvall, 2014]. Because these records were not collected using standardized recording methods or comprehensively validated by researchers, their quality needs to be assessed to determine whether, and to what extent, the results from their analysis are valid, or unbiased [Espetvedt et al., 2013, Emanuelson and Egenvall, 2014].

Farmers have not been required by law to record removed animals until recently (National Animal Identification and Tracing Act 2012), and, therefore, not all New Zealand farmers have practiced complete and accurate recording in the past. Farmers may use one or a combination of several systems to record animal events, which is a further risk to data quality. Commonly, hand-written, on-farm records (**OFR**) are made in paper-based systems, and these data are later entered into on-line EDB (e.g. MINDA, LIC, Hamilton; or MISTRO, CRV-Ambreed, Cambridge) or transcribed onto paper recording forms and sent by mail to the database manager. Alternatively, a farmer may enter data directly into on-line EDB without firstly entering it into OFR. The electronic systems place certain requirements on the extent of data required and restrictions on the range of options to enter. Data loss or error at transfer may occur at any of these steps. We therefore reasoned that the estimates of the IR of animal removal and the results of analysis of records of their causes of removal would be biased because of incomplete (missing) and incorrect records in the EDB. Furthermore, we hypothesized that we might discover factors associated with data quality that could inform programs to improve recording systems, as have been reported in Nordic countries [Rintakoski et al., 2012, Wolff et al., 2012]. The main aims of this study were to firstly, evaluate records of removal of cows in EDB compared with OFR from a convenience sample of seasonal-calving New Zealand dairy farms, secondly, to estimate any bias in the calculated IR of removal, and thirdly, to investigate factors associated with discrepancies in the EDB.

6.3 MATERIALS AND METHODS

This was a prospective observational study. We collected data over a two year period, starting in June 2014, from pasture-grazed, seasonal-calving dairy herds in the Waikato and South Canterbury regions of New Zealand. The current study operated in a subset of herds in another observational study in which antibiotic usage in animals was recorded. A convenience sample of herd-owners were enrolled from clients of one veterinary business in each region. Herd-owners were enrolled if they had a seasonal-calving herd (all cows within the herd calved within a three-month period over late-winter and early-spring), were located within a 50 km radius by road from the veterinary center in each region, used LIC services for their animal record management, and if the herd owner provided access to their data in OFR and EDB of the dates, fates and causes of removal of cows that were culled, sold or died. Herds were ineligible to be enrolled in the current study if they only recorded cow removals in electronic format with no OFR to compare EDB records against.

All female dairy animals in the EDB greater than one year of age that were present in the study herds at any time in the two dairy seasons over the study period were enrolled in the study. A dairy season was defined as the interval between the date 130 d prior to the start of the breeding program for a particular herd in the current and subsequent season [Brownlie et al., 2014]. Therefore, seasons started in study herds in the May to June period in winter, and were usually of 365-d duration. Cows were defined as present at any time throughout the season if they had not been removed previously, had a record of a calving or a breeding or a production test in the current or previous season, or had been purchased and entered the herd in the current season.

Records of removed cows in the OFR were only accepted where the animal was identified with a tag number, a fate at removal was assigned, and a removal date was recorded. The fate at removal could be either culled for immediate slaughter, sold for dairy purposes, died on-farm (either unassisted or euthanized), or temporarily moved off-farm. Farmers could optionally choose to record the cause of cow removal from a selection of codes when data was entered into an EDB, or they could use the same codes or another text description of the cause of removal in the OFR. Technicians made electronic copies of OFR at five farm visits at approximately six-month intervals over a two-year period, commencing in December 2014. The target number of herds to enrol for the concurrent study was approximately 80. Approximately 40% of herds were expected to have only electronic recording systems, and would, therefore be excluded from this study, leaving approximately 48 herds eligible for enrollment.

6.3.1 Data Management

The records of cow management tag numbers, dates and fates at removal, and, if present, farmer-attributed causes of removal in OFR were photocopied and entered into a custom-built Microsoft Access database (Version 2010, Redmond, WA) by technicians. All records of cow removals in the OFR were verified against those in the custom database by the study investigator. The criteria for inclusion in the analyses, and the codes for fate and cause of removal were the same for both EDB and custom database of OFR. Farmer-reported codes for cause of removal were categorized separately for each fate after Compton et al. [2017, see Appendix Tables 5 and 6]. All records in the EDB of animals present in the study herds between June 2014 and December 2016 were loaded into a Microsoft SQL Server database (Version 2008, Redmond, WA) by a custom on-line procedure with LIC (Hamilton, New Zealand) and a unique record for each dairy season assigned to each cow. The most recent dates that EDB records and OFR were retrieved were 30 Nov 2016 and 14 Dec 2016, respectively. The primary unit of analysis was the unique combination of a cow within a season (cow-season). There was a minimum interval of 6 mo between the latest possible date for records of removal of cows in OFR and the date EDB records were retrieved. These electronic data included lifetime identification and management tag number, date of birth and entry into the herd, and records of any removal event, as previously described.

6.3.2 Statistical Methods

Where removal records were in the OFR, they were were the standard for comparisons against EDB records because OFR were made closer in time to the event than the EDB record, and were original and, therefore, assumed to be less prone to recall bias or transcription error. We defined our main outcomes similarly to Rintakoski et al. [2012] with modification because our records were of removed cows rather than animal diagnostic events and because our study objectives were different. A record was considered present in the EDB if the cow had the same identification and the removal occurred in the same season as in the OFR; therefore comparisons were for the same season. We calculated completeness as the percentage of records in OFR that were also present in the EDB. We calculated correctness as the percentage of records in OFR that were correctly recorded in the EDB, with different categories of discrepancy. For fate at removal, discrepancies were categorized as either 'major' (fate incorrect), 'moderate' (fate correct but date difference > 7 d), 'minor' (fate correct but date difference ≤ 7 d), or 'none' (fate and date correct); and for cause of removal, discrepancies was categorized as either 'major' (both cause code and category of cause incorrect), 'minor' (cause code incorrect and category of cause correct) and 'none' (cause code and therefore also category of cause correct). Completeness and correctness were effectively the same as sensitivity and positive predictive value (in a diagnostic sense), respectively. Specificity could not be assessed because the number of removal events in neither OFR or EDB could not be determined. Completeness and correctness were calculated separately for fate at removal and cause of removal. Records only in the EDB were not considered for these calculations because there were no records in the OFR against which they could be compared. These definitions in mathematical notation are shown below:

$$Completeness_{Fate} = \frac{No.\ removed\ cows\ in\ EDB\ also\ in\ OFR \times 100}{No.\ cows\ removed\ in\ OFR}$$

$$Completeness_{Cause} = \frac{No.\ removed\ cows\ in\ EDB\ with\ a\ recorded\ cause\ \ also\ in\ OFR \times 100}{No.\ cows\ removed\ in\ OFR\ with\ recorded\ cause}$$

$$Correctness_{Fate} = \frac{No.\ in\ EDB\ with\ fate\ discrepancy\ vs.\ OFR \times 100}{No.\ cows\ removed\ in\ OFR}$$

$$Correctness_{Cause} = \frac{No.\ in\ EDB\ with\ cause\ discrepancy\ vs.\ OFR \times 100}{No.\ cows\ removed\ in\ OFR\ with\ recorded\ cause}$$

We used logistic and multinomial regression models to investigate risk factors associated with completeness and different categories of correctness, respectively. We adjusted for the clustering of records within herds by use of generalized estimating equations with exchangeable correlation structures [Prentice and Zhao, 1991] for the binary completeness outcomes in logistic models, and cluster-specific model estimation [Ibragimov and Müller, 2010] for the categorical correctness outcomes in multinomial models. We assessed the following putative variables and forms (as continuous or categorical variables) for associations with completeness of fate and cause and correctness of fate: the year the dairy season started in (categorical), interval from start of the dairy season to date of removal (continuous and four-level categorical), and fate at removal (categorical). Separate models were needed for each correctness of cause because of different categories for causes of removal for each type of fate. Multinomial models were only fit for the models for correctness where the number of records per herd were ≥ 10 to reduce the effect of extreme distributions on the results (number of herds = 15, 10, and 26, for models for culling, mortality and fate of removal, respectively). Models were fit in a manual forward stepwise manner and variables were retained if Wald tests for the added variable were significant ($P < 0.05$) or another model coefficient changed by $> 15\%$. All excluded variables were then added in one step to the retained variables before selecting a preliminary final model. The fit of the preliminary final multinomial models were assessed by fitting them in the form of ordinary logistic regression models and then by examination of plots of residuals against fitted values and Cook's distance against row labels. The fit of the preliminary final logistic regression models were assessed directly in the same way. No concerning patterns were observed and the preliminary models were declared final.

The seasonal IR of culling ($\mathbf{IR_{SC}}$), sale ($\mathbf{IR_{SS}}$) or mortality ($\mathbf{IR_{SM}}$), were calculated as the percentage of animals that were removed with that fate divided by the number of animals present at any time in the season. For example, the seasonal $\mathrm{IR}_{\mathrm{SC}}$ was defined as:

$$IR_{SC} = \frac{\sum \text{cows culled during the season}}{\sum \text{cows present at any time throughout the season}} \times \left(\frac{100}{1}\right)$$

and so forth for sale and mortality. This method does not account for the fact that the population was not closed or for removal of animals for other causes, as is normally recommended [Dohoo et al., 2009, pg 69], but is likely not greatly biased because few cows are purchased and most cows are culled at the end of the season, and the measure provided an estimate that is familiar to farmers. We calculated a crude IR_{S} that used only EDB records, and an adjusted estimate that included in the numerator any additional removals in the OFR that were not recorded in the EDB. A total of 89 herds were initially enrolled in the concurrent study. A total of 10 herds (11.2%) withdrew because they no longer wished to participate and a further 7 (8.9%) were excluded because they were unable to provide data of sufficient quality, for example lost part or all of their OFR, or changed their data recording service from LIC and, therefore, were no longer available. Finally, we excluded data from a further 39 herds (54.2%) because they only recorded cow removals electronically. The final data set consisted of records from 33 herds and 35,524 cow-seasons.

6.4 RESULTS

The mean herd size and per cow production per lactation of the study herds were 538 cows (SD = 381) and 361 kg milksolids i.e. milk fat plus milk protein (SD = 125), respectively. Most of the study herds were in the Waikato region (82%). The periods of greatest incidence of culling, mortality, and sale were 240 d or greater, 30 to 120 d, and in the first 30 d after the start of the season, respectively (Figure 6.1). Overall, 23.6% of all removal records in either the EDB or OFR were present in OFR, and this proportion varied little between fate at removal (culled = 24.3%, sold = 27.9% and died = 25.4%).

Removal records in the EDB was least complete for cows that died (77.1%) and most complete for cows that were culled (84%). Mean overall completeness of fate was 81.8% (Figure 6.2). The EDB records

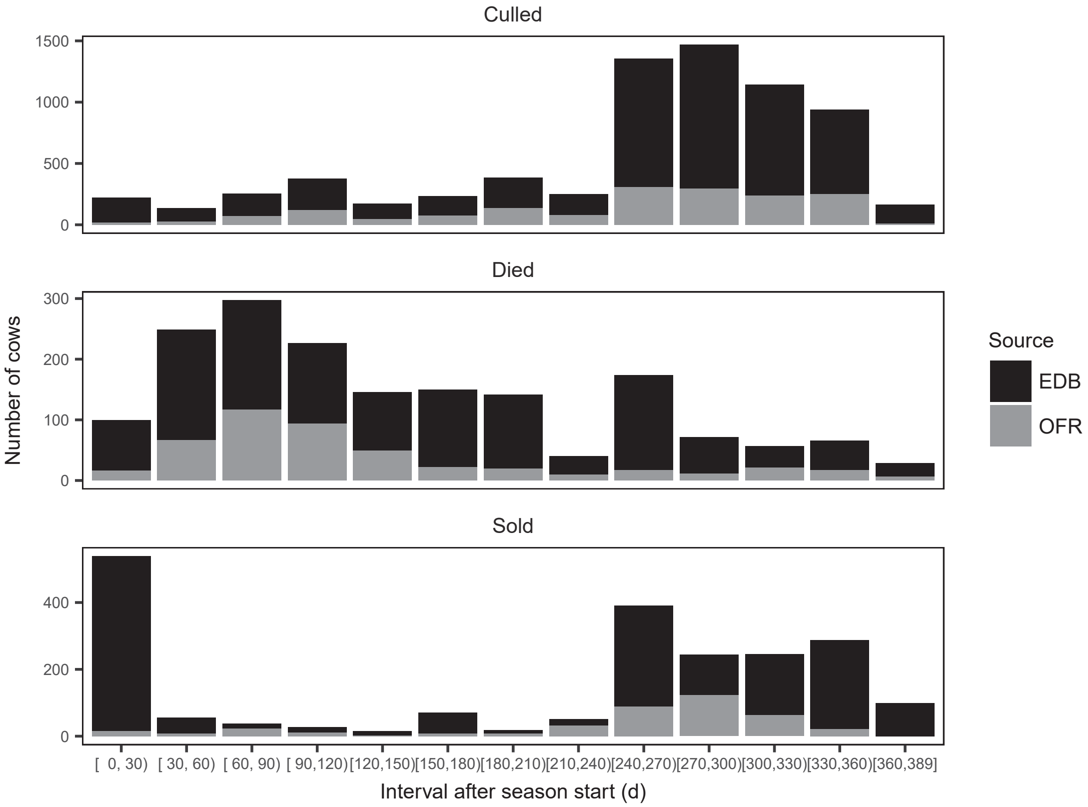

Figure 6.1: Number of cows with records of removal from herd in either electronic data base (EDB) or paper-based on-farm records (OFR), grouped by fate (culled, died or sold) and interval from start of season at removal, from a study sample of 33 herds from two regions of New Zealand over two dairy seasons

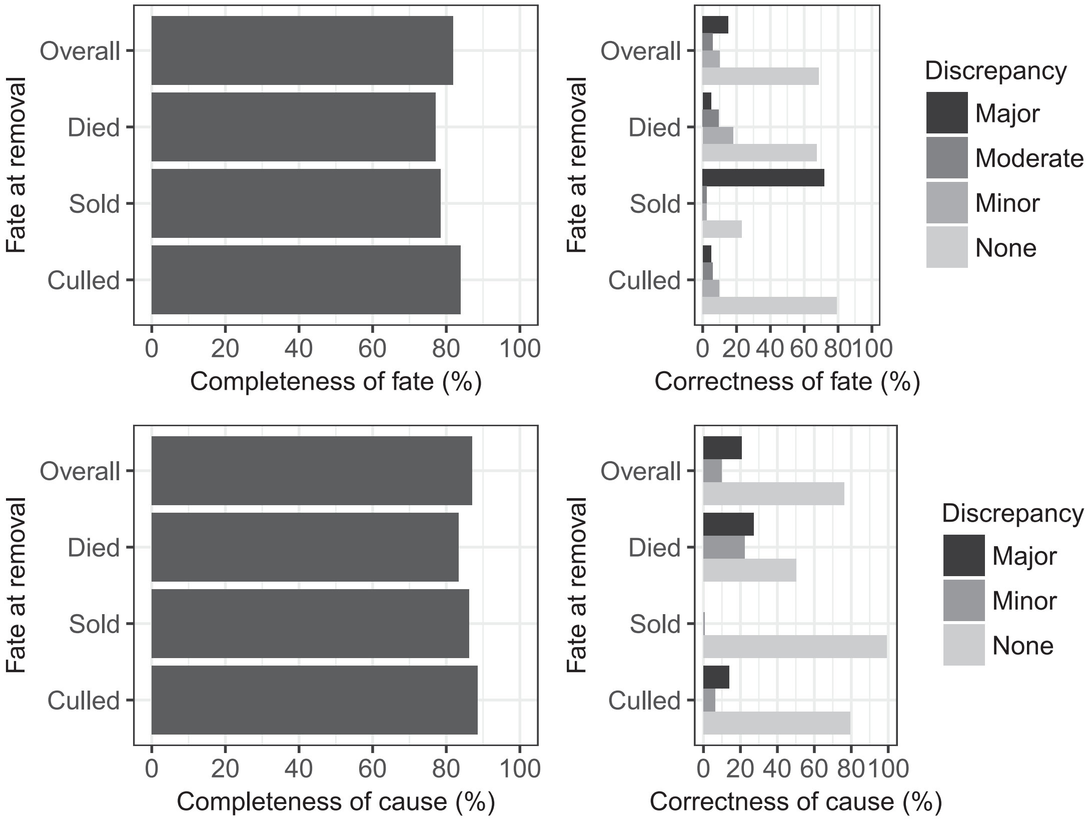

Figure 6.2: Percentage of electronic records of fate and cause of fate at removal from the herd that were complete and correct, from a study sample of 33 herds from two regions of New Zealand over two dairy seasons (Complete: Presence (yes/no) of fate or cause of removal in both on-farm records (OFR) and electronic database records (EDB): Correct: Discrepancy between record of either fate or cause of removal that was present in both OFR and EDB, using the record where present in OFR as the reference standard, categorized for record of removal (major = fate incorrect, moderate = fate correct and date difference > 7 d, minor = fate correct and date difference ≤ 7 d, none = both fate and date correct) or cause of removal (major = category of cause of removal incorrect, minor = cause of removal incorrect but category of cause correct, none = cause of removal correct))

of cows that were culled or died had only a few major discrepancies in correctness of fate (5% and 4.9%, respectively), but 72% of removal records among sold cows had an incorrect fate code (i.e. culled or died recorded in EDB instead of sold). The overall mean completeness of cause of fate in the EDB for all fates was 87% and varied little between fates (min = 83.3, max = 88.6%). Nevertheless, cows that died had a greater percentage of major discrepancies in their cause of removal recorded in the EDB (27.3%) compared with culled cows (14%), but almost all records of sold cows had no major discrepancies for the cause of removal (99.2%).

The absolute mean difference between estimates of crude and adjusted IR (adjusted minus crude IR)

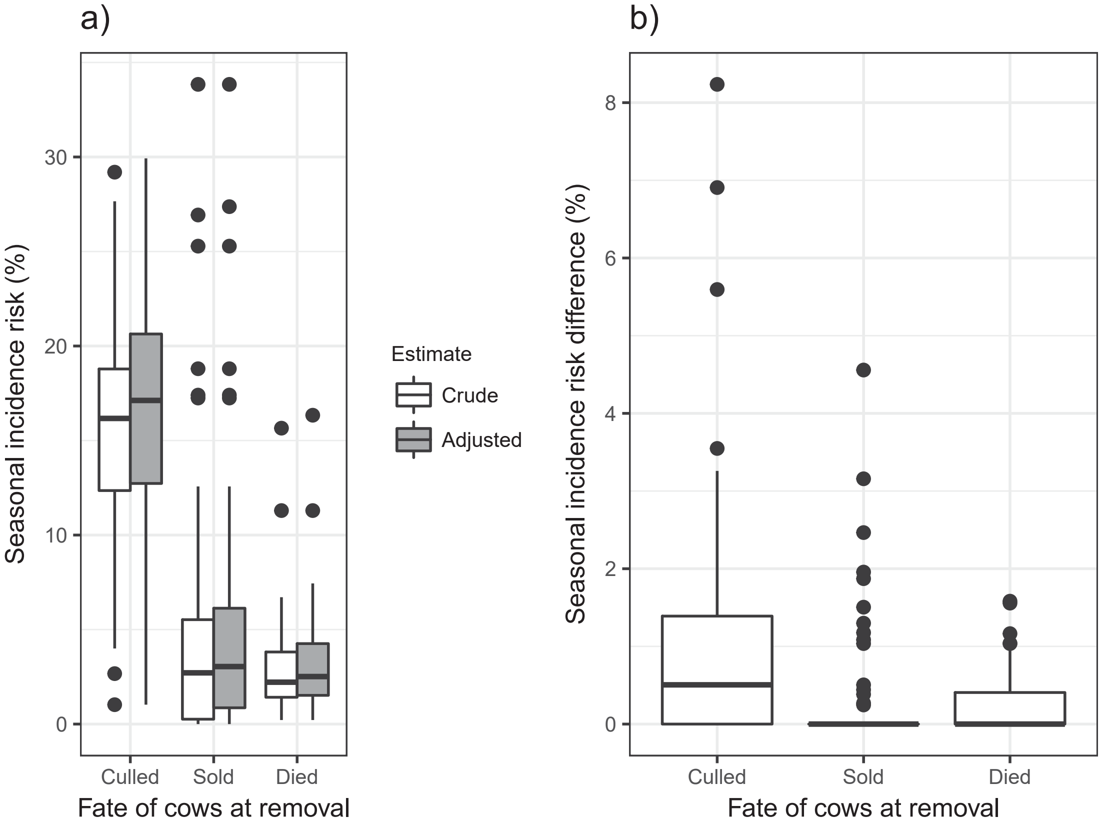

Figure 6.3: Box and whisker plots grouped by fate of cow at removal of distribution of a), seasonal incidence risk (IR) of removal when calculated using only electronic records (Crude), and when cows recorded in on-farm records but not in electronic database records were included in the calculation (Adjusted), and b), herd-level seasonal IR difference (difference = adjusted IR - crude IR), from records of 33 dairy herds from two regions in New Zealand over two dairy seasons (Median difference denoted by solid line in box (where not visible, median difference = 0), 1.5 times the interquartile range denoted by 'whisker', outlier estimates denoted by solid dots)

varied for each fate, but was greatest for $\mathrm{IR}_{\mathrm{SC}}$ (1.1%) compared with $\mathrm{IR}_{\mathrm{SM}}$ (0.3%) and $\mathrm{IR}_{\mathrm{SS}}$ (0.3%). The median absolute difference between crude and adjusted $\mathrm{IR}_{\mathrm{SC}}$ was 0.5% (Figure 6.3), whereas the median difference between crude and adjusted $\mathrm{IR}_{\mathrm{SS}}$ and $\mathrm{IR}_{\mathrm{SM}}$ were zero, denoted by lack of a horizontal bar visible in the boxes of these variables. Several outlier herds had differences between crude and adjusted $\mathrm{IR}_{\mathrm{SC}}$ and $\mathrm{IR}_{\mathrm{SS}}$ as great as 8.2% and 4.6%, respectively, but fewer outlier herds were identified for differences between crude and adjusted $\mathrm{IR}_{\mathrm{SM}}$.

The odds of complete recording of mortalities of cows 300 to 364 d after the start of the season in EDB were reduced 0.5-fold (95% CI = 0.3 to 0.7), compared with cows culled before 136 d following the start of the season, and the odds of complete recording the cause of removal in cows that were sold were reduced 0.3-fold (95% CI = 0.1 to 0.8) compared with cows that were culled.

The odds of major discrepancies in correctness of records of the fates of sold cows were increased 5.8 to 40.8 times compared with culled cows. Additionally, the odds of moderate or major discrepancies in the correctness of records of any fate were increased between 2.4 and 27.4-fold and between 1.2 and 22.8-fold, respectively, in the period < 142 d after the start of the dairy season compared with 259 to 299 d after the start of the season . No significant associations were detected with correctness of cause of culling or mortality, and no model was fit for correctness of cause of sale because there were so few discrepancies.

6.5 DISCUSSION

This study is the first known to the authors that describes how dairy farmers record the removal of cows from their herds. Our findings provide new insights into the quality of these EDB records in herds that also kept them in OFR, and the effect of incorrect and missing records in EDB on the results of their analysis.

It is important to consider the completeness of recording of cow removals and the causes of their fates in the EDB to evaluate the risk of bias from analysis of these data. First, incomplete transfer of records of removed cows to the EDB contributed to downward bias in the estimated incidence of removal of all types of fate. The mean completeness of records of removals and their causes estimated in our study (81.8% and 87%, respectively) were similar to those for health events reported by Rintakoski et al. [2012, 76%] and Espetvedt et al. [2013, 87%]. Although this estimate of completeness of fate appears concerning, it only considers the 23.6% of records in the OFR. Therefore, if it is assumed that the remaining 76.4% of records in the EDB are complete, then the overall percentage of incomplete records equals 100 - 81.8 = 18.2%, of 23.6% = 4.3%. Second, if the causes of removal are not missing at random in the EDB, the estimates of fate-specific incidence of removal may be biased. In the current study, records of mortality in late lactation had greater odds of not being transferred to the EDB compared with records of culling in early lactation. This finding indicates that mortality records were not missing at random over a whole season, and that estimates of the incidence of mortality in late lactation would be biased downward and the importance of their contributing causes would be underestimated. As a consequence of both forms of bias, resources could be incorrectly allocated to a program to control mortality over the whole season.

Incorrect removal records in the EDB may further bias results. We determined that the fate of sold cows had greatly increased odds of being incorrectly transferred to EDB, which biased downward the estimate of IR_{SS}. Possible reasons for this were that farmers were unclear about the definitions of either cull or sale fates, or that during a public sale process, cows that the farmer hoped might be sold for dairy purposes for a higher price did not find a buyer and were actually culled and slaughtered for human consumption at a lower price. Both possibilities support our belief that the fates of culling and sale of cows that have calved once or more, should be combined for analysis of the total financial burden of cow losses. Additionally, the records of any fate type of cows removed in the first 142 d of the season were less likely to be correctly transferred to the EDB records compared with cows removed in mid to late season (259 to 299 d after the start of the season). The impact of discrepancies for correctness that varied with stage of season is that estimates of IR_S of fates and causes of removal will be biased in complex and uncertain ways because their patterns also vary by stage of the season. Our estimates for correctness (no discrepancies) of fate and cause of removal (56.6% and 76.3%, respectively) were less than those of animal treatment records to EDB reported by Espetvedt et al. [2013, 98%] and Rintakoski et al.[2012, 84%]. Reasons for the reduced estimates of correctness in our study compared with Nordic studies may be related to the lack of standardized OFR systems and the only recent change to mandatory reporting of removals in New Zealand. It is also possible that farmers were too busy in the first part of the season with calving and breeding in the herd to enter data in the EDB immediately, and when they did enter it into the EDB, could not locate the cow in the OFR, or could not remember, or did not think it important to enter accurate data. We recommend a re-evaluation of the current processes used by farmers to record animal events in both OFR and EDB with a view to providing solutions that improve the quality of data and thereby improve its usefulness to farmers, researchers, and the dairy genetics industry.

The adjustment of the IR_S of each fate across all herds resulted in a relatively small increase in the median herd-level $\mathrm{IR}_{\mathrm{SC}}$ (0.5%), but no change in the same measures for sale and mortality because in half or more of the study herds, there were no records of cows sold or died that were not transferred to the EDB. The magnitude of downward bias was not as great as indicated by our estimates of completeness because that measure only related to records in both OFR and EDB, as discussed earlier.

The findings from this study have several limitations. First, the study herds were a restricted group of a convenience sample of a sample of herds, which means they may not represent seasonal-calving herds in general, particularly into the future if dairy farmes increasingly use only electronic methods of data capture. However, they were all commercial herds of diverse size and productivity from different geographic regions. Second, the number of herds and cows in the final data set were less than expected due to greater than expected percentage of herds that only made electronic records of removed cows, and because of the withdrawal of more herds than expected due to an economic downturn during the study that forced several farmers to change their farming and recording practices. Furthermore, the shortfall of records reduced the statistical power to find associations with completeness and correctness of records that may have truly been present, especially for correctness of causes of removal which required separate models. This is regrettable, but was unforeseen when the study was planned because no previous description of farmer-recording behavior was available and the economic conditions could not have been foreseen. It is also possible that other cows were removed from herds that were not recorded in the EDB, or alternately, that the OFR contained false positive removals. But the number of these cases could not be determined and it is not possible to say to what extent the adjusted IR_{S} would have changed as a result of these possibilities.

However, possibly the greatest limitation of the study arose because only approximately one quarter of removals were present in both OFR and EDB. This is because until recently, there has been no mandatory requirement to maintain OFR of removed cows, and our data indicates that most farmers instead rely mainly on an EDB to manage herd information. The implication of this to the current study was that OFR could not be considered as the reference standard against which all EDB records could be evaluated, and our inferences about completeness and correctness could not extend beyond the 23.6% of records that we found in OFR.

This report provides practical information and advice that should be considered by farmers and researchers who analyze data from the National Dairy Herd Animal Database, whether they work at the population- or at the individual herd-level. Furthermore, it suggests a need for further research to validate the majority of records of removals which are apparently only recorded electronically.

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Chapter 7

Simulation model of financial consequences of reduced culling and mortality in New Zealand dairy herds

7.1 ABSTRACT

We investigated the financial consequences of non-production culling and mortality of cows, in a simulation model of a pasture-grazed, seasonal calving dairy farm, typical in New Zealand. We considered costs and revenues that would change in a partial budget-type analysis, under six hypothetical scenarios with uncosted interventions that reduced the seasonal incidence of culling for non-production causes, and of mortality, from middle to lower quartiles of population performance. Our stochastic, dynamic, simulation model estimated changes in partial dairy operating profit ($\mathbf{DOP_p}$) in scenarios that reduced culling and mortality in early-, or mid- to late-lactation. We analysed demographic and milk production records from a recent multicenter study to determine the parameters used in the model. This was a group-based model of a (Holstein Friesian-Jersey) Crossbred herd, with eight age- and five calving-groups, simulated over 10 seasons. Stochastic inputs of the model were provided by the incidence density of culling and mortality, and values for expenditure and revenue. Initial breeding value and genetic gain for milk yield, and milk yield, provided the deterministic inputs. Under scenarios of decreased culling and mortality in early-lactation, and culling in late-lactation, the revenues from milk and heifer sales increased, and decreased from culled and sold cows; whilst costs were little changed. The $\mathrm{DOP_p}$ increased by 2.0% when culling and mortality in early lactation were reduced by 50%, and culling in mid- to late- lactation were reduced by 25%. The estimated $\mathrm{DOP_p}$ was most sensitive to changes in the price of milk, followed by the incidence of culling in mid- to late-lactation. Our model or its estimates may be combined with other financial data to estimate the opportunity to invest to control diseases or reproductive failure that result in culling, and mortality of cows. This model has direct application in pasture-grazed, seasonal calving herds in New Zealand, but the methodology may also inform research and extension in other dairy systems.

Key words: economic, dynamic, stochastic, Monte Carlo

7.2 INTRODUCTION

Animal diseases and disorders not only have adverse effects on the welfare of affected animals, but they reduce the financial efficiency of production by incurring additional costs and reducing revenues. Farms with effective disease and reproductive management programs have options to improve their economic returns through two additional complementary pathways [Stott, 1994, Rogers et al., 1988]. Herds (with a constant size) that have a greater length of productive life, have an economic advantage because they have a greater proportion of cows in the more productive middle-age group, and can reduce their rearing costs because they need fewer replacements. Moreover, when the incidence of culling cows in a herd because of disorders or reproductive failure is so great that few possibilities exist to cull for poor production, the average productivity of the herd is decreased because less productive cows are retained longer [Stott, 1994].

In a financial evaluation of a specific disease or disorder, any increase in the risks of culling or mortality are usually considered alongside other indirect costs, such as increased risks of other associated diseases, delayed calving and other lost income. These are then combined with direct costs, such as additional labor, veterinary and animal treatments costs, and lost income from reduced and discarded milk production arising from the disease itself, to calculate the total financial impact. These direct costs are more obvious to farmers and are readily estimated from empirical data, but calculation of the indirect costs is more complicated because they may be interrelated and the outcomes are uncertain. Most economic analyses of the consequences of culling have considered the decision-making required to answer the question as to whether or not to replace an individual animal for operational management reasons, for example to inseminate or treat a cow with a clinical disease, and thereby opt to retain the cow in the herd, or alternatively, to cull the cow and replace it with a more profitable animal. Several analytic methods have been reported to solve this “retention pay-off” question, including linear programming, Markov chain analysis, and simulation modeling [Dijkhuizen et al., 1991]. However, the majority of research on financial consequences of culling and mortality have been developed and applied in partial- or fully-housed dairy systems [Congleton, 1984, van Arendonk, 1985, Dijkhuizen et al., 1986] where milk production per cow is greater than in pasture-grazed systems, and year-round calving provides immediate replacements for culled cows compared with delayed replacement in seasonal-calving systems. Much less has been published on this subject from work in pasture-grazed, seasonal-calving systems, where milk production per cow is less and replacement of culled cows is delayed. Harris [1990] used stochastic programming to rank New Zealand cows on future profitability, and Crequer and MacArthur [1996] reported that decisions to cull cows because of low production should be mainly based on their performance in their first lactation. However, farmers may also have the option to sell cows for non-production reasons. The choice made will likely be driven by the age and health status of the animals, and the price for a live sold cow compared with a cow culled for slaughter. To our knowledge, the financial consequences of this option have not been considered in pasture-grazed, seasonal-calving systems.

In addition to the need for information to aid the decision to cull or sell individual animals, farmers also need guidance for their medium- to long-term planning, for example, whether or not to invest in interventions against avoidable disorders or reproductive failure. Such interventions will not only reduce direct costs, but also reduce indirect costs caused by increased risk of culling and mortality. However, compared to cow-level decision-support systems, fewer tools are available to help farmers that want to consider long-term and herd-level effects. Rogers et al. [1988] used a cow-level dynamic programming model to determine that the revenues and returns at the herd-level in the US dairy system could be improved from reduced rates of involuntary culling. Gartner [1982] concluded that where replacements compete with cows for feed in the UK pasture-grazed herd, it was generally, but not always the case, that profitability was reduced as replacement rates increased. Lopez-Villalobos and Holmes [2010] used a simulation model to report how profitability of New Zealand dairy farms varied with different combinations of strategies of annual replacement rate, voluntary and involuntary culling rate, and policies for the selection of heifers. However, information is still unavailable for pasture-grazed, seasonal-calving dairy systems on the potential to improve farm profit if the incidence of avoidable culling and mortality at different stages of lactation were to be reduced.

We hypothesized that potential financial benefits are available to farmers with pasture-grazed, seasonal-calving dairy systems, such as in New Zealand, if avoidable culling and mortality are reduced. We considered only non-production related removals, that is, due to disease or reproductive failure. We reasoned that these benefits would arise for two main reasons. First, herd milk production would increase because the average age of cows would increase as a result of a reduced number of 2 yr old replacements in the herd, which have reduced milk production compared with the older animals they replace; and because the mean number of days in milk would increase as a result of decreased culling and mortality during lactation. Second, costs of rearing replacements would be reduced because fewer replacements would be needed to maintain herd size, or alternately, revenue would increase because of the sale of more replacements. We also reasoned that reduced incidence of culling and mortality would affect other parts of the farm system. First, annual feed requirements would change because of opposing effects of fewer replacements grazing on the farm in their first year of life, and more cow grazing-days in lactation. Second, genetic gain, a desirable goal, would be reduced because fewer replacements of greater genetic merit would be required in the herd. We hypothesized that herd feed requirements and genetic gain for milk production would also change as a result of alterations in the incidence of culling and mortality, and should be included in an economic model of the financial consequences of changes in the incidence of culling and mortality.

We estimated the technical performance and potential financial benefits available to herd owners from hypothetical strategies that reduced the incidence of culling and mortality of cows in a model of a pasture-grazed, seasonal-calving, dairy farm after accounting for changes in feed requirements and genetic gain. We aimed to use this model and its results as a basis in the future to estimate total costs of diseases or reproductive failure, and to inform the strategic decision-making of farmers and scientists.

7.3 MATERIALS AND METHODS

We developed a stochastic, dynamic, simulation model of a typical New Zealand dairy herd. Simulation models represent parts of typically complex systems, on which experiments are performed to predict outcomes, and are useful when research questions cannot be answered using other analytic techniques or normal experimental methods [Rushton et al., 1999]. New Zealand dairy farms generally have a seasonal, spring-calving program, and the great majority of feed consumed by cows is pasture grazed in-situ [Holmes et al., 2002]. Female replacement animals are high genetic merit calves sired by artificial breeding. They are generally grazed off the dairy farm for one yr beginning at approximately 10 mo of age when pasture growth rates decline in winter, and enter the herd at 22 mo of age, prior to their first calving. We modeled the animals in each age group from the birth of a new cohort of replacements, and given their survival from culling or mortality, as they transitioned through time and from one age group to the next in each subsequent season, until they were finally culled for old age. The herd demographic model served as the foundation for models of milk production, feed intake and genetic gain. Costs and revenues were attached to inputs and outputs, to model the financial consequences of reduced incidence of culling and mortality in hypothetical intervention scenarios.

7.3.1 Definitions

Unless otherwise stated, we considered cows that were sold to be included with culled cows for the purposes of a hypothetical intervention program. This is because they could be removed from the herd for the same disease or reproductive-related reasons as culled animals, and could similarly benefit from control of the same conditions. However, in the demographic and economic components of the

Table 7.1: Definitions of terms

Term	Definition
Age group	Age (yr) at the start of a season of a cohort of cows
Calving group	Cohort of cows in the same age group that calve within a time interval of 14 d
Cow	Female dairy animal that has calved once or more
Culling	Removal of animal from the herd direct to slaughter for non-production causes
Herd size	Number of cows in the milking herd at a defined time. When measured at the start of the season, it includes all female animals expected to calve in that season
Incidence density (ID)	Density of cases (culling, sale or mortality), measured in cases per 1,000 cow-days in the model
Incidence risk (IR)	The count of cases among a specified group in as specified time period (1 season in this simulation) divided by the number of animals in that group at the start of the time period
Mortality	Death of an animal on the farm, either unassisted or euthanized
Peak number milking cows	Maximum number of cows milked at any one time in a season
Replacement rate	Proportion of 2 yr old heifers among all cows at the start of the season
Sale	Sale for non-production reasons to another farmer for dairy purposes
Season	Interval between 1 June and 31 May in the subsequent year
Time step	Interval of 14 d

model they were considered separately because their removal had different financial consequences. We further defined avoidable culling, sale and mortality, as that due to non-production causes which was greater than the lower quartile of performance in the reference population. Definitions of the other terms used are shown in Table 7.1.

7.3.2 Herd Demographic Model

A demographic model of a dairy herd was developed from analysis of data collected in the National Herd Fertility Study [Brownlie et al., 2014] over two consecutive seasons commencing in 2009. Briefly, this was a multicenter, longitudinal observational and management intervention study which aimed to define reproductive performance and related management practices from New Zealand dairy herds, and to test the effect of a herd-level management intervention on reproductive performance. Data used in the current study were from a subset of 77 of these herds with herd production records on at least four occasions in a season [henceforth known as the ‘reference population’; Compton et al., 2016].

Farmer-recorded data on births, culls, sales and mortalities were analysed to calculate the ID of culling, sale and mortality in 14 d intervals from either date of birth (for replacements), or calving (for cows). Animals were categorized by age at the start of the season into 10 groups of zero to nine yr, inclusive (calves were 0 yr). Cows 9 yr of age or older were grouped together as 9 yr. Our estimates were for (Friesian-Jersey) Crossbred animals, the predominant breed in the reference population [Compton et al., 2016].

The number of animals in the herd was simulated in 26 time steps of 14 d intervals, beginning from the start of the season (June 1), for 10 seasons. Cows were divided into five calving groups, each representing cows that calved in non-overlapping 14 d intervals. Thus, the model consisted of 40 age-calving groups of cows. The calving program started in the fifth time step, two mo following the start of each season, and was of 10 wk duration. Additionally, we modeled three groups of replacements born in the first three time steps (six wk) of the calving program, weaned after six time steps (12 wk), and then modeled up to 10 mo of age in their first season. A single group of replacements was modeled from 10 mo to 22 mo of age. The surviving animals in a group at the end of the time step subsequently entered the next time step. This provided the dynamic part of the model.

Any surplus female replacements were sold at two possible time points. First, if there were a surplus of more than 10% of weaned calves greater than the number of pregnant nulliparous heifers that joined the herd in the previous season, these were sold at weaning. Second, the number of pregnant nulliparous heifers that joined the herd was calculated so that the herd size at the start of the season met a predetermined number. Any surplus pregnant heifers at that time point each season were sold (or purchased, if there were a deficit).

We used the concept of two parallel timelines in the model to account for the fact that risks of culling and mortality, and milk production, are mainly related to the interval from birth or calving; but that farms also operate on a seasonal time basis for important management events and for financial accounting purposes. We therefore defined time steps for each timeline separately. First, ‘parity time step’, used date of birth or calving as the reference date, and was used to model age-calving group demographics, milk production, feed requirements and genetic merit. Second, ‘season time step’, used start of the season as the reference date and this timeline was used to aggregate parity time steps to report technical and financial results of the model on the basis of a 'season time step'.

The mean IDs of culling, sale, and mortality, were estimated for each age group and parity step in the reference population. These IDs provided the Poisson parameters for each parity time step. The number of cows culled, sold or died in each parity time step was calculated in each model iteration from a random draw from a Poisson distribution defined by the mean ID, multiplied by the number of cows present at the start of the time step. The Poisson distribution was chosen because it is directly related to the ID and is efficiently estimated. This provided the stochastic element to the model.

We made the following assumptions in our model: the interval between successive calving programs was 365 days, the proportion of an age group calving in each 14 d parity time step did not vary between seasons, the IDs of culling, sale and mortality beyond parity step 26 in the reference population were summed together for the final parity time step, the cows in each age-calving group were dried off at the end of parity time step 19 (266 d lactation, mean lactation length in the reference population), and, all 9 yr old cows in their calving group that survived to the end of parity time step 18 of their lactation (252 d of lactation) were culled in parity time step 19. The model did not provide for any culling for poor production.

7.3.3 Milk Production Model

We estimated milk yield (**MY**) curves for each age group over a 266 day lactation from the production test data from the reference population. We used the Wilmink exponential model [Wilmink, 1987] after the method used by Roche et al. [2006] to predict MY for each day of lactation. The regression parameters for the model were solved using the 'nls' function in base R [R Core Team, 2016]. The MY in each 14 d parity time step for each age group was estimated from the area under the curve using the composite trapezoid rule. We named this 'MY Model 1'.

7.3.4 Genetic Gain and Incorporation with Milk Production Model

We incorporated the effect of change in breeding value (**BV**) over time on milk production after the method of Lopez-Villalobos et al. [2000]. The current BV for milk yield, $\mathrm{BV}_{\mathrm{my}}$ (Table 7.2 was assigned to calves born in season 1. The $\mathrm{BV}_{\mathrm{my}}$ of the next ascending age group (1 yr) in season 1 was assigned that value, less the mean annual rate of genetic gain for milk yield, $\mathrm{BV}_{\mathrm{myg}}$ (Table 7.2), which was assumed constant over time. In the following season, season 2, the genetic merit of calves was calculated as $\mathrm{BV}_{\mathrm{my}} + \mathrm{BV}_{\mathrm{myg}}$, and so forth for each age group in each season. We calculated the mean proportion of MY from MY Model 1 produced over all age groups at each parity step ($\mathrm{MY}_{\mathrm{pstepmn}}$) from MY Model 1. The expected phenotypic MY at each age and parity step ($\mathrm{MY}_{\mathrm{exppheno}}$) was then calculated as the sum of the expected increase in MY due to $\mathrm{BV}_{\mathrm{my}}$ plus $\mathrm{MY}_{\mathrm{pstepmn}}$. An age adjustment factor for MY ($\mathrm{MY}_{\mathrm{ageadj}}$) was estimated for each age group as the relative proportion of MY produced compared to the peak production age group (6 yr) from the NZ population [Anonymous, 2010]. Finally, we estimated the expected MY ($\mathrm{MY}_{\mathrm{exp}}$) for each age group and calving step as the product of $\mathrm{MY}_{\mathrm{exppheno}}$ and $\mathrm{MY}_{\mathrm{ageadj}}$ (MY Model 2). The $\mathrm{MY}_{\mathrm{exp}}$ was then used as the output variable for milk production and to determine feed requirement.

7.3.5 Feed Requirement Model

The daily feed requirement in kg of DM for each age class of animal was based on the requirements for metabolizable energy (**ME**) according to AFRC recommendations [Alderman and Cottrill, 1993], and an average ME value of pasture of 10.5 MJ/kg DM. The ME requirement for each age group and time step was calculated from the equation:

$$M_{mp}(MJ/d) = C_L(E_m/k_m + E_l/k_l + E_g/k_g + E_c/k_c)$$

Where M_{mp} is the ME requirement for maintenance and production, C_L is a correction factor for feeding level above maintenance (C_L = 1 + 0.018(L - 1), L = multiples of maintenance ME requirement), E_m, E_l, E_g, and E_c are net energy requirements for maintenance, lactation, body-weight change and pregnancy, respectively; and k_m, k_l, k_g, k_c are the efficiency of utilization of

Table 7.2: Values[1] and distributions[2] used in a simulation model of a New Zealand dairy herd

Variable	Mean	SD	Distribution	Units
Milk solids price	6.84	1.62	RiskExtValue(6.1,1.3)	$/kg MS
Weaned heifer calf sale price	889.30	243.61	RiskExtValue(780,190)	$/hd
Heifer (22 mo) sale price	1,641.16	265.01	RiskNormal(1641,265)	$/hd
Cull cow sale price	555.37	52.90	RiskExtValue(532,41)	$/hd
Sold cow sale price	1,954.62	320.95	RiskExtValue(1810,250)	$/hd
Animal health costs	81.54	2.54	RiskNormal(82,2.5)	$/hd/season
Breeding and herd improvement costs	44.00	1.45	RiskExtValueMin(45,1.1)	$/hd/season
Heifer grazing costs	9.23	1.38	RiskPareto(7.7,8.0)	$/hd/wk
Dead cow disposal costs	25.00		Fixed	$/hd
Calf rearing (to weaning) costs	195.14	28.59	RiskLaplace(195.1,28.6)	$/hd
Supplementary feed costs	315.80	30.07	RiskTriang(250,300,420)	$/T DM
Pasture spared price	100.00		Fixed	$/T DM
Breeding value for MY of calves in season = 1	165.00		Fixed	l/yr
Average gentic gain in BV for MY	20.50		Fixed	l/yr

[1] Lincoln University (2006-2014), Wallace Corporation (2016), Fausett et al. (2015), McCarthy (2015), DairyNZ and LIC (2015), DairyNZ (2016)

[2] 'AtRISK' function for distribution within Excel simulation model

ME for maintenance, lactation, body-weight change and pregnancy, respectively. Body-weight and body-weight change were estimated from previously published data from Crossbred cows in New Zealand [2008; Anonymous, 2015; Alawneh et al., 2011] and interpolated where necessary to estimate a body-weight for each time step. We assumed that the total pasture available for grazing in a season was constant over the simulated seasons and that any additional feed purchased was in the form of maize silage, with an energy value of 10.5 MJ ME per kg DM.

Total season herd feed requirements were permitted to vary with the number of cows and their milk yield, and therefore, feed requirements were included in the financial evaluations so that comparisons between scenarios were valid. We used two means of adjustment in each scenario to ensure this: first, the herd size at the start of the seasons was held constant and any change in feed requirement accounted for by varying the purchase of supplementary feed, or second, the herd size at the start of the season was adjusted post-hoc to maintain total feed requirements for the seasons approximately constant. Different monetary values were applied to any supplementary feed purchased and pasture spared (Table 7.2) in each scenario.

7.3.6 Financial Analysis Model

The financial analysis of the model farm considered only the revenues and expenses that we considered would change under scenarios of reduced incidence of culling, sale or mortality, as in a partial budget. We considered contributions to gross farm revenue (**GFR**) from the sale of replacement calves and heifers, the sale and culling of cows, and from milk production. Contributions to dairy operating expenses (**DOE**) were mean costs on a per peak milking cow number basis for animal health, breeding and herd improvement, the costs of calf rearing and grazing of replacements, the costs of disposal of dead cows, and the costs of any supplementary feed to meet feed requirements. We did not consider the nature or cost of interventions required to reduce the incidence of culling or mortality, which was beyond the scope of our study. Thus, we reported a 'partial' dairy operating profit ($\mathbf{DOP_p}$) as the difference between GFR and DOE, without the cost of the intervention in each scenario. The difference in $\mathrm{DOP_p}$ between the baseline and a scenario represented the potential economic opportunity to invest in that intervention. Median $\mathrm{DOP_p}$ were reported because the distributions were right-skewed.

Means and distributions of monetary values were assigned to the inputs and outputs of the demographic, milk production and feed requirement models using the distribution-fitting functions in 'AtRisk' from published data (Table 7.2). The unit financial values for revenues and expenditures were estimated from a biennial publication by Lincoln University, New Zealand, of farm costs and prices that together reported data over a 10 yr interval from 2006 to 2015 [Burt, 2006, Chaston, 2008, Pangborn, 2010, Askin and Askin, 2012, 2014]. These values were adjusted for inflation to $NZ value in 2015 by multiplying the price for that year for dairy farms by the ratio of the price index for 2015 to the price index for that year [Statistics New Zealand, 2016]. Distributions for each value were chosen by visualizing the best fit for the alternate distributions, and the greatest overall relative ranking for fit by the Akaikie information criterion, Bayesian information criterion, Chi-squared, Kolmogorov-Smirnov and Anderson-Darling test statistics, in the 'Distribution fit' function in 'AtRISK' (Palisade Corporation, Ithaca, NY, version 7.5). Finally, these distributions were used in the model so that the financial results after 10 seasons of simulation were in $NZ with a base year of 2015.

Table 7.3: Definitions of scenarios used in simulation model of a seasonal-calving dairy farm

Term	Definition
Baseline	Herd of 419 cows at the start of each season, 22% of the herd size were 10 mo heifers, and 21% were 22 mo pregnant heifers. The mean seasonal incidence risks of culling, sale and mortality of cows were 15.3%, 3.9% and 2.0%, respectively
Fixed herd (FH)	Herd size fixed to the same as Baseline with additional feed purchased as required
FH-Early-50	As for Baseline plus an hypothetical intervention to control acute peripartum disease that resulted in 50% reduction of ID of culling and mortality in early lactation (< 84 d, or 6 parity time steps)
FH-Late-25	As for Baseline plus an hypothetical intervention to control chronic disease or reproductive failure that resulted in 25% reduction of ID of culling and sale in mid to late lactation
FH-Early+Late	As for Baseline plus an intervention to control both acute peripartum and chronic disease, and reproductive failure
Fixed feed (FF)	Feed requirement fixed to the same as Baseline with herd size adjusted to meet the feed available
FF-Early-50	As for FH-Early-50 except feed constraint
FF-Late-25	As for FH-Late-25 except feed constraint
FF-Early+Late	As for FH-Early+Late except feed constraint

7.3.7 Model Scenarios

The same rate of reduction was used across all age groups, and the scenarios were constant throughout ten seasons of simulation.

7.3.8 Software

The model was implemented in a Microsoft Excel (Redmond, WA, version 2010) spreadsheet, with the add-in 'AtRISK'. The means and 95% probability intervals of 1,000 iterations of the model were reported. We investigated the effect of increasing the number of iterations, and found that the $\mathrm{DOP_p}$ changed negligibly (-0.1%) as the number of iterations increased from 1,000 to 10,000. We analysed the model results using 'R' (R Core Team, Vienna, Austria; version 3.3.2) in "R Studio" [RStudio Team, 2016]; managed data with "readxl" [Wickham, 2016], "survival" [Therneau, 2015a], "Epi" [Carstensen et al., 2016] and "dplyr" [Wickham and Francois, 2016]; estimated the Poisson parameters with "epiR" [Stevenson, 2016]; and prepared plots and the document with packages "ggplot2" [Wickham, 2009], "knitr" [Xie, 2016].

7.3.9 Model Validation

We validated our model by verifying that its outcomes were plausible and the directions of changes were logical. We further validated the model by reporting the mean and interquartile range of our results against other similar published data.

7.3.10 Sensitivity Analysis

We used two sensitivity analysis functions in 'AtRISK' to determine the effect of changes in the stochastic input values under two scenarios: FH-Early+Late and FF-Early+Late. The functions varied these values over their previously-described distributions, and also varied the ID of culling, sale and mortality within the range of zero to 100% of the changes simulated in each of their scenarios. The function output provided simualted estimates of the mean change in $\mathrm{DOP_p}$ when each of the input variables varied over their distribution. We inspected 'tornado' plots in 2 scenarios (FH-Early+Late and FF-Early+Late) for the effects of a 1 SD increase in the value of each of the stochastic variables on mean $\mathrm{DOP_p}$, and also an increase or decrease in the stochastic variables about the mean on $\mathrm{DOP_p}$ (not shown).

7.4 RESULTS

7.4.1 Herd Demographics

The simulated herd sizes at the start of season ten were reduced by up to 6 cows in the FF scenarios that reduced cow numbers in order to match total feed requirements compared with with the FH scenarios in which herd sizes were fixed (Table 7.4). The peak number of milking cows were greater under FH scenarios, but reduced under scenarios FF scenarios, compared to the Baseline. The number of calves reared, and heifers sold, were greater under all scenarios compared to the Baseline. Herds with scenarios where the ID of culling and sale in mid- to late-lactation, but not mortality in early-lactation only, were reduced (scenarios FH-Late, FH-Early+Late, FF-Late, FF-Early+Late), had increased mean cow age at the start of season ten.

Table 7.4: Mean values and 95 percent probability intervals at the start of the tenth season of simulation that describe a model of a seasonal-calving dairy herd under different scenarios[1] that reduced the incidence of culling and mortality

Scenario	Herd size at season start	Cow age at season start (yr)	Replacement rate (%)	Calves reared	Heifers grazed	Heifers sold	Culling IR (%)	Sale IR (%)	Mortality IR (%)
Baseline	417	4.5	20.7	95	92	2.3	15.3	4.0	2.0
	(411, 422)	(4.3, 4.7)	(17.0, 25.0)	(86, 104)	(85, 100)	(-16, 20)	(12.0, 19.0)	(2.2, 6.0)	(0.72, 3.4)
FH-Early	417	4.5	20.5	96	93	3.5	15.5	4.0	1.6
	(411, 422)	(4.3, 4.7)	(16.5, 24.6)	(86, 104)	(85, 100)	(-15, 21)	(12.0, 19.2)	(2.2, 6.0)	(0.48, 2.9)
FH-Late	418	4.7	18.5	98	94	12.9	14.0	3.0	2.1
	(412, 423)	(4.5, 4.9)	(15.0, 22.4)	(89, 107)	(87, 102)	(-5, 29)	(10.8, 17.5)	(1.5, 4.8)	(0.95, 3.6)
FH-Early+Late	418	4.7	18.3	99	94	14.1	14.3	3.0	1.6
	(412, 423)	(4.5, 4.9)	(14.7, 22.3)	(89, 107)	(87, 102)	(-4, 30)	(11.0, 17.7)	(1.4, 4.8)	(0.48, 2.9)
FF-Early	415	4.5	20.5	95	92	3.5	15.6	4.0	1.6
	(409, 421)	(4.3, 4.7)	(16.5, 24.6)	(86, 104)	(84, 99)	(-15, 21)	(12.0, 19.1)	(2.2, 6.0)	(0.48, 2.9)
FF-Late	410	4.7	18.5	97	93	12.8	14.0	3.0	2.1
	(405, 416)	(4.5, 4.9)	(15.2, 22.5)	(87, 105)	(85, 101)	(-5, 30)	(10.7, 17.4)	(1.5, 4.7)	(0.74, 3.6)
FF-Early+Late	409	4.7	18.2	97	93	13.7	14.3	3.0	1.6
	(404, 414)	(4.5, 4.9)	(14.8, 22.1)	(87, 105)	(85, 101)	(-5, 30)	(11.1, 17.8)	(1.5, 4.7)	(0.49, 2.9)

[1] See Table 7.3

The change in mean cow age reflected differing proportions of each age group in the herd under each scenario (Figure 7.1). The count of cows in the 2 yr and 3-4 yr age groups decreased, and the count of cows in the 5-7 yr and 8+ yr age groups increased under all scenarios, compared to the Baseline. This change in proportions among the age groups was greatest when culling in mid- to late lactation were reduced (scenarios FH-Late, FH-Early+Late, FF-Late, FF-Early+Late).

7.4.2 Technical Performance

The mean number of days in milk (**DIM**), mean milksolids (**MS**) production per cow and total herd MS production increased under all scenarios compared to the baseline (Table 7.5). The greatest increase in total MS production was for FH-Early+Late compared with the Baseline. Conversely, the gain in BV for milk yield at the start of season 10 was slightly reduced (5% from the base of 165) in the scenarios with reduced ID of culling and sale. When herd size at the start of the season was constant (FH scenarios), additional supplementary feed was required to meet the demand from increased cows in milk and increased production per cow.

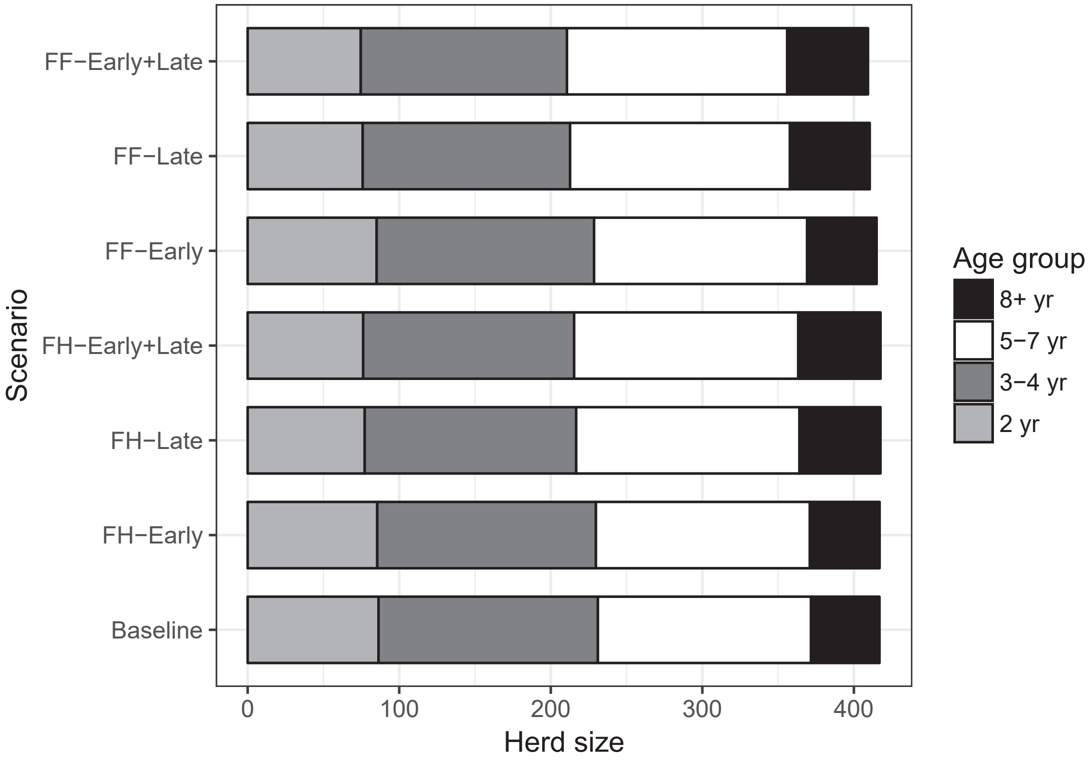

Figure 7.1: Proportion of herd in each age group at the start of season 10 of a simulated New Zealand dairy herd under different scenarios that reduced the incidence of culling and mortality (see Table 7.3 for scenario definitions)

Table 7.5: Mean technical performance with 95 percent probability intervals of a model of a seasonal-calving dairy herd in the tenth season of simulation under different scenarios[1] that reduced the incidence of culling and mortality

Scenario	Peak milking herd number	Days in milk	MS[2] per cow (kg)	Total MS (x 1,000 kg)	BV[3] milk yield (l) at season start	Supplementary feed (T DM)
Baseline	401	257	376	150.7	257	-0
	(391, 410)	(254, 260)	(370, 382)	(146.5, 154.9)	(253, 261)	(-45, 47)
FH-Early	402	257	377	151.5	257	7
	(393, 411)	(254, 260)	(371, 383)	(147.1, 155.7)	(253, 261)	(-40, 55)
FH-Late	403	258	380	153.4	254	30
	(394, 412)	(255, 260)	(375, 386)	(149.1, 157.5)	(249, 257)	(-17, 79)
FH-Early+Late	405	258	381	154.2	253	39
	(396, 413)	(255, 260)	(375, 386)	(150.1, 157.9)	(249, 257)	(-7, 82)
FF-Early	400	257	377	150.8	257	-1
	(391, 409)	(254, 260)	(371, 382)	(146.3, 154.9)	(253, 261)	(-49, 46)
FF-Late	396	258	380	150.8	253	-2
	(387, 406)	(255, 260)	(375, 386)	(146.5, 154.9)	(249, 257)	(-50, 42)
FF-Early+Late	397	258	381	151.2	253	1
	(388, 405)	(255, 260)	(375, 386)	(146.9, 154.9)	(249, 257)	(-45, 42)

[1] See Table 7.3

[2] Milk fat + milk protein

[3] Breeding value

7.4.3 Financial Performance

Revenues from milk production and heifer sales increased in all alternative scenarios, but decreased from culled and sold cows (Table 7.6). Costs for heifer grazing were approximately constant under each scenario, but the cost of supplementary feed increased under FH scenarios. Overall, $\mathrm{DOP_p}$ was greatest under FH-Early+Late compared to the Baseline, whilst scenarios that reduced herd size at the start of each season (FF scenarios) had reduced $\mathrm{DOP_p}$ compared to their counterparts where starting herd size was maintained (FH scenarios).

Table 7.6: Mean values (NZD x 1,000 with 95 percent probability intervals) of main contributors to farm revenue (positive values) and expenditure (negative values), median partial dairy operating profit (DOP), and change of DOP, compared with the baseline (scenario 1), in the tenth season of a simulated seasonal-calving dairy herd under different scenarios[1] that reduced the incidence of culling and mortality

Scenario	Milk production	Cow culls	Cow sales	Heifer sales	Heifer grazing	Supplementary feed	Median DOP	Change DOP (percent)
Baseline	1,033.1	35.6	32.2	3.8	-44.5	0.0	943.7	
	(681.27, 1,593.1)	(26.4, 48.5)	(16.7, 53.9)	(-27.2, 32.6)	(-36.8, -64.5)	(0.0, 0.0)	(619.4, 1,545.2)	
FH-Early	1,038.2	36.1	32.3	5.8	-44.6	-2.3	950.2	0.5
	(686.79, 1,605.0)	(27.2, 49.4)	(16.7, 53.9)	(-24.5, 34.7)	(-36.8, -64.5)	(12.3, -17.1)	(624.6, 1,559.5)	(-0.9, 2.4)
FH-Late	1,051.6	32.6	24.7	21.2	-45.4	-9.5	959.6	1.5
	(693.53, 1,624.6)	(24.1, 44.5)	(11.5, 43.1)	(-8.1, 51.2)	(-37.7, -65.3)	(5.3, -24.5)	(627.4, 1,573.8)	(-0.6, 4.1)
FH-Early+Late	1,056.9	33.1	24.7	23.1	-45.5	-12.0	965.0	2.0
	(698.02, 1,638.2)	(24.3, 45.0)	(11.5, 42.8)	(-6.1, 51.6)	(-37.6, -66.0)	(2.2, -24.9)	(625.5, 1,573.6)	(-0.2, 4.7)
FF-Early	1,033.3	35.9	32.1	5.8	-44.4	0.0	947.1	0.3
	(683.90, 1,598.9)	(27.2, 49.3)	(16.6, 53.8)	(-24.9, 34.6)	(-36.8, -63.8)	(0.0, 0.0)	(624.2, 1,549.3)	(-1.3, 2.2)
FF-Late	1,033.9	32.1	24.2	21.1	-44.7	0.0	951.5	0.7
	(681.81, 1,602.2)	(23.5, 43.8)	(11.2, 42.6)	(-8.9, 51.9)	(-37.1, -65.1)	(0.0, 0.0)	(628.9, 1,566.0)	(-1.6, 3.3)
FF-Early+Late	1,036.1	32.5	24.2	22.6	-44.6	-0.2	955.4	1.1
	(683.94, 1,609.4)	(24.0, 44.4)	(11.2, 42.6)	(-7.1, 52.2)	(-37.0, -64.5)	(14.1, -13.0)	(625.4, 1,563.3)	(-1.0, 3.7)

[1] See Table 7.3

Table 7.7: Comparison of mean results and their 95 percent probability intervals (PI) from a model of a typical New Zealand dairy herd[1] in the tenth season of simulation with mean values from external validation data[2]

Statistic	Replacement rate (%)[4]	Milk production[3] 2 yr	3-4 yr	5-7 yr	8+ yr	Mixed-age	Lactation (d)[5]	Feed[6]
Model mean	20.7	304	382	413	384	376	257	4.7
Model 95% PI	(17.0, 25.0)	(298, 308)	(376, 388)	(404, 420)	(363, 401)	(370, 382)	(254, 260)	(4.6, 4.8)
Validation data	22.6	288	359	387	358	369	276	4.8

[1] Baseline herd see Table 7.3
[2] From DairyNZ (2012) and DairyNZ and LIC (2016)
[3] MS = kg milksolids (milk fat + milk protein)
[4] Percentage of 2 yr old cows in population
[5] Length of lactation
[6] Dry matter requirement calculated after allowance of 6% for wastage subtracted

7.4.4 External Validation

The Baseline model mean replacement rate and DIM were lesser than, and milk production for each age group, greater than, other industry data for this breed (Table 7.7), but these differences were less than 10% of the means of the external validation data. The model feed requirements were approximately the same as those in other published data.

7.4.5 Sensitivity Analysis

A change in MS price had the greatest impact on $\mathrm{DOP_p}$ in both scenarios analyzed: an increase by 1 SD ($NZ 1.62) in the MS price increased the $\mathrm{DOP_p}$ by $NZ 252,489 and $NZ 246,740 in scenarios FH-Early+Late and FF-Early+Late, respectively (Figure 7.2). Other variables in the models had much lesser impact, although among these, increases in the ID of culling in mid- to late-lactation caused a relatively large reduction in $\mathrm{DOP_p}$ ($NZ -3,766 and $NZ -5,147 in FH-Early+Late and FF-Early+Late, respectively). After the milksolids price, the most influential external farm factors were the prices received for sold cows followed by the costs paid to graze replacement heifers. Both models were insensitive to variations in the IDs of culling and mortality in early-lactation, and of sale in late-lactation. Inspection of the plots of the effects of an increase or decrease in the stochastic variables

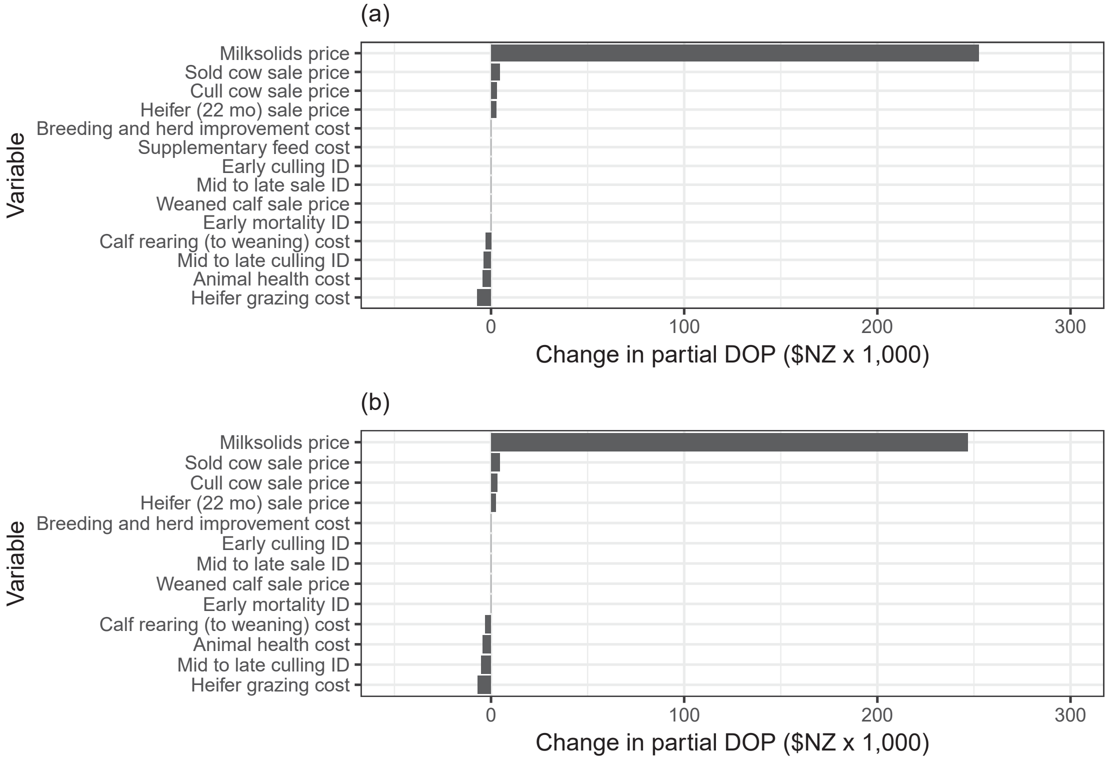

Figure 7.2: Estimated change in partial dairy operating profit (DOP) of a simulation model of a New Zealand dairy herd after 10 seasons under 2 scenarios (a) FH-Early+Late and (b), FF-Early+Late, that were associated with a 1 SD increase of stochastic input variables (see Table 7.3 for scenario definitions)

about their mean on DOP_p (not shown) found them approximately symmetrical. There were no meaningful differences between these two scenarios in their sensitivity to each stochastic variable .

7.5 DISCUSSION

7.5.1 DOP Under Different Scenarios

The model scenario that provided the greatest increase in DOP_p reduced the ID of culling and mortality from the middle to lower herd quartiles of performance from the reference cow population, and purchased supplementary feed to meet requirements. This finding is supported by that of Lopez-Villalobos and Holmes [2010], who reported increased farm profit with a combination of reduced culling rates, selection of high genetic worth replacements, and artificial breeding of dairy heifers. Recommended best management practice for NZ dairy farms is to maintain an appropriate stocking rate to maximize the efficiency with which pasture is harvested, especially in early lactation, and where it is financially beneficial to do so, to purchase supplementary feed to extend lactation [Holmes et al., 2002].

Whilst increasing feed purchased and milk production by reducing the incidence of culling and mortality might be a favorable management strategy in pasture-grazing, seasonsal-calving dairy systems, with few regulatory constraints on purchase of feed, this may not be the case in other systems. For example, where either available feed or production of dairy waste and nutrients are limited by environmental regulations or economic constraints, or milk is produced under a quota management system, farmers must aim to improve profitability within these restrictions. However, even under these constrained conditions, reduced mortality and non-production related culling of cows would still offer potential financial benefits. Furthermore, dairy farm systems that minimize greenhouse gas emissions through longer herd life and reduced proportion of non-productive, yet greenhouse gas-emitting time of replacements, are likely to become increasingly attractive in the future [Grandl et al., 2016].

7.5.2 Technical Performance

The relative changes under different scenarios of key herd performance indicators, namely mean DIM and MS production per cow were subtle, but when added together, approximated the relative change in total MS production. However, the relative change in $\mathrm{DOP_p}$ was modified slightly by concurrent changes in other revenues and expenditures. Hence, although the simple metrics of mean DIM and MS production per cow are useful to predict total herd milk production, other relevant revenues and expenditures must be considered to calculate total financial consequences of any interventions for the herd.

The genetic gain for milk production was slightly less after 10 seasons under scenarios that reduced the incidence of culling in mid- to late-lactation. This effect would be expected where replacement rate is consequently also reduced and fewer high genetic merit heifers enter the herd. This difference would likely be greater if the model had a longer time horizon, and may have reduced the financial benefits calculated in our model, but this was not tested.

7.5.3 Sensitivity Analysis

Changes in milk price had the largest impact on $\mathrm{DOP_p}$. This is because not only is milk the predominant source of income for dairy farmers, but the price received by New Zealand farmers has been highly variable in the past decade because of its close linkage to international milk prices. Under quota-based or government-supported milk pricing systems, this variability and likelihood of change of economic returns to milk price would likely be much reduced. Regardless of the pricing system, volatility in milk prices means that the effect of long-term decisions on farm management will be uncertain. The model was also sensitive to changes in the ID of culling in mid- to late lactation: an increase by 1 SD of this variable reduced $\mathrm{DOP_p}$ by $NZ 3,766. This is important because it indicates the potential to improve farm financial performance across a range that farms are currently achieving, and focuses attention on efforts to reduce culling in mid- to late lactation as a key outcome in any intervention program to improve farm profitability. Interestingly, $\mathrm{DOP_p}$ was not sensitive to changes in feed costs within the range reported in the reference source. This finding might be explained by the fact that where supplementary feed was purchased for FH scenarios, only a small amount was required per cow. However, if feed price was increased by a further 50%, $\mathrm{DOP_p}$ was decreased by a relatively small amount (not shown), indicating that the model was sensitive to extreme changes in feed costs.

7.5.4 External Validation

The technical performance of our model farm was generally similar to other published data, and where they occurred, differences may be explained by differing populations and methods of calculation. The reference population were not a random sample of the national herd, but rather represented herds with greater feed inputs than average herds, and therefore greater production per cow; and likely greater herd management skills than the average herd, also. This would in part explain the differences in model estimates of milk production and replacement rate. Additionally, the validation values were estimated after 10 seasons, over which time, genetic gain would have accounted for some of the difference in milk production. The estimates of DIM from published data vary between seasons, mainly due to climatic factors, and should be considered indicative only. The feed requirement estimates are in close agreement. Therefore, overall, the model made reasonable estimates of the technical performance of pasture-grazed, seasonal-calving, Crossbred herds in New Zealand.

7.5.5 Study Limitations

We simulated our model over a 10 season period so that calves born in season 1 would have the opportunity to express their maximum productive life and enable the herd structure to reach a stable equilibrium. If we had continued the simulation for more seasons, we may have recorded a greater difference in the mean herd genetic gain under the different strategies because of varying numbers of replacements, themselves daughters of replacements, and that the advantage of reduced replacement rate would have been reduced. However, a 10 yr period is still a reasonably long planning horizon for dairy farmers. One further limitation of our model was that removal from the herd because of culling or mortality was independent of a cow's milk production, which may not always be the case where there is opportunity for a farmer to cull a cow for multiple causes, including low production; or when greater production predisposes a cow to a disorder, that itself increases the risk of removal. This was necessarily the case with a group-based model, but may not be such a serious flaw when a farmer has little ability to cull for low production, as is commonly the case in New Zealand herds, where reported cause for culling of poor production is approximately 10% of all culls [Compton et al., 2016]. Where culling because of low production is possible, our model would underestimate the cost of avoidable removal, because the potential productive benefits of retained greater-producing cows [Seegers et al., 1998] were not considered. The national dairy breeding objectives in New Zealand includes breeding values for fertility and residual survival with positive economic values and genetic gains for these traits [Anonymous, 2017c], and although these were not included in this model, it can be modified in the future to include them.

Although not a limitation because of the aims of this study, it should be remembered that farmers have varying attitudes, constraints and goals concerning animal health management programs. Financial considerations may not be their only, or their most important consideration [Jansen et al., 2009]. Hence, financial analysis of the benefits of disease control should only be part or a range tools used by animal health advisers when they discuss this subject with farmers.

7.5.6 Conclusion

The findings of this novel study provide estimates of the cost of avoidable culling and mortality, at the herd-level, in the pasture-grazing, seasonal-calving system, typical in New Zealand. This equates to 2.0% of $NZ 943,700, equalling $NZ 18,874 or $NZ 47 per cow. This information or the model itself may be used together with the direct and other indirect costs of diseases and reproductive failure for further economic analysis of investment in surveillance, diagnostic, and control programs, and genetic selection of fertility and survival.

7.6 ACKNOWLEDGEMENTS

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Chapter 8

General Discussion

8.1 AIMS OF THESIS

The three main aims of the Thesis were, in brief, to:

1. Define the incidence and reported causes of culling and mortality of dairy cows, both internationally and in New Zealand, and evaluate the various data and methods to calculate those measures
2. Investigate both cow- and herd-level factors associated with culling and mortality of New Zealand dairy cows
3. Estimate the financial consequences for an average New Zealand dairy farmer if they made an achievable reduction in the incidence of culling and mortality.

8.2 KEY FINDINGS

8.2.1 Culling and Mortality in New Zealand and Overseas

Comparisons between the incidence of culling in New Zealand herds and of other countries are inevitable. However, as we explained in Chapters Three, Five and Six, culling is based largely on financial factors which can vary widely between countries. For this reason, comparisons should be made cautiously. Nevertheless, our research presented in Chapters Two, Three and Four of this Thesis indicates that the incidence of culling of New Zealand dairy cows in pasture-grazed, seasonal-calving systems (a long-term average of approximately 20%) is generally less, and sometimes, much less, than cows in countries with other management systems. The financial implications of the current culling and replacement policies of New Zealand dairy farmers are less clear, although we have contributed new information to that discussion with our findings in Chapter Seven. For this reason, we have not suggested a performance benchmark for culling of cows, and would even question if such a goal would be sensible for all dairy farms. We believe it would be preferable for farmers to use decision-support tools that account for their own circumstances and goals, and benchmark their performance against their own 'optimal' measure.

It is more straightforward to make comparisons of the incidence of mortality between different countries because this type of removal involves less farmer choice and is never a favored outcome. Whilst we estimated (in Chapters Three and Four) that the approximately 2% overall incidence of mortality in New Zealand dairy cows was less than in other countries, there are still areas of concern. First, there was a considerable range (five-fold or more) between mortality incidence among herds, which means that while some herds are doing well, others have opportunities for improvement. Furthermore, the consequences of a high incidence of mortality are not carried only by the farmer; it is a cow-welfare issue, and the wider industry carries the risk to their reputation along with potentially adverse reactions from consumers to publicity of this problem [von Keyserlingk et al., 2013, Wolf et al., 2016].

In Chapter Four we did not detect any long-term trends in the incidence of culling in New Zealand in the past two decades, in common with the results from our meta-analysis using data across various countries (as reported in Chapter Two). In addition, the inverse relationship between the incidence of culling and price farmers received for milk supports the assertion of Fetrow et al. [2006] that total incidence of culling results primarily from an economic decision by farmers. In New Zealand, when the milk price is relatively high, culling incidence declines as farmers are more likely to keep cows in the herd to increase their total milk revenue, and they are more willing to purchase supplementary feeds to keep cows milking through summer dry conditions to achieve longer lactations. However, although the incidence of culling has mainly economic consequences for the dairy farm, if increased incidence of clinical disease is an important causal factor for culling, then animal welfare concerns also arise.

The international temporal trend of increasing mortality reported in Chapter Two is an issue not only to farmers, but also to the public, consumers and markets concerned about the welfare conditions of dairy cows [Thomsen et al., 2004, McConnel et al., 2015]. However, we did not detect a trend of increasing overall incidence of mortality using New Zealand data from 1990 up to 2012 (Chapter Four). This was somewhat surprising, as the international trend was detected across a range of countries with modern dairy industries, including Ireland, which has a similar seasonal-calving system to New Zealand's, except, due to the Irish climate, cows are housed indoors over winter and go out to graze pasture in early lactation. We speculated that the non-housed, year-round pasture-grazing systems used almost universally in New Zealand, and the increasing proportion of crossbred cows in its dairy herd, have been protective. However, we did find evidence that the incidence of mortality in the largest 20% of dairy herds in New Zealand had increased by approximately 10% compared with average-sized herds over the last two decades. This result needs to be confirmed by further studies, but signals that the incidence of mortality of cows in New Zealand, or at least in some herds, may be following the increasing trend we reported in other countries (Chapter Two).This is concerning because these herds represent a disproportionately high number of cows in the national population, and if this trend has continued beyond our study period, it might result in an overall increase in the incidence of mortality in the national herd. If this occurs, it will likely threaten the goals of the New Zealand dairy industry for sustainability and high welfare standards.

The consistent figures for the incidence of culling and mortality of New Zealand cows between Chapters Three and Four indicates that the herds enrolled in the NHFS were representative of the national population, and supports the validity of the results. Furthermore, farmers need confidence that the annual mortality benchmark for mixed-age cows (1.2%) for comparing against their own herds' performance are robust and stable. Our findings in Chapter Four of few indications of geographic patterns of culling or mortality also indicate that region-specific benchmarks are not required, which greatly eases communication of a benchmark to farmers.

8.2.2 Measuring Culling and Mortality

We reported in Chapter Three that there were only small differences in the estimated incidence of culling and mortality between four different calculation methods. This finding is important because it means that some flexibility is possible for farmers to choose appropriate and achievable methods for their individual circumstances. Computational difficulties should be less of a concern for providers of animal management software, but it is important that the method chosen is epidemiologically sound and appropriate for the farming system used. Furthermore, the methods we used to calculate incidence were all standard and comparable to those currently used in other countries. This means that that our results from the different methods used to calculate incidence in this Thesis are not only comparable with one another, but also with most international reports. Furthermore, if adopted in New Zealand in the future, those estimates could be compared with the incidences estimated in either Chapters Three or Four.

While the estimates of incidence of culling and mortality in seasonal-calving herds were robust between different calculation methods, the quality of electronic data used in those analyses might bias results. In Chapter Six, we showed that individual herd estimates of the incidence of culling and mortality could be biased downwards, and that missing or incorrect electronic records of culling and mortality, and their reported causes, could cause several different biases. When considering many herds or a national population, we estimated that the downward bias in estimated incidence would likely be small, but could be considerable for individual herds. The potential impact of these biases on the results in the other chapters needs to be considered. As we have stated, the population incidences of culling and mortality that we estimated are not likely to be severely biased, and therefore our suggested benchmarks do not need to be reconsidered. We only described the reported causes of culling and mortality and calculated cause-specific incidences of culling and mortality, but we cautioned their use because of biases found by previous researchers and oversimplification by using cause-specific measures of culling. In our analysis of risk factors for culling and mortality (Chapter Five), we combined the categories ‘culled’ and ‘sold’, and therefore the frequent misclassification we found of the latter for the former, would have had no effect. However, it is probable that other missing records and misclassified types of removal would have biased the results of the risk factor analysis, but we could not say to what extent or in what direction. Our findings support a goal of the dairy industry to improve on-farm recording [Anonymous, 2013a, p 40] as a means to "provide the evidence to promote and defend New Zealand dairy farming practices"

8.2.3 Peripartum Period

We reported in Chapter Five that cows with a record of common peripartum disorders had increased rates of culling and mortality. This finding is consistent with many other studies of the importance of the transition period of the dairy cow for the establishment of a productive and long-lasting lactation [LeBlanc et al., 2006]. Many of these disorders likely have causal associations either directly with mortality, or indirectly through impaired reproductive performance or udder health, on culling. Therefore, animal health programs that control these disorders are likely to also reduce mortality and culling for non-production reasons. As further evidence of the importance of peripartum disorders on mortality, the increased incidence rates of mortality within 30 d of calving described in Chapter Three are consistent with the findings of increased rates of mortality associated with the peripartum disorders of dystocia, metabolic disease, and treatment for calving trouble reported in Chapter Five.

But our results also indicate that there is often a delay between the first case of the common disorders, such as clinical mastitis and increased somatic cell count, and the timing of culling. We reported in Chapter Five that the first cases of these common disorders occurred within approximately the first month of lactation, and yet in Chapter Three and Chapter Six, we indicated that most culling occurs in mid- to late-lactation. This delay may have occurred because some farmers may be contracted to keep a minimum number of cows, or because the affected cows recovered or their disorders were subclinical, and it was still profitable for farmers to keep them milking, at least in the short-term. However, when a combination of two factors arose in mid-lactation: the results of pregnancy-testing on which farmers could base culling decisions, and reduced pasture growth rates because of dry mid-summer conditions, farmers began to cull cows at increasing rates to form their herd for the next season and manage feed supply as they approached the end of lactation. Cows were prioritized for culling if they were not pregnant, and then for a range of other causes, as we indicated in Chapter Three. The timing with which cows are culled is therefore based on a complex of animal, farm management and environmental factors, but ultimately, is based on economic reasoning and has financial consequences for the farmer.

Our findings support a focus on prevention of disorders of the peripartum period as a means to reduce non-production culling and peripartum mortality. The factors associated with these disorders have common causes, although maybe to differing extents, on most farms. This makes them amenable to a national control program.

This Thesis provided less information on factors associated with mortality outside the peripartum period. McConnel et al. [2010] suggested that to control mortality, a deeper understanding of the chain of causal factors and farm characteristics are needed than can be provided solely by autopsy-defined causes, which would mean that herd-specific programs are required. This challenge remains for dairy farmers in New Zealand, in common with other countries.

8.2.4 Increased profits

Farmers may be more motivated to change management to improve animal health when they understand the opportunity to improve farm profit, although that may not always be their only consideration [Kristensen and Jakobsen, 2011]. We used a simulated farm system in Chapter Seven to evaluate how farm profitability was affected by reduced incidence of culling and mortality. We defined achievable improvements for reduced culling and mortality, from the distribution of herd-level performance for culling and mortality of New Zealand cows we reported in Chapter Three. With that information we estimated that over the long term increased profit could be expected from such improvements, depending upon the cost of the interventions used to reduce culling and mortality.

8.3 POTENTIAL IMMEDIATE APPLICATIONS

Some findings in this Thesis could be immediately extended to and applied by dairy farmers.

First, a clear application now exists to extend information to dairy farmers on, for example, how to measure the incidence of mortality in their herd, and what the herd performance benchmark for mortality of cows is. This would enable farmers to understand what achievable performance is, guide them to set their own goals, and prevent ‘poor’ performance from becoming ‘normal’ for them.

A second immediate application concerns record-keeping by farmers. Our findings suggest that the usefulness of data on animal removals is limited on some farms because of missing or incorrect information. We believe that more value could be obtained from them for decision-making with little additional effort. However, farmers firstly need to be convinced that the additional effort required will provide them with a reward, namely, information useful to make management decisions, and secondly, that it will be of value to the wider industry. We believe that communication needs to be enhanced between farmers and data managers within the dairy industry on the value and use of improved information about the health and removal of New Zealand dairy cows.

Finally, some of the new information presented in this Thesis can be used to update the currently-available animal health management programs for dairy cows. For example, the results from Chapter Five could be included in the background information in the ‘SmartSAMM’ program to update knowledge on the associations between mastitis and culling. These steps would provide visible, short-term returns to New Zealand dairy farmers.

8.4 FUTURE OPPORTUNITIES

8.4.1 Herd-Level Risk Factors

A need remains to investigate modifiable herd-level factors associated with the incidence of culling and mortality of New Zealand dairy cows. In Chapter Four, we reported only factors that could be calculated from existing data, for example change in herd size, that were associated with the incidence of culling and mortality. While these findings are important in understanding between-herd variation and directing further research, they do not in themselves provide a management solution that can be implemented. New studies are required to gather data on modifiable herd-level factors that are associated with peripartum disorders, and culling and mortality, to form control programs for dairy farming systems in New Zealand.

8.4.2 Mortality Beyond the Peripartum Period

We previously noted the lack of information about mortality of cows outside the peripartum period. A pilot study that used a novel method to autopsy cows that died on-farm indicated a wide range of diagnoses [Bryan et al., 2015], but further data is required from a more representative sample of cows. To explore possible causal factors for deaths occurring during lactation, the option should be considered of prospective, long-term monitoring of herds and their cows presented for casualty-slaughter or collected by processors for rendering.

8.4.3 Financial Modeling

The economic model reported in Chapter Seven could be further developed to provide a decision-support tool for farmers. Such a tool could enable farmers and their advisers to enter herd-specific information to provide financial information that would support their planning. Furthermore, this software tool could be enhanced with modules that provide cost-benefit analyses for the profitability of introducing specific disease-control measures or diagnostic tests for specific disorders. This capability will become increasingly important in the future to evaluate new technologies developed in a ‘precision-farming’ approach that target improved animal health based on data provided by novel animal monitoring systems.

8.4.4 Update New Zealand Dairy Herd analysis

The most recent season that data were analysed from in Chapter Four were from 2012. These data are already five years old and may not represent more recent changes in performance. A new analysis on an updated New Zealand Dairy Herd data set could be efficiently conducted and provide important information on any changes over recent seasons.

8.4.5 Enhancing Value of Records

More value could be made of data that is already collected by farmers. To enable this, farmers and their advisers require consistent definitions of a restricted list of options that are available to them, computer software systems that facilitate complete and accurate entry of records, and that also provide reports that are useful for decision-making. These two activities could be self-reinforcing. However, it would still be important to evaluate the likely economic consequences of any option for intervention to determine if it would be profitable. This change could be implemented by farmers communicating to their software providers about their need to improve the value they currently receive from the data they record.

8.4.6 Recording Euthanized Cows

Farmers in New Zealand are currently unable to distinguish euthanized cows from those that die unassisted in their electronic records, but this is common in other countries. Whether a cows dies unassisted or is euthanized has important welfare consequences, and as such, it is important that such a distinction is made in the electronic records. This would require changing the options a farmer can select for the fate of animals that are removed to expand 'died' to either 'died unassisted' or 'euthanized'. It is important that composite variables that combine both cause and fate, for example, 'sick-humanely destroyed', are not used, as this makes the reporting of these data unclear.

8.4.7 Improving Data Capture

We reported in Chapter Six that a high proportion of farmers used only electronic methods to record cows that were culled or died on-farm. This proportion is likely to increase with the trend of increased herd size and consequent need to improve the efficiency of farm data management. Efficient and accurate recording practices are especially important in large- or multi-herd enterprises where sharing of information may improve decision-making and health management practice. However, there is no published information on how farmers record events in these electronic-only systems or of the quality of the records they make. Hence, a study of the methods and technology farmers use to only record culling and mortality in electronic databases would provide valuable information on the suitability of these data for analysis, and ways in which data recording practices can be improved.

8.4.8 CONCLUSION

We have set out in this Thesis our results on the most important themes that needed investigation in our epidemiological study of culling and mortality of dairy cows in New Zealand. These results build on previous national and international science on this subject, update and expand that knowledge, and point towards future needs for research and extension.

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Appendix

Table A.1: Critical appraisal tool to asses eligibility of articles for review

Domain	Element
1) Study question	a) Clearly focused and appropriate
2) Methods for selecting study population	a) Appropriate source population and sampling method to control bias
	b) Specific inclusion and exclusion criteria
	c) Criterial applied equally to all participants
	d) Study participants comparable to non-participants (source population) with regard to confounding factors
	e) Comparability of follow-up among participants
3) Stratification variables	a) Exposure(s) clearly defined where assessed
	b) Method of exposure measurement standard, valid and reliable
4) Outcome measurement	a) Primary/secondary outcome(s) clearly defined
	b) Method of outcome measurement standard, valid and reliable
5) Statistical analysis	a) Statistical analysis of primary outcome(s) appropriate
	b) Assessment and control of confounding
6) Results	a) Description of study population
	b) Measure (of effect) for outcomes and measure of precision appropriate
7) Conflict of interest	a) Declarations of conflict of interest or identification of funding sources assessed as not contributing to bias

Table A.2: Assessment of risk of bias[1] in four elements of design and conduct of 54 studies selected for review

Author(s) and year	Study population[2]	Outcome definition[3]	Outcome measurement[4]	Statistics appropriate[5]
Agger & Willeberg 1991	L	L	L	U
Ahlman et al 2011	L	L	L	L
Alvasen et al 2012	L	L	L	L
Alvasen et al 2014	L	L	L	L
Beaudeau et al 1994	H	L	L	L
Bendixen & Astrand 1989	L	L	L	L
Burow et al 2011	L	L	L	L
Lopez de Maturana et al 2007	L	L	L	L
de Vries et al 2010	L	L	L	L
Dechow and Goodling 2008	L	L	L	L
Durr et al 1997	L	L	L	L
Fuerst-Waltl & Sorensen 2010	L	L	L	L
Gardner et al 1990	L	L	L	L
Gates 2013	L	L	L	L
Gulliksen et al 2009	L	L	L	L
Hadley et al 2006	U	L	L	L
Hultgren et al 2008	U	L	L	L
Hultgren & Svensson 2009	L	L	L	L
Maher et al 2008	L	L	L	L
Mee et al 2008	L	L	L	L
Menzies et al 1995	L	L	L	U
Meyer et al 2001	L	L	L	U
Milian-Suazo et al 1988	U	L	L	U
Mohd Nor et al 2014	L	L	L	L
Olsson et al 1993	U	L	L	L
Perez et al 1990	U	L	L	L
Perrin et al 2011	L	L	L	L
Pinedo et al 2010	L	L	L	L
Pryce et al 2006	L	L	L	U
Raboisson et al 2011	L	L	L	L
Raboisson et al 2013	L	L	L	L
Rajala-Schultz & Grohn 1999	L	U	U	L
Santman-Berends et al 2014	L	L	L	U
Schneider et al 2007	L	L	L	L
Seegers et al 1998	H	L	L	L
Sivula et al 1996	L	L	L	L
Sogstad et al 2007	L	L	L	L
Stevenson & Lean 1998	U	L	L	U
Svensson et al 2006	L	L	L	L
Thomsen et al 2004	L	L	L	L
Thomsen et al 2006	L	L	L	L
USDA 1993	L	L	L	L
USDA 1994	L	U	U	L
USDA 1996	L	L	L	L
USDA 2002	L	L	L	L
USDA 2007	L	L	L	L
USDA 2010	L	L	L	L
USDA 2012	L	L	L	L
Walker et al 2012	L	L	L	L
Whitaker et al 2004	H	L	L	L
Zucali et al 2013	H	L	L	U

[1] L = low, H = high, U = unclear

[2] Selection of source population and sampling methods appropriate to control bias

[3] Outcome measure(s) clearly defined

[4] Method of outcome measurement standard, valid and reliable

[5] Appropriate statistical analysis of outcome(s)

Table A.3: Results of tests for heterogeneity of meta-regression models for measures of culling and mortality among dairy animals

Age group[1]	Study outcome[2]	Cochran's Q statistic	Cochran's Q p-value	Higgins I-squared
Adult cows	Annual mortality IR	87371	<0.001	NA
	Mortality ID	55300	<0.001	NA
	Annual culling IR	732574	<0.001	100.00
	Annual culling & mortality IR	20670	<0.001	99.99
	Annual culling, mortality & sale IR	8823	<0.001	99.94
	Udder-specific annual culling IR	2743	<0.001	99.93
	Reproductive-specific annual culling IR	515	<0.001	98.37
	Production-specific annual culling IR	3194	<0.001	NA
Calves	Perinatal mortality IR	12205	<0.001	NA
	Neonatal mortality IR	385	<0.001	98.13

[1] Adult cows = calved >= 1 times, calves = aged between birth and weaning

[2] IR = incidence risk, ID = incidence density

Table A.4: Percentage[1] of animals removed for each category of farmer-reported cause [2]

Age group	Fate	Cause category	Percent
Mixed-age cows	Culled	ACC	0.4
Mixed-age cows	Culled	BEH	0.3
Mixed-age cows	Culled	LMN	1.6
Mixed-age cows	Culled	LPR	10.0
Mixed-age cows	Culled	MIS	2.3
Mixed-age cows	Culled	OTH	25.6
Mixed-age cows	Culled	RPR	42.0
Mixed-age cows	Culled	UDD	14.1
Mixed-age cows	Culled	UNK	3.6
Mixed-age cows	Died	ACC	13.9
Mixed-age cows	Died	LMN	2.2
Mixed-age cows	Died	MIS	2.3
Mixed-age cows	Died	OTH	31.7
Mixed-age cows	Died	UDD	5.4
Mixed-age cows	Died	UNK	14.2
Mixed-age cows	Died	CLV	10.2
Mixed-age cows	Died	DIG	10.0
Mixed-age cows	Died	MET	10.0
Mixed-age cows	Sold	ACC	0.0
Mixed-age cows	Sold	BEH	0.1
Mixed-age cows	Sold	LMN	0.1
Mixed-age cows	Sold	LPR	1.0
Mixed-age cows	Sold	MIS	16.3
Mixed-age cows	Sold	OTH	20.6
Mixed-age cows	Sold	RPR	33.1
Mixed-age cows	Sold	UDD	0.1
Mixed-age cows	Sold	DAI	28.7
Replacements	Culled	ACC	0.9
Replacements	Culled	BEH	0.0
Replacements	Culled	LMN	0.9
Replacements	Culled	LPR	4.3
Replacements	Culled	MIS	6.3
Replacements	Culled	OTH	23.0
Replacements	Culled	RPR	60.4
Replacements	Culled	UDD	0.3
Replacements	Culled	UNK	3.9
Replacements	Died	ACC	6.1
Replacements	Died	LMN	1.0
Replacements	Died	MIS	2.6
Replacements	Died	OTH	42.5
Replacements	Died	UDD	0.0
Replacements	Died	UNK	32.2
Replacements	Died	CLV	1.8
Replacements	Died	DIG	13.6
Replacements	Died	MET	0.2
Replacements	Sold	ACC	0.0
Replacements	Sold	BEH	0.0
Replacements	Sold	LMN	0.0
Replacements	Sold	LPR	0.0
Replacements	Sold	MIS	26.3
Replacements	Sold	OTH	12.3
Replacements	Sold	RPR	5.9
Replacements	Sold	UDD	0.0
Replacements	Sold	DAI	55.5

[1] Percentage calculated within the fate for each age group

[2] See Appendix Table 5 for definition of abbreviations

Table A.5: Categories of farmer-reported cause of removal available for each animal fate

Fate	Cateory
Culled	BEH = Behaviour, OTH = Other known, LMN = Lameness, LPR = Low production, MIS = Missing, RPR = Reproduction, UDD = Udder-mastitis, UNK = Unknown
Died	ACC = Accident, CLV = Calving-related, DIG = Digestive, LMN = Lameness, MET = Metabolic, MIS = Missing, OTH = Other, UDD = Udder-related, UNK = Unknown
Sold	BEH = Behaviour, DAI = Dairy purposes, LMN = Lameness, LPR = Low production, MIS = Missing, OTH = Other known, RPR = Reproduction, UDD = Udder-related, UNK = Unknown

Table A.6: Categories of farmer-reported code for cause of removal available for each animal fate cause category

Fate	Fate cause category	Fate cause code
Culled	BEH = Behavior	SK = sucker, TE = temperament unsuitable
	LMN = Lameness	FT = feet or leg problems , LM = lame unspecified
	LPR = Low production	LP = Low production
	MIS = Missing	
	OTH = Other known causes	Other available codes
	RPR = Reproductive	AB = abortion, HM = hermaphrodite, LC = late calver, MT = empty (not pregnant)
	UDD = Udder/mastitis	MA = mastitis unspecified, SC = high cell count, SM = slow milker, TT = three-titter, UD = udder disorder unspecified, UT = unsuitable udder teats
	UNK = Unknown cause	OC = other condition (unspecified), OD = other diseases, SR = surplus, EX = export
Died	ACC = Accident	CA = cast, DR = drowned, IA = injured or accident, IN = injury
	CLV = Calving-related	CT = calving trouble
	DIG = Digestive	SO = scours
	LMN = Lameness	FT = feet or leg problems , LM = lame unspecified
	MET = Metabolic	MF = milk fever, MS = magnesium staggers
	MIS = Missing	
	OTH = Other known causes	Other available codes
	UDD = Udder/mastitis	MA = mastitis unspecified, UD = udder disorder unspecified
	UNK = Unknown cause	DU = died cause unknown, OA = old age, OC = other condition unspecified, OD = other diseases,
Sold	BEH = Behavior	As for culled
	DAI = Dairy purposes	SR = surplus, EX = export
	LMN = Lameness	As for culled
	LPR = Low production	As for culled
	MIS = Missing	
	OTH = Other known causes	As for culled
	RPR = Reproductive	As for culled
	UDD = Udder/mastitis	As for culled
	UNK = Unknown cause	As for culled