On-Farm Cow Mortality in Swedish Dairy Herds

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Abstract

A high rate of on-farm cow mortality (i.e. unassisted death and euthanasia) is both a financial concern and an important animal welfare issue. The overall aim of this thesis was to evaluate the development of mortality in Swedish dairy herds and to identify characteristics associated with on-farm mortality at cow and herd levels.

In paper I, two analyses were performed using data from the cattle database with the objective of identifying risk factors at the herd level: one multiple-year study of 6898 herds between 2002 and 2010; and one single-year study of 4252 herds in the year 2010. Paper II is based on information from a designed questionnaire sent in 2012 to herds with either high or low mortality rates to evaluate differences in herd characteristics. In paper III, data were retrieved from the cattle database to assess hazard rates for mortality at the cow level and included cows with a calving between 1 July 2008 and 30 June 2009 (209,236 lactations). In paper IV, a field study on destruction plants was performed to assess the relative proportion of unassisted death and euthanasia. Dairy cow cadavers were examined and a hole in the forehead (caused by a bullet or a captive bolt) was used as an indication of euthanasia. Telephone interviews were carried out with the farmer to verify the type of death and to obtain a short anamnesis.

The results show that the cow mortality rate has gradually increased between 2002 and 2010, from 5.1 to 6.6 deaths/100 cow-years. At the herd level, a larger herd size, longer calving intervals and the Swedish Holstein breed were associated with greater mortality. Lower mortality was observed in herds with a higher average milk yield, during autumn-winter, and in organically managed herds. In the questionnaire, the same effects of breed and herd size were identified, but also having cows on exercise pasture (instead of production pasture) during summer was associated with high mortality herds. At the cow level, the highest mortality hazards were found for traumatic events and diseases. The mortality hazard was higher in early lactation and increased with parity. Of the 433 cows in the destruction plant study, 30% had died unassisted. A high herd average stillbirth rate increased the risk of unassisted death.

In conclusion, the Swedish mortality rates were found to be high from an international perspective, and several risk factors at both the cow and the herd level were identified.

Keywords: animal welfare, euthanasia, unassisted death, dairy cattle, epidemiology.

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Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Alvåsen K, Jansson Mörk M, Hallén Sandgren C, Thomsen PT, Emanuelson U (2012). Herd-level risk factors associated with cow mortality in Swedish dairy herds. *Journal of Dairy Science* 95, 4352-4362.

II Alvåsen K, Roth A, Jansson Mörk M, Hallén Sandgren C, Thomsen PT, Emanuelson U. Farm characteristics related to on-farm cow mortality in dairy herds: a questionnaire study. *Submitted manuscript*.

III Alvåsen K*, Jansson Mörk M*, Dohoo I, Hallén Sandgren C, Thomsen PT, Emanuelson U. Risk factors associated with on-farm mortality in Swedish dairy cows. *Submitted manuscript*.

IV Alvåsen K, Thomsen PT, Hallén Sandgren C, Jansson Mörk M, Emanuelson U (2014). Risk factors for unassisted on-farm death in Swedish dairy cows. *Animal Welfare* 23, 63-70.

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Abbreviations

AI	Artificial insemination
AMS	Automatic milking system
BMSCC	Bulk milk somatic cell count
BSE	Bovine spongiform encephalopathy
CDB	Central register of bovine animals
CI	Confidence interval
CM	Conventional milking
ECM	Energy-corrected milk
HM	High mortality herd
LM	Low mortality herd
MR	Mortality rate
OR	Odds ratio
PAF	Population attributable fraction
SCC	Somatic cell count
SDA	Swedish Dairy Association
SEK	Swedish crowns (1 SEK = 0.11 Euro in March 2014)
SH	Swedish Holstein
SOMRS	Swedish Official Milk Recording Scheme
SR	Swedish Red

1 Background

On-farm cow mortality is an important animal welfare issue that also causes financial losses for the dairy farmer. Studies have reported that the on-farm cow mortality rate (MR) in dairy herds has increased during the past few decades. For example, Thomsen *et al*. (2004) reported that the MR among Danish dairy cows increased from 2.0 deaths/100 cow-years in 1990 to approximately 3.5 deaths/100 cow-years in 1999. In the USA, it was reported from the National Animal Health Monitoring System that the overall on-farm cow MR increased from 3.8 deaths/100 cow-years in 1996 to 4.8 deaths/100 cow-years and 5.7 deaths/100 cow-years in 2002 and 2007, respectively (USDA, 2007). In Sweden, Sandgren *et al.* (2009) and Nyman *et al.* (2011) reported that cow mortality was one of six herd-level parameters associated with the animal welfare state of dairy herds. With these findings as a back drop, the need for investigating the situation of cow mortality under Swedish production conditions was clearly indicated.

1.1 Mortality

1.1.1 Definition

Mortality includes cows that die on farm, either an unassisted death or by euthanasia, but not cows that leave the farm to be slaughtered. Mortality is one form of culling, as culling refers to cows exiting the herd for such reasons as sale, slaughter, unassisted death or euthanasia (Fetrow *et al.*, 2006). Hereafter, death refers to both unassisted death and euthanasia. Two common measures are used in describing mortality (Thrusfield, 1999):

Mortality rate: The number of deaths (i.e. unassisted death and euthanasia) in a population per unit of animal-time during a given period.

Mortality risk: The number of deaths during a given time period divided by the population at risk at the beginning of the period.

The mortality rate having the number of animal-time units as the denominator makes it suitable to use when dealing with open populations and when the follow-up period is long (e.g. deaths/100 cow-years). The mortality risk (i.e. cumulative mortality) is better to use in closed populations or when animals are observed for the full risk period (e.g. deaths/100 lactations).

Calving is a risk event for death in dairy cows (Thomsen *et al.*, 2004; Milian-Suazo *et al.*, 1988). Following cows from calving during the whole lactation may give a more correct picture than analysing a separate year, as some cows will calve twice during that year and others once or not at all (Thomsen & Houe, 2006).

1.2 Culling

1.2.1 Slaughter

To send a cow to slaughter requires that the cow is in good general condition; is free from wounds and abscesses; is able to move independently without pain using all four limbs; and has not been treated with drugs with a withdrawal period, or alternatively has been treated but the withdrawal period has expired (Anonymous, 2004). The farmer must declare that the cow is in a fit condition to enter the human food chain before sending her to the abattoir. The farmer's decision-making process for sending a cow to slaughter or to destruction is illustrated in Figure 1.

At the abattoir, an official veterinarian examines the animal before slaughter. If the animal is not accepted for human consumption, it will be euthanised and the carcass will be sent to destruction. If the official veterinarian discovers or suspects animal welfare problems, the county administrative board is contacted. In these cases, the farmer is paid an unannounced visit by an animal welfare inspector and receives a penalty if there are shortcomings in the animal welfare at the farm.

1.2.2 Home slaughter

Farmers are allowed to slaughter animals on farm and consume the meat in their own household. In the case of home slaughter, there is no requirement for a veterinary examination of the animal before slaughter or for an examination of the carcass afterwards, but if the purpose is to sell the meat, a veterinarian's certificate is needed. There is no restriction on how many cows a farmer can take for home slaughter. Still, only a small number of dairy cows are home-slaughtered every year. In 2013, 1382 cows were home-slaughtered (Larsson, Växa Sverige, personal communication).

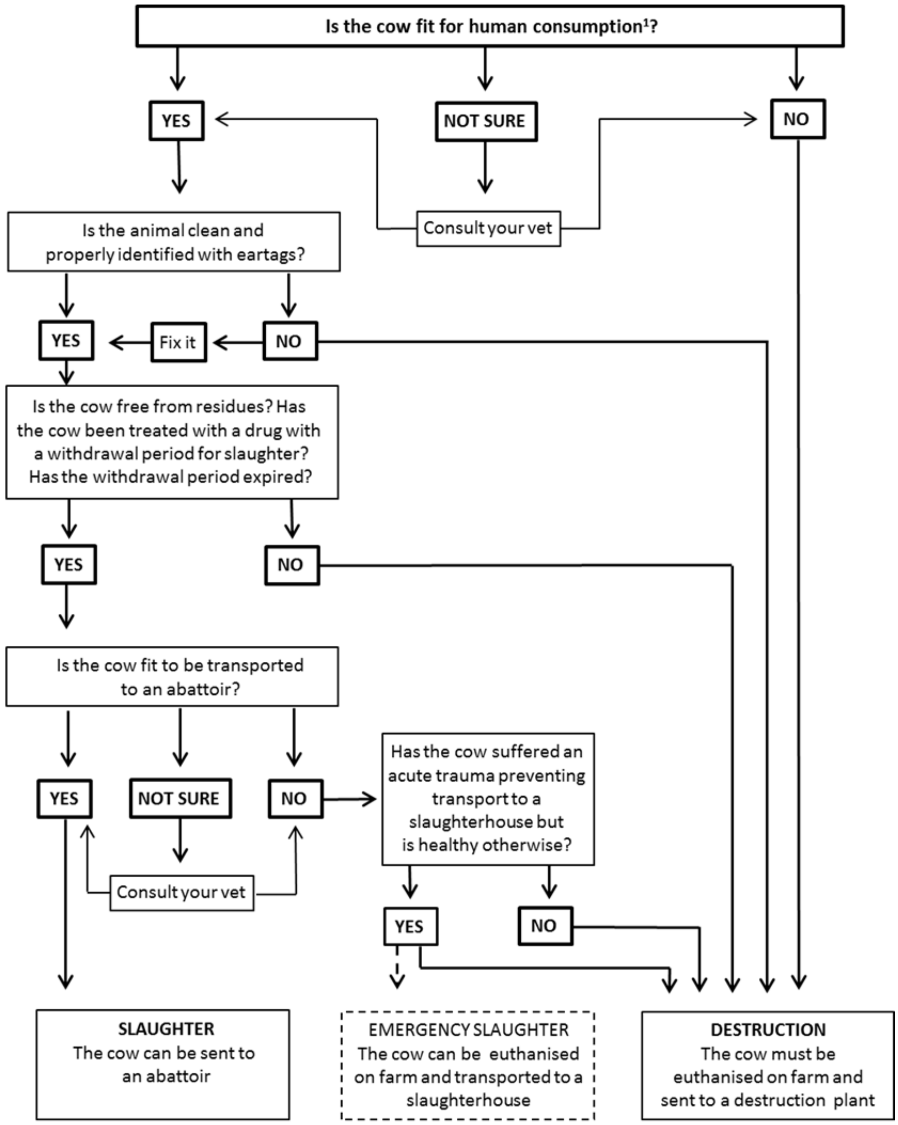

Figure 1. Flow diagram representing the process of a farmer's decisions for sending a cow to slaughter, to emergency slaughter (rarely used) or to destruction (modified from BCVA, 2010).[1]

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[1] *Fit for human consumption* is determined by visually inspecting the cow's general condition and determining that the cow is free from wounds, prolapse or abscesses.

1.2.3 Emergency slaughter

At the beginning of the 1990s, it was common to see the emergency slaughter of animals that were healthy but had to be culled due to, e.g. acute trauma. These animals were handled separately at the abattoir and were tested to ensure that the meat was acceptable for human consumption. The separate handling of these animals and the additional testing made the process too expensive and the emergency slaughter service ceased in 1998. Nowadays, emergency slaughter is only used to a negligible extent in some small-scale abattoirs. Instead, some of these cows are home-slaughtered and the majority of the cows are sent for destruction.

1.2.4 Unassisted death and euthanasia

In Sweden, sufficient knowledge of animal welfare regulations, skills in animal handling and confidence in the method to use are required to perform euthanasia. Captive bolt stunning, followed by exsanguination or stunning with a gun, followed by exsanguination are the approved methods to use. Performing euthanasia by giving an overdose of an anaesthetic (e.g. barbiturate) is restricted to veterinarians, while other types of euthanasia can be performed by, for instance, farmers, hunters and butchers, provided they have sufficient knowledge (SJVFS, 2008).

Cadavers resulting from unassisted death or euthanasia are classified as high-risk material, and farmers have to send them to destruction plants (SJVFS, 2010a). Salvage contractors employed by Svensk Lantbrukstjänst collect the cadavers on farm and can also euthanise the cow if the farmer has ordered it. The cost for removal of a dairy cow is 1350 SEK (Svensk Lantbrukstjänst, 2014). The cadavers that are collected from the farm are transported to transshipment places. The containers are filled up and cow cadavers are mixed with other species and slaughter wastes. Thereafter, lorries transport them to the destruction plants. Normally, cadavers reach the destruction plant within two days after the farmer contacted Svensk Lantbrukstjänst.

There are two main destruction plants in Sweden: Mosserud in Karlskoga and Krutmöllan in Kävlinge. These plants can together process 165,000 tonnes of animal wastes each year. The containers with cadavers are tipped out and a crane grabber is used to handle the cadavers individually. Cattle aged more than 48 months are tested for bovine spongiform encephalopathy (BSE) using a brain-stem sample (Anonymous, 2001). When all the animals have been sampled, they are tipped into a mill and are crushed and ground into slurry. This slurry is called Biomal and has an energy content equivalent to that of woodchip. The Biomal slurry is transported to thermal power stations for incineration (Ehn, Konvex AB, personal communication).

In some sparsely populated areas, there is no requirement to send cows to a destruction plant. Instead, farmers in these areas have to follow the regulations in their municipality, which usually means that they are allowed to bury cadavers at approved places (Granström, 2009).

1.3 Data sources

Data collected for a specific study are referred to as primary data. Secondary data are data that are also used for other purposes than the originally intended. In this thesis, both primary and secondary data were used.

1.3.1 Secondary data

The use of secondary data is common in observational studies when a large number of animals are needed - e.g. when studying a rare disease or an uncommon exposure. As the researcher is not involved in the data collection, it is difficult to know the quality of the secondary data (Emanuelson & Egenvall, 2014). On the other hand, some studies would not be able to be performed if secondary data were not available, for such reasons as the data being far too expensive and time consuming to collect, a representative study population being impossible to obtain (e.g. due to poor response rates).

1.3.2 Data registers and recording schemes for Swedish dairy herds

What follows is a brief description of the registers and recording schemes present in Sweden.

The central register of bovine animals

Swedish dairy farmers are required under regulation EC 1760/2000 to report all cattle movements (including birth, culling, death and euthanasia, as well as movement between farms) to the central register of bovine animals (CDB; Anonymous, 2000). This register is kept by the Swedish Board of Agriculture and contains information on all cattle in Sweden. The event should be found on the CDB register within one week post-occurrence.

The Swedish Official Milk Recording Scheme

The Swedish Official Milk Recording Scheme (SOMRS) is a voluntary service similar to a dairy herd improvement programme. It started in southern Sweden in 1898. At that time, only a small proportion of the Swedish herds participated. The scheme became computerised during the 1960s, and since that time, enrolment has gradually increased. The cost for participating is approximately 140-170 SEK/cow and year (Larsson, Växa Sverige, personal communication). The SOMRS includes information from the monthly test milkings, where milk yield, fat and protein percentage, urea concentration and somatic cell count are recorded, and also information on pedigree. In 2012/2013, 80% of Swedish dairy herds were enrolled in the SOMRS, and produced 86% of the milk during that year.

The artificial insemination recording system

The artificial insemination (AI) recording system contains information on insemination or natural service dates, some fertility treatments and pregnancy checks. Almost all Swedish herds (97%) are enrolled in the AI recording system. Löf *et al.* (2007) reported that the accuracy of reproductive performance indicators is affected by certain herd characteristics and also that there is a time lag for the registrations to be recorded, especially from herds carrying out AI by themselves instead of using a professional AI technician from the livestock associations.

Claw trimming register

An electronic system is available for use by claw trimmers for registration of claw health observed at trimming. Claw trimming records include the type of claw disorder and its severity. Approximately 280,000 claw trimming records from 1800 dairy herds are registered annually.

The Swedish dairy disease recording system

The national disease recording system is managed by the Swedish Board of Agriculture and contains information on disease treatments (Olsson *et al.*, 2001; Emanuelson, 1988). In Sweden, a veterinarian has to examine the animal to prescribe drugs and initiate treatment (SJVFS, 2013). All veterinarians must report drug treatments to the disease recording system within three months (Swedish Board of Agriculture, 2014). State-employed veterinarians report through electronic software. Private veterinarians can either use electronic software or, more commonly, use manual records that are sent in by mail or by an electronic file to the Swedish Board of Agriculture. Mörk *et al.* (2010) validated the national disease recording system and found that 75% of the treatment records kept on the farm appear in the disease recording system. As a result, even though the disease recording system should document all treatments, one treatment out of four is not correctly registered.

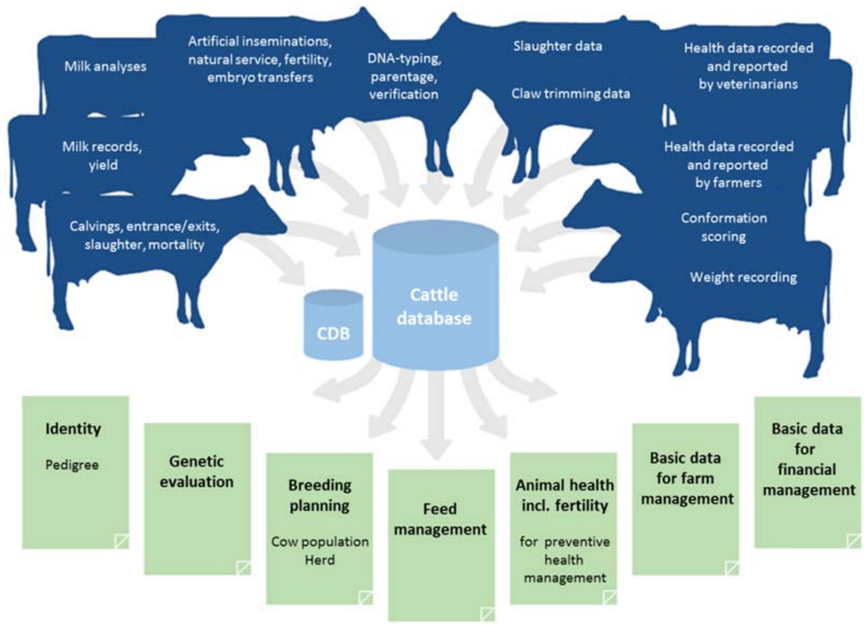

Figure 2. Illustration of the information flow to and from the cattle database at Växa Sverige (modified from Växa Sverige).

1.3.3 The Swedish cattle database

Herds participating in the SOMRS have records stored in the cattle database, which is managed by Växa Sverige[2]. The cattle database combines records from the SOMRS, the CDB, the AI recording system, the claw trimming register and the national disease recording system (Figure 2). The information is registered by farmers, milk analysis laboratories, DNA laboratories, field staff at the livestock associations, claw trimmers, abattoirs, veterinarians and the Swedish Veterinary Institute.

The information in the cattle database is mostly used for herd advisory services, sire evaluations, benchmarking of farm performance, annual statistics and research. The cattle database uses fiscal years ranging from September 1 to August 31.

[2] On 1 January 2013, all livestock activities at the Swedish Dairy Association were transferred to Växa Sverige, one of the three livestock associations with advisory services for dairy production in Sweden.

1.3.4 Reporting of unassisted death and euthanasia

Reporting of all movement events, including mortality, should be done by the farmer within seven days. Farmers with herds enrolled in the SOMRS report such events to the cattle database, and the information is automatically sent to the CDB at the time of reporting. Farmers who are not enrolled in the SOMRS report only to the CDB. Until May 2012, only two codes were available in the databases: "Unassisted death or euthanasia and sent to destruction" and "Unassisted death or euthanasia and not sent to destruction". It was not possible to differentiate between unassisted death and euthanasia in either of the databases. In May 2012, however, the cattle database separated the codes into four new codes: "Unassisted death and sent to destruction", "Euthanasia and sent to destruction", "Unassisted death and not sent to destruction" and "Euthanasia and not sent to destruction".

1.4 Today´s dairy industry in Sweden

Dairy cattle production in Sweden has undergone considerable changes during the past decades. These structural changes have led to a decreased number of cows in fewer but larger herds (Table 1). More and more cows are kept in free-stalls than in tie-stalls, which is an on-going trend, as farmers have not been allowed to build new tie-stalls since 2007. Eighty percent of Swedish dairy herds participate in the SOMRS. In 2012, 55% of the cows were held in free-stalls, where half of them were milked in automatic milking systems (AMSs) and the other half in parlours. The most common breeds were Swedish Holstein (SH; 51%) and Swedish Red (SR; 42%). The SH breed is increasingly replacing the SR breed (Växa Sverige, 2013). These trends, with an increasing average milk yield per cow, an increased herd size and larger proportion of the Holstein breed, are seen in most countries with an intensive dairy production.

Table 1. *Description of herds participating in the Swedish Official Milk Recording Scheme (SOMRS)*

Year	Cows	Herds	Average herd size	Average milk yield, kg ECM[1]	SOMRS enrolled[2]
1990	421,780	14,891	28	7319	75
2000	368,350	9115	48	8612	87
2010	275,716	4302	64	9468	85

[1] ECM = Energy-corrected milk
[2] Percentage of cows participating in the SOMRS

Figure 3 shows the different geographical regions and legislated pasture regions in Sweden. Norrland is less populated in terms of both people and cows compared with the other regions. Also, the herd sizes differ between regions and are generally smaller in the northern parts and larger in the southern parts. Of the 54 herds with over 300 cows participating in the SOMRS, only one of them is located in Norrland (Växa Sverige, 2013). Sweden covers different climate zones with colder and stronger winters in the north and longer growing season in the south. In contrast to other countries in the EU, Swedish legislation stipulates that cows should be let out on pasture during summer and have access to pasture for at least six hours per day for two, three and four months in the North, Central and South region, respectively (Figure 3b; SJVFS, 2010b). Eighty percent of the outdoor area should be covered with grass, but there is no requirement regarding the quantity or quality of the pasture.

Approximately 12% of the Swedish dairy herds are organically managed (KRAV, 2014). These herds are certified according to the organic organisation KRAV's standards.

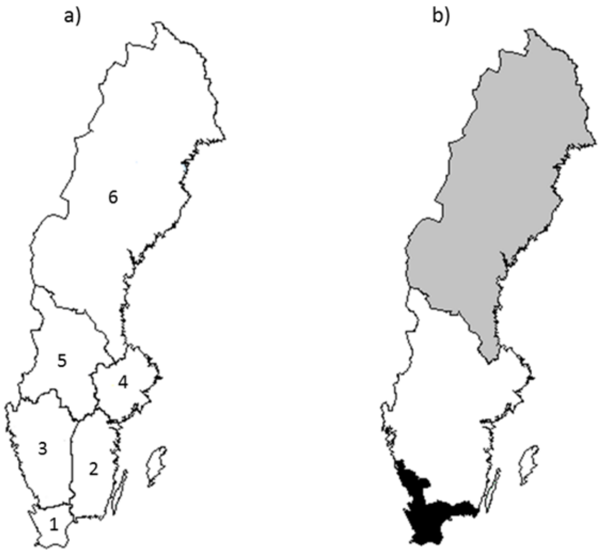

Figure 3. Definition of the different a) geographical regions in Sweden: 1 = Södra Götaland; 2 = Östra Götaland; 3 = Västra Götaland ; 4 = Östra Svealand; 5 = Västra Svealand; 6 = Norrland; and b) legislated pasture regions: black = four months; white = three months; grey = two months.

2 Aims

The overall aim in this thesis was to investigate mortality in Swedish dairy cows and to identify risk factors for unassisted death and euthanasia at the herd and cow level, with the leading hypothesis being that there are systematic differences in mortality between herds and between individual cows.

The more specific aims were to do the following:

- Quantify the development of cow mortality over time and evaluate regional and seasonal trends of cow mortality in Swedish dairy herds (paper I).

- Identify risk factors associated with cow mortality at the herd level (papers I and II).

- Evaluate cow-level risk factors associated with cow mortality (paper III).

- Quantify the relative proportion of unassisted death among cows that die on farm, and evaluate risk factors at the herd and cow level that differentiate unassisted death from euthanasia (paper IV).

3 Materials and Methods

This section gives an overview of the materials and methods used in the studies that are the basis of this thesis. Full descriptions are given in each paper (I-IV).

3.1 Data collection and study populations

3.1.1 Temporal and spatial trends

To quantify the development of cow mortality over time and to evaluate regional and seasonal trends in Swedish dairy herds, a multiple-year study was performed (paper I). Secondary data on the reported number of dead and euthanised cows from each herd for every month between 2002 and 2010 were extracted from the CDB. Herd-level data was retrieved from the SOMRS for the period between 1 September 2002 and 31 August 2010. These secondary data included information on breed, calving interval, herd size and milk yield. All herds with a herd size larger than 20 cows and an MR below 40 deaths per 100 cow-years were included. This latter criterion was used to exclude herds with high mortality due to diseases (e.g. *Salmonella*), as Swedish farms with certain diseases in the herd are forced to euthanise large proportions of animals. In total, 6898 herds were included in the study.

Three seasons were studied: winter-spring (January to April), summer (May to August), and autumn-winter (September to December). The herd's postal code was used to categorise them into the six geographical regions of Sweden shown in Figure 3a.

3.1.2 Risk factors at herd level

To identify herd-level risk factors associated with cow mortality, both secondary herd-level data from the SOMRS (paper I) and primary data from a questionnaire study (paper II) were analysed.

A single-year analysis was carried out, as some herd information is not stored historically in the SOMRS (paper I). The information in this study included not only the explanatory variables from the multiple-year analysis, but also the housing/milking system and the management type (conventional or organic).

In paper II, a questionnaire was designed to capture potential risk factors not present in the secondary SOMRS data. The questionnaire was constructed with help from knowledgeable persons in the field and in the academy. In a pilot study, 10 dairy farmers answered the questionnaire and gave their comments. Confusing or unclear questions were reformulated. The questionnaire focused on management routines and consisted of 49 questions in five sections: “About the farm”, “Milking and housing”, “Feeding”, “Routines” and “Lame and sick cows”. The questionnaire was distributed by mail to herds with a herd size of >35 cows and either a high or a low MR for three consecutive years. High mortality herds had had an MR in the fourth quartile for the years 2009/2010 and 2010/2011 (>8.1 and 7.7 deaths/100 cow-years, respectively) and above the median for 2008/2009 (>5.2 deaths/100 cow-years). Low mortality herds were herds with an MR in the first quartile during 2009/2010 and 2010/2011 (<2.7 deaths/100 cow-years, for both years) and below the median for 2008/2009 (<5.2 deaths/100 cow-years). In total, 194 herds met the criteria for high mortality herds and 250 for low mortality herds, and all were sent a questionnaire in October 2012. Of the 148 returned questionnaires, 60 from high mortality herds and 85 from low mortality herds could be used in the analysis. All variables were treated as categorical variables, permitting the inclusion of not reported answers as its own category.

3.1.3 Risk factors at cow level

To identify cow-level risk factors for cow mortality (paper III), data from all cows enrolled in the SOMRS with a calving between 1 July 2008 and 30 June 2009 from herds with a herd size larger than 40 cows were retrieved. The following cow-level information was used: breed, dates of entrance and removal, reasons for removal, if the cow was born in the present herd, results from the first test milking after calving, pedigree, information on the calving in 2008/2009, and disease diagnoses. Additionally, information on the previous lactation (yield, fat and protein content) and calving interval was retrieved for multiparous cows. The following information on herd level was also used: number of calvings in the herd in 2006/2007, 2007/2008 and 2008/2009, milking system and management type (conventional or organic).

Observations were excluded when inconsistent reports were discovered (e.g. an entry into the same herd or into another herd on a date after the reported date for culling, or an entry into a herd after the date a cow calved in the same herd). Fewer than 0.1% of the lactations were excluded. All potential risk factors were categorised in order to handle missing observations, and the usable data included 209,236 lactations.

3.1.4 Proportion of unassisted death and euthanasia

In paper IV, a field study was carried out to quantify the relative proportion of unassisted dead cows among cows that die on farm. In Sweden, cows that die on farm are transported to the two main destruction plants Krutmöllan and Mosserud.

Before the start of the study the required sample size was calculated according to the following equation (Toft *et al*., 2004):

$$n = \frac{(Z_{1-\alpha/2})^2 \times p(1-p)}{L^2}$$

where n is the number of cows to examine,
$Z_{1-\alpha/2}$ is 1.96 for a confidence level of 95%,
p is the probability for unassisted death and
L is the maximum allowable error.

As p was unknown it was set at 0.5, which gives the largest sample size. L was set to 0.05. The sample size was therefore:

$$n = \frac{1.96^2 \times 0.5(1-0.5)}{0.05^2} = 384$$

The results from paper I indicated that approximately 30 dairy cows per day would be found at the destruction plants. Krutmöllan and Mosserud were therefore visited during three days in three different seasons to be able to examine a sufficient number of cows. The intention was to perform the samplings during the same year, but we did not receive permission from one of the plants in time, and the spring sampling at that destruction plant was therefore performed the year after.

All dairy cow cadavers over 48 months are tested for BSE at the destruction plants. They are handled individually with a crane grabber and the head and neck are washed with water before the brain stem sample is taken. The type of death was examined in connection to the testing. A hole in the forehead (caused by a bullet or by a penetrating captive bolt) was used as an indication of euthanasia. Dairy cows younger than 48 months are normally tipped directly in to the grinder, but to enable examination of the type of death, they were handled individually during the sampling occasions. A total of 556 dairy cows were examined at the destruction plants.

Farmers who had sent the cows were identified and contacted by telephone directly after each sampling occasion, to verify the type of death and to give a short anamnesis. Both the examinations at the destruction plants and the telephone interviews were carried out by the author herself.

Available information from the SOMRS was retrieved for all cows examined at the destruction plant from herds that were enrolled in the SOMRS. These data contained the following cow-level information: breed, disease treatments, parity and the latest calving. It also included the following information at the herd level: bulk milk somatic cell count (BMSCC), stillbirth rate (stillborn calves and calves that died within 24 hours after birth), calving interval, on-farm cow MR, proportion of cows with a calving to first artificial insemination interval above 70 days, housing system, herd size, management type, milk yield, geographical region and proportion of first parity cows. The different geographical regions are shown in Figure 3a. The herd-level information was means based on the period between 1 September 2010 and 31 August 2011. Complete herd level information was obtained for 374 cows from 318 herds. Cow- and herd-level data were analysed to identify risk factors associated with unassisted death (as opposed to euthanasia). Cows were included in the analysis if the examination at the destruction plant and the information from the farmer matched, and if the herd participated in the SOMRS. In total, 433 cows from 368 herds were included in the analysis.

3.2 Statistical analyses

Different types of multivariable models have been used to analyse the data materials.

A negative binomial regression model was used in the single-year and multiple-year analysis to evaluate the effect of different herd-level variables on herd mortality (paper I). The number of unassisted dead and euthanised cows for each season was the outcome variable in the single-year analysis. In the multiple-year analysis, the number of unassisted dead and euthanised cows in each season in every year was the outcome variable. Herd size was set as the exposure variable and herd as a random effect in both analyses. The explanatory variables in the multiple-year analysis were year, region, season, herd size, breed, milk yield and calving interval. The single-year analysis included region, season, herd size, breed, milk yield, calving interval, management type and housing/milking system.

When analysing the data to find potential differences between high mortality herds and low mortality herds, and also between dying an unassisted death and being euthanised, logistic regression models were applied (papers II and IV).

In paper III, Weibull proportional hazards models with gamma-distributed frailty common to cows within a herd was used to evaluate the time from calving to unassisted death or euthanasia in individual cows. Primiparous cows and multiparous cows were analysed in separate models. The event of interest (failure) was on-farm mortality in the on-going lactation. Cows that calved again, were slaughtered or sold, or had an on-going lactation 500 days after calving were right-censored. The contribution of a risk factor to death was quantified using the population attributable fraction (PAF). This was done by combining information on the prevalence of the risk factor in the population with estimates of the strength of the association between the risk factor and the outcome (Dohoo *et al.*, 2009). However, the PAF is usually based on risks (the proportion of animals affected by a disease) and not rates (the rate at which disease is occurring). As most deaths in paper III occurred over a reasonably short period and as there was relatively little censoring before 300 days, it is possible to calculate the PAFs from the hazard ratios (Laaksonen *et al.*, 2010). The calculations were performed using the following formula (Takashima *et al.*, 2010):

$$\text{PAF} = pd\left(\frac{HR - 1}{HR}\right)$$

where *pd* is the proportion of cases at the exposure level, and
HR is the hazard ratio.

Even though different multivariable models were used in these studies, the model-building strategies were quite similar in all the studies. Spearman rank-order correlation coefficients were used to assess potential collinearities between the explanatory variables, with the intention of excluding one of the variables if the correlation coefficient (rho) indicated strong collinearities. Whenever strong collinearities were found, the variable with the best fit, determined by likelihood statistics, was used in the analysis. Potential risk factors were first screened in a univariable analysis in all studies, except in paper I where all available variables were included. Variables with a univariable association with the outcome of $P<0.2$ were included in the multivariable model building. Here a manual step-wise backward elimination procedure was carried out and continued until all remaining effects had $P<0.05$. The initial full multivariable model in paper II did not converge and sub-models were therefore first used to further reduce variables for the final multivariable model. Potential confounders were considered in each step of the model development by inspecting changes in the parameter estimates with and without the possible confounder. A change in the parameter estimates of >20% was considered to indicate confounding. Biologically plausible two-way interactions were included in the model development when they were deemed relevant. The fit of the models was evaluated using different approaches depending on model type.

Statistical analyses were performed using SAS® (SAS Institute Inc., Cary, NC, USA) or STATA (StataCorp LP, College Station, TX, USA).

4 Results

4.1 Temporal and spatial trends

From 2002 to 2010, the MR gradually increased from 5.1 to 6.6 events per 100 cow-years (Figure 4). The mean MR during the study period in paper I was 6.0 events per 100 cow-years for the 6898 herds included in the multiple-analysis. More than 15% of the included herds had no mortality events in separate years, during the study period.

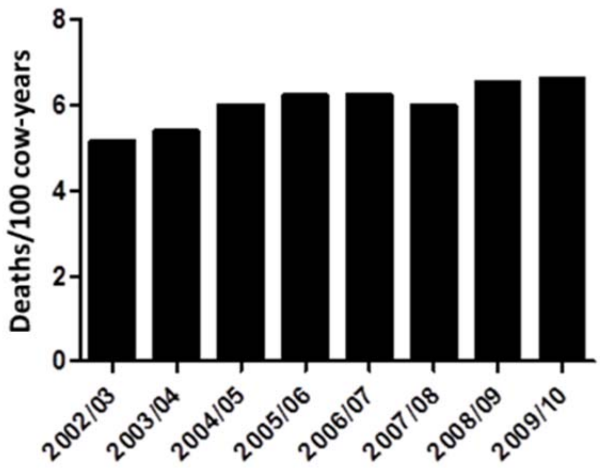

Figure 4. Mortality rate (MR) for dairy herds participating in the Swedish Official Milk Recording Scheme from herds with >20 cow-years and annual MR <40 deaths/100 cow-years in the period between 1 September 2002 and 31 August 2010.

There was a significant interaction between herd size and season. Higher MRs were found during the summer season (Figure 5). The difference between autumn-winter and summer was statistically significant for all herd size groups, except for herds with ≥200 cows in the single-year analysis, where no statistically significant differences between seasons were found (Figure 5b).

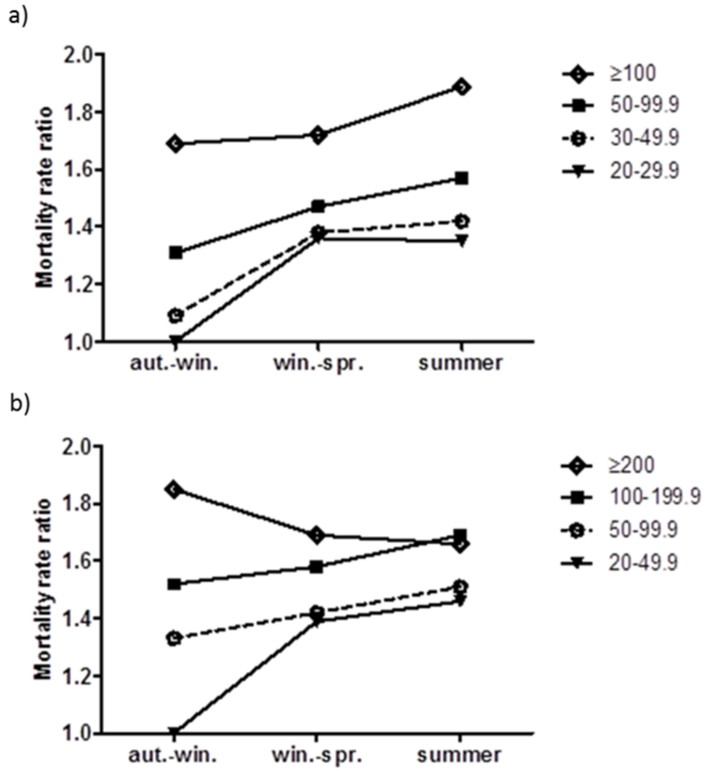

Figure 5. Mortality rate ratio for different herd size groups in September to December (aut-win), January to April (win-spr) and May to August (summer) between the periods (a) 1 September 2002 and 31 August 2010, and (b) 1 September 2009 to 31 August 2010.

In addition, regional differences were found: Östra Götaland and Norrland had greater MR ratios than Södra Götaland. When the region variable was replaced with the effect of legislated pasture period in the multiple-year analysis the results showed that herds with a longer legislated pasture period (3 and 4 months) had reduced mortality (MR ratio = 0.94, 95% CI = 0.90-0.97 and MR ratio = 0.90, 95% CI = 0.86-0.94, respectively) compared with that of herds with a legislated pasture period of two months.

4.2 Risk factors at herd level

In both the multiple-year and the single-year analysis in paper I, the SR breed was associated with a lower MR then the SH breed. These studies also showed that a longer calving interval was a risk factor for a higher MR. A significant interaction between herd size and season was found (Figure 5), demonstrating a higher MR in larger herds. The multiple-year analysis showed a reduced MR with an increase in herd's annual milk yield, and the single-year analysis identified an interaction between milk yield and housing system, which showed a tendency for a lower MR ratio in herds with a higher average milk yield. Free-stalls with an AMS had the numerically lowest MR ratio. A lower MR ratio was also found in organically managed herds than in conventional herds in the single-year analysis.

The questionnaire study (paper II) showed that being a high mortality herd compared with being a low mortality herd, was associated with having the SH breed, a larger annual herd size and an exercise pasture (i.e. an out-door area with a limited amount of pasture for grazing). A missing answer on the question of bedding improvement frequency was associated with being a high mortality herd. There were no statistical differences between the bedding improvement frequencies otherwise. "Natural service (bull) used" was associated with high mortality herds; the variable was however, borderline significant and was kept in the final model, as it confounded point estimates for three other variables.

4.3 Risk factors at cow level

The 76,720 lactations for first parity cows and 132,516 lactations for multiparous cows were analysed separately in paper III. Out of these lactations 12,813 (6.1%) ended due to unassisted death or euthanasia. Mortality occurred at a median of 89 days after calving, while 29.5% of the deaths occurred during the first 30 days. The risk for mortality was highest early in lactation and increased with increasing parity.

The hazard for mortality was highest for different disease complexes. In primiparous cows, "Other disorders" followed by "Infections and parasitic disorders", "Metabolic disorders" and "Trauma" represented the highest hazards of mortality among diseases in the lactation stage where death or censoring occurred. For multiparous cows, "Trauma", "Other disorders", "Puerperal paresis" and "Infection and parasitic disorders" represented the highest hazards. For diseases in the previous lactation stage, "Trauma" followed by "Infection and parasitic disorders" and "Metabolic disorders" showed the highest mortality hazards in both primiparous and multiparous cows.

In both primiparous and multiparous cows, the mortality hazard was higher in cows of the SH breed, in conventionally managed herds and in herds with a high number of annual calvings. A low milk yield, a high somatic cell count, or a missing value at the first test milking also increased the mortality hazard in both analyses. Furthermore, dystocia, stillbirth and spring calving increased the hazard. The risk was higher for cows with one reported disease event than for cows with no disease event or more than one disease event. A relapse of disease within 30 days increased the risk for multiparous cows. In primiparous cows, a higher age at first calving increased the hazard, as did being housed in a free-stall with parlour or rotary milking. In multiparous cows, a milk yield in previous lactation >10,372 kg energy-corrected milk (ECM) and being purchased for the herd within 90 days before calving slightly increased the hazard for mortality. The hazard also increased during the summer season, in cows giving birth to twin calves and in cows with reproductive disorders in a previous lactation stage. A low milk urea reduced the mortality hazard in multiparous cows.

Table 2. *Population attributable fractions (PAFs) for 76,720 primiparous and 130,032 multiparous cows in a study on cow-level risk factors for cow mortality.*

Variable	Category	PAF (%)	
		Primiparous	Multiparous
Parity	≥3 vs. parity 2	-	32
Milk yield at 1st test milking	None vs. >Q3[a]	21	26
Management type	Conventional vs. organic	23	15
Breed	SH vs. other breeds[b]	13	14
Age at 1st calving	≥30.1 vs. <25.2 months	10	-
Calving interval	≥14.2 vs. <11.7 months	-	10
Total number of disease events	1 vs. ≥2	10	9
Total number of disease events	0 vs. ≥2	-	9
No. of calvings during 2008/09	>160 vs. <74	-	9
Puerperal paresis	Yes vs. no	-	8
Dystocia	Yes vs. no	8	-
Calving season	Sept-Dec vs. Jan-Apr	7	-
Milking system	Pipe vs. AMS	7	-
SCC at 1st test milking	None vs. <100,000 cells/ml	6	-

[a] ≥30.1 kg ECM for primiparous cows and ≥40.7 kg ECM for multiparous cows

[b] other breeds = crossbreds (SHxSR), Swedish jersey and Swedish polled

The population attributable fraction shows the proportion of mortality in the population that is attributable to the exposure, and which would be avoided if the exposure were removed (Dohoo *et al.*, 2009). The categories with PAFs greater than 5% are shown in Table 2 for primiparous and multiparous cows.

4.4 Proportion of unassisted death and euthanasia

Of the 433 cows examined at the destruction plants with confirmed information from the farmer on the type of death, and with information from SOMRS, 130 cows died unassisted (30%) and 303 cows were euthanised (70%). The farmer interviews showed that 76% of the euthanised cows were euthanised by the owner or employees at the farm, 8% by a veterinarian, and 16% by other persons (mainly knackermen or hunters). The methods used for euthanasia were: stunning with a captive bolt followed by immediate exsanguination (88%); stunning with a rifle followed by immediate exsanguination (11%); and injecting an overdose of an anaesthetic (1%). The reasons for death stated by the farmers differed between the two types of deaths (Figure 6).

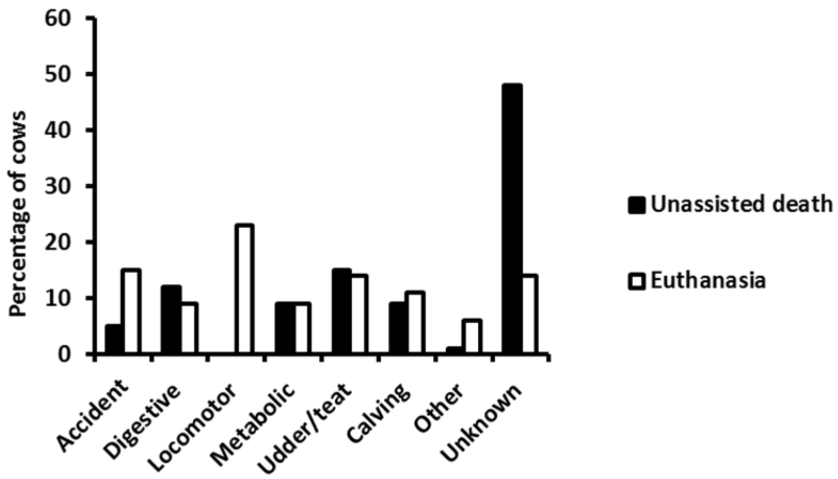

Figure 6. Primary reasons for unassisted death (% of n=130) and euthanasia (% of n=303) in Swedish dairy cows as stated by the farmer in a telephone interview.

The mean age of death was 1858 days (minimum = 674; Q1 = 1329; median = 1770; Q3 = 2246; maximum = 4780) and 161 of the 433 examined cows were younger than 48 months. Death occurred on average 145 days after calving (minimum = 0; Q1 = 20; median = 78; Q3 = 233; maximum = 1004). The distribution of mortality after calving was right-tailed, with a small increase in mortality after 300 days when approaching the next calving. One third of the mortality events occurred during the first month. The yearly on-farm cow mortality in the herds included in the study was on average 7.31 deaths/100 cow-years. The mean herd size and milk yield of the herds with cows included in the study were 108 cows and 9462 kg ECM, respectively.

In the multivariable conditional logistic regression model a high stillbirth rate in the herd was the only statistically significant risk factor for unassisted death as opposed to euthanasia. The odds ratio of unassisted death was 1.57 (95% confidence interval 1.00–2.47, $P<0.05$) for cows in herds with a stillbirth rate of 7% or greater.

5 Discussion

The papers in this thesis demonstrate that Swedish cow mortality rates have increased in recent years and that they are relatively high from an international perspective. A number of risk factors at the cow and herd level have been identified and the proportion of unassisted death among cows dying on farm has been assessed. The purpose in this section of the thesis is to discuss the results in a general manner. A more detailed discussion can be found in the respective papers.

5.1 Animal welfare

A variety of causes are attributable to on-farm dairy cow mortality (Alvåsen *et al.*, 2014; Thomsen *et al.*, 2012; McConnel *et al.*, 2009). High levels of unassisted death and euthanasia are an animal welfare problem, as almost all on-farm deaths represent an endpoint for animal suffering (Garry & McConnel, 2013). Several studies have found an association between animal welfare and the level of on-farm mortality (Kelly *et al.*, 2013; de Vries *et al.*, 2011; Kelly *et al.*, 2011; Nyman *et al.*, 2011; Sandgren *et al.*, 2009). Kelly *et al.* (2013) found that farmers with Irish cattle herds with known welfare concerns did not send as many animals to slaughter as did farmers with herds without welfare problems; instead, the herds with known welfare concerns had higher rates of illegal on-farm burial and movements to knackeries. Obviously, an animal in good general condition would most likely be sent to slaughter if removed from the herd.

Hitherto, only a few studies of on-farm mortality distinguish between euthanasia and unassisted death (Alvåsen *et al.*, 2014; Thomsen *et al.*, 2012; McConnel *et al.*, 2010; McConnel *et al.*, 2009; Thomsen & Sørensen, 2009; Thomsen & Sørensen, 2008; Thomsen *et al.*, 2004). Two of these studies have identified risk factors for either dying unassisted or being euthanised among the dead cows. Thomsen & Sørensen (2009) found that herds with a larger proportion of euthanised cows (as opposed to unassisted dead cows) had a larger herd size, higher milk yield per cow and year, and higher frequency of disease recordings per cow and year. Conversely, Alvåsen *et al.* (2014) identified that a high herd average stillbirth rate was the only factor differentiating unassisted death from euthanasia.

The reasons behind unassisted death and euthanasia could be totally different or very similar, which makes it difficult to identify risk factors between the two types of deaths, but it also makes it complicated to decide whether euthanasia or unassisted death is “less bad” from a welfare perspective. It surely varies from case to case and depends on farmers’ attitudes and decisions (Yeates, 2010). A high proportion of unassisted dead cows could indicate neglect of animals and may therefore be associated with pain and suffering before death. On the other hand, unassisted death could be so quick that preceding clinical signs go unnoticed, which might imply a limited amount of suffering for the cow. Another possible scenario could be that the farmer does whatever is possible to do to save the cow, but despite care and attention the cow dies unassisted.

As well, a high proportion of euthanised cows may be an indication of a high number of seriously ill cows, which is problematic, but it may also be a consequence of a reduced threshold for euthanasia (i.e. euthanasia instead of treatment). A reduced threshold for euthanasia would possibly imply that cows are euthanised at an early stage of disease and will therefore not have to go through a period of suffering from the disease and treatment attempts.

At the same time as euthanasia can be used to shorten painful conditions, it can also indicate a farmer’s unwillingness to try to treat the illness because of, e.g. lack of compassion, financial constraints, or apathy towards animal life. Kelly *et al.* (2013) suggested that euthanising cows on farm might also be a strategy to conceal welfare problems or to avoid antemortem inspections by official veterinarians at the abattoir. In line with Thomsen & Sørensen’s (2008) findings, some Swedish farmers stated that the veterinary antemortem examinations at abattoirs have become stricter in recent years. This change has affected the farmers’ behaviour and some of the cows that were sent to slaughter a few years ago would now probably be euthanised on farm instead (paper IV).

During telephone interviews in study IV, the farmers were asked if the cow died unassisted or was euthanised. Some farmers answered that it was a question of interpretation as the cow was in such poor condition that it was hard to determine if she was alive at the time of euthanasia. Nevertheless, even though the cow could have experienced severe pain for a long period before euthanasia, it indicates that someone has noticed the cow and taken action, and therefore we believe it is generally less bad from a welfare perspective.

The relative proportion of euthanasia found in Swedish dairy cows (70%) was higher than figures from other countries (paper IV). One explanation for this finding could be that Swedish farmers have a lower threshold for euthanasia. Another explanation may be that they more frequently use euthanasia as an alternative to calling for a veterinarian than do farmers in e.g. Denmark and the USA. In Denmark a higher proportion of euthanasia was performed by a veterinarian, and over 20% of the euthanised cows were euthanised with an overdose of an anaesthetic (Thomsen *et al.*, 2004). In Sweden, that method of euthanasia was very uncommon; instead, the majority of the euthanised cows were stunned using a captive bolt and exsanguinated by the farmer or an employee. This discrepancy may indicate that Swedish farmers are trying to minimise the time of suffering for the animal. It may also be because a larger percentage of the Swedish farmers are hunters and therefore more familiar with euthanising animals, or possibly because they are reluctant to incur veterinary costs.

5.1.1 Acceptable level of cow mortality

Even though an increasing MR is a major concern within the dairy industry, there is no stated figure on what could be considered a “natural” or “normal” level of cow mortality (Thomsen & Houe, 2006). In fact, during telephone interviews in paper IV, the impression was that many farmers were unaware of their own annual herd MR and did not know what level they considered acceptable. In cases where farmers said what level they considered “normal”, the level varied widely between individuals (data not shown).

A literature review covering the years 1965 to 2006 found 19 published studies that focused on dairy cow mortality in countries with relatively intensive dairy production (Thomsen & Houe, 2006). Until the middle of the 1990s, reported mortality rates were below 2.5 deaths/100 cow-years (Dematawewa & Berger, 1998; Esslemont & Kossaibati, 1997; Faye & Perochon, 1995; Menzies *et al.*, 1995; Gardner *et al.*, 1990; Harris, 1989; Milian-Suazo *et al.*, 1989; Milian-Suazo *et al.*, 1988; Barfoot *et al.*, 1971; Batra *et al.*, 1971), with a few exceptions (Nørgaard *et al.*, 1999; Karuppanan *et al.*, 1997). At the end of the 1990s, mortality rates of 4.3% and up to 8.6% were reported from Australia and the USA (Smith *et al.*, 2000; Stevenson & Lean, 1998).

Swedish dairy farmers can use a web report titled *Animal Welfare Signals* for benchmarking their herd welfare parameters (including cow mortality) against other dairy herds (Winblad von Walter *et al.,* 2012). To continuously measure and evaluate welfare parameters is important in preventing the bad from becoming normal (Grandin, 2010). This benchmarking tool has only been available since 2010, so it could not have had any impact on the results in paper I. However, from 2010 there has been a declining trend in mortality rates which could indicate positive effects of the benchmarking tool.

5.2 Economic aspects

Unassisted death and euthanasia may have a large impact on the farm's economy. The direct cost of a dead cow is on average 8200 SEK, which includes the loss of income represented by the slaughtered carcass and the cost of its removal and destruction (Engelbrekts, Växa Sverige, personal communication). This value varies significantly, since the payment for slaughtered cows differs. Moreover, the true loss of a dead cow involves more factors and is likely to be larger when the indirect costs are also considered. The extent of the loss depends on the situation of the death event - e.g. which animal that died and at what time in relation to calving, pregnancy status, investment in treatment attempts, and the cow's condition and genetic traits, as well as slaughter and feed prices. A dead cow is not part of a normal culling plan for a herd, and she may be difficult to replace, depending on the herd's stocking rate and access to replacement cows, and the actual cost may therefore be much higher.

5.3 Intensification

5.3.1 Structural changes in the dairy industry

Many dairy farms have evolved with a focus on maximising efficiency and production, for example, rather than optimising health and welfare and other such aspects (McConnel, 2010). The competitive global market forces farmers to constantly adopt new and more intensive production systems (Nørgaard *et al.*, 1999). Modern technology (e.g. AMSs, robot scrapers, automatic feeding systems and surveillance systems) in the constantly growing herds is being introduced with the aim of reducing labour and feed costs and increasing milk yield. The trust in technology has led to a decreased number of man-hours per cow and year (Mayer & Kammel, 2010; Agger & Alban, 1996) and thus less time for surveillance of individual animals. Also, a tight working schedule due to a decrease in labour means that additional tasks, e.g. moving cows to sick-pens, administering tedious treatments or intensively monitoring an animal, are sometimes difficult to manage, and more rational decisions about euthanasia or treatments will sometimes have to be taken.

The question is if there is a conflict between profitability and good animal welfare and if the welfare of animals has been compromised due to the economic pressure. The studies in this thesis have identified some risk factors that can be seen as associated with the on-going intensification in the dairy industry, e.g. larger herd sizes, increased use of the high-yielding SH breed, occurrence of production diseases and access to exercise pasture only. However, not all results indicate that the high intensification has resulted in increased mortality rates. For instance, the numerically lowest mortality rate, related to different milking systems, was found for AMSs (papers I and III), which shows that it is not the technology per se that results in increased mortality. Also, the results in our studies show that high herd annual milk yields and a high yield for an individual cow at first test-milking were in fact associated with lower mortality. However, a high previous lactation milk yield (paper III) was found to be associated with higher mortality at the individual cow level, which again is an indication of the effects of intensification. It is important to remember that today's high-producing cow (especially SH) is fragile, and any disturbances could lead to detrimental effects.

5.3.2 Other structural changes

The slaughter industry in Sweden has also gone through structural changes that affect dairy farmers. The former possibility of emergency slaughter was probably beneficial from an animal welfare point of view, as farmers most likely contacted the emergency slaughter service at an early stage when they discovered a sick cow that they then decided not to treat. When this possibility was removed, there might be a risk that some farmers "wait and see" if the cow will recover. This means that cows that were previously slaughtered will now be at risk of euthanasia or unassisted death.

Another factor affecting the mortality rate is the services from the abattoirs. The centralisation of the slaughter industry has reduced the number of abattoirs and there is usually a line-up, which means that it takes at least a few days, and up to several weeks, before a cow can be sent to slaughter. This delay might be one part of the reason for the regional differences, with a higher mortality rate observed in Norrland. If farmers were able to send animals the same day as they discover a problem it could result in an increase of more normally slaughtered cows (e.g. finding clots in the milk in an old, low-producing, non-pregnant cow might lead to the decision not to treat if the slaughterhouse delivery truck were to arrive after a few hours, permitting the cow to be slaughtered the same day before developing fever, etc., and risking to be euthanised).

5.4 Repeated risk factors

In Table 3, the characteristics that were identified in three or more of the studies in this thesis are shown. The most consistent risk factor was that cows of the SH breed, or herds with mainly cows of the SH breed, had an increased mortality risk. It should be emphasised that these results are from multivariable analyses, i.e. where the effect of other factors such as milk yield has already been considered, and this increased risk with the SH breed is thus something in addition. A number of other studies have reported that the Holstein breed is associated with greater mortality rates (Hare *et al.*, 2006; Thomsen *et al.*, 2006; Miller *et al.*, 2008; Raboisson *et al.,* 2011). Swedish Holstein cows have shown a higher incidence of common production-related diseases (Nyman *et al.*, 2007; Emanuelson *et al.*, 1993; Bendixen *et al.*, 1988; Bendixen *et al.*, 1987; Bendixen *et al.*, 1986) and a higher culling risk (del P. Schneider *et al.*, 2007) than have the SR. It may be possible that the farm’s choice of breed is influenced by the management system and breed differences could therefore reflect differences in management (Dechow *et al.*, 2011). It may also be that stalls are not adapted to the size of the cows, especially in herds that have switched to new breeds over time.

Short calving intervals were associated with reduced mortality. A high level of management is needed to achieve short calving intervals, and this variable may therefore serve as a proxy for management. This has been indicated by Sandgren *et al.* (2009) and Nyman *et al.* (2011), who reported that short calving intervals are associated with good animal welfare.

Larger herd sizes were a consistent risk factor in several of the studies in this thesis. Earlier studies have also found that mortality increased with increasing herd size (e.g. Smith *et al.*, 2000; Thomsen & Houe, 2006; Dechow & Goodling, 2008). Nørgaard *et al.* (1999) concluded that increased mechanisation and larger herd size contribute to less attention per cow and increased mortality. It may also be that owners of larger herds take more rational decisions, e.g. to euthanise cows, instead of giving them special treatment that could be both time-consuming and difficult. Another explanation for the higher mortality in larger herds may be that weak cows are detected at a later stage when chances of recovery have decreased significantly. Other reasons for higher mortality in larger herds may be that pasture management could be more complicated and that cows do not get the beneficial effects from the pasture e.g. improved claw health.

Organically managed herds had a lower mortality than conventional herds. The lower mortality risk in organic herds may partly be explained by closely regulated animal trading which only allows trading between other organic herds. There are also recommendations relating to quarantine before introducing new animals (KRAV, 2014), which may lower the risk of introducing infectious diseases that increase the risk of on-farm mortality. In addition, organic herds generally have a longer and more regulated pasture season. Accordingly, organically managed cows in Sweden have to get >6kg of the daily DMI from the pasture and spend at least 12.5 hours a day on pasture during the pasture season. There are also restrictions in the proportion of concentrate in the feed ration (KRAV, 2014). Furthermore, managerial differences between organic and conventional herds may explain the differences. Some of them, such as herd size, milk yield, housing system and breed, were accounted for in the multivariable analyses and additional explanations should be investigated further.

Table 3. *Summary of how different characteristics affect mortality rates at the herd and cow level in three of the studies. A protective factor is indicated by an arrow pointing down and a risk factor is indicated by an arrow pointing up. A dashed arrow indicates an irregular association, a hyphen indicates that no association was found and a blank entry indicates that the characteristic was not considered in the analysis.*

	Herd level			Cow level	
	Paper I		Paper II	Paper III	
Characteristic	Multiple	Single	Questionnaire	Primiparous	Multiparous
Swedish Red	↓	↓	↓	↓	↓
Long calving interval	↑	↑			↑
Large herd size	↑	↑	↑	⇡	↑
Organic management		↓	-	↓	↓
Low milk yield[a]	↑	↑		↑	↕
Summer season	↑	⇡		-	↑

[a] Paper I: mean herd annual milk yield per cow; paper III: Individual milk yield at first test milking after calving, and in the multiparous column, the arrow pointing both up and down indicates the different directions on mortality of the milk yield at first test milking and the previous lactation milk yield.

The mortality hazard was higher in low producing herds and for cows with a low milk yield or a missing value at the first test-milking. Rather than implying that a low milk yield is causing mortality, the study results may indicate that the low-producing cows and herds might have problems that prevent them for achieving high milk yields and that are related to high mortality risks. It has also been found that herds with low milk yields will most likely have poor outcomes on many health and production variables (Albright, 1987). Furthermore, a high herd average milk yield might be a proxy for good management, which also would be reflected in a low mortality risk. However, the herd average milk yield was not found to be associated with the level of welfare in dairy herds (Coignard *et al.*, 2014; Nyman *et al.*, 2011; Sandgren *et al.*, 2009). A high milk yield in the previous lactation at the cow level was associated with a higher mortality hazard (the double pointed arrow in Table 3). This is in agreement with Miller *et al.* (2008), who found higher death frequencies in high-yielding cows. A low or missing milk yield at first test-milking is an indication of disturbance due to, e.g. disease, whereas a high lactation milk yield could be an indication of greater physiological stress due to the higher yield and, most likely, a larger proportion of concentrate in the diet (Nørgaard *et al.*, 1999).

The mortality rate was higher during summer season. In paper I, a lower herd-level mortality rate was found in September to December compared to January to April and June to August in smaller herds but no seasonal differences was found in larger herds. In paper III, the season did not differ for primiparous cows, but in multiparous cows, a higher hazard was found in May to August than in the rest of the year. Miller *et al.* (2008) found a higher death frequency in June and the lowest in November. Hertl *et al.* (2011) demonstrated that season had no effect on probability of mortality in primiparous cows, but found that multiparous cows were more likely to die in spring and summer than in fall or winter.

Also, Pinedo *et al.* (2010) showed that annualized death rates were highest in spring and summer (7.8% and 6.9%, respectively) and lowest during autumn (5.5%). No significant seasonal variation was observed by Faye and Perochon (1995), although they found that the beginning of the grazing period seemed to be associated with a higher MR. It can be debated whether the high MR ratio observed during summer is a consequence of the previous indoor period or if it is due to the changed routines or possible heat stress for cows on pasture (Kendall *et al.,* 2006). Burow *et al.* (2011) found that free access between barn and pasture was associated with higher mortality compared to systems where the farmer followed the herd out to the pasture and then brought them home for milking. Burow *et al.* (2011) proposed that less frequent observation of the cows (and the associated non-identification of sick cows) could be part of the explanation. Lesser MR ratio during autumn-winter can be a positive effect of the previous pasture season, as Alban and Agger (1996) found that grazing is associated with better health. Burow *et al.* (2011) and Dechow *et al.* (2011) concluded that the more time cows spend on pasture, the lower the mortality. This is also supported by univariable results in paper II. Pasture has been shown to improve claw health and this might reduce the mortality rates, as the most common reason for euthanasia were due to locomotor disorders (paper IV).

5.5 Modifiable risk factors

In the questionnaire study (paper II), the majority of the farmers stated that their mortality rates depended on if they were lucky or unlucky. This attitude of “it depends on luck” or “stuff happens” is not likely a successful mindset when mortality rates are high (Garry, 2011). Death losses can, to some extent, be managed and reduced, which is clearly demonstrated in this thesis, because a large proportion of the dairy herds are able to have low mortality rates (at least during certain years). Successful management of cow mortality in a herd should obviously focus on the factors that have the strongest association with the risk and ideally are not too expensive or difficult to modify. However, not all risk factors are possible to modify. Which factors are modifiable or not definitely depend on each farm’s particular conditions and possibilities. Figure 7 presents a schematic representation of some of the risk factors identified in this thesis according to their impact on mortality and an estimation of the possibility of modifying them. For example, even if a large herd size was associated with an increased risk for mortality, it is not likely a good idea to advise farmers who have invested in a new milking system and a larger barn to reduce the number of cows. We should, as McConnel (2010) stated, rather work within the present system to improve the outcomes than attempt to reverse the irreversible. Farmers with a large herd can, e.g. educate their employees and develop standard operating procedures to improve their everyday routines (e.g. to examine all cows daily so that early signs do not go unnoticed, or to keep the cows in smaller groups). With such actions, a larger proportion of the cows could leave the herd in a more favourable way (slaughter) than as on-farm dead cows, even though the herd size is large. Another example is parity, which had a large impact on mortality, but is not very practical to modify, because keeping only first-parity cows is likely not only economically unsound, but also unsustainable from an environmental point of view, as the greenhouse gas emissions per kg of milk will be high.

One aspect in Figure 7 that merit specific attention is the stage of lactation. The risk for mortality was higher in early lactation which is also the time where the cow is at highest risk for disease. The early lactation is not modifiable, because all cows have to pass it once in each lactation, but it is imperative that the cow is well prepared for it. Obviously, giving the cow a good start for the lactation is necessary, and the transition period (i.e. from approximately three weeks before parturition to three weeks after) is fundamental in this respect. The transition period is a critical period in the lactation cycle of the dairy cow (Cook & Nordlund, 2004; Grummer *et al.*, 2004). Large physiological changes are taking place as the cow leave pregnancy and initiate lactation. The cow's energy need for milk production is larger than its feed intake capacity, which results in a metabolic imbalance (negative energy balance). The transition cow is also experiencing immunosuppression, and has to cope with changed diets and most likely environmental stress. It is important to reduce the turmoil for the transition cow by preventive actions and prompt detection of disturbances (Mulligan & Doherty, 2008). The extent of the negative energy balance can be altered by appropriate pre-partum feeding and management strategies, e.g. keeping the cows in the right body condition, doing sufficient monitoring, minimising social stress (social ranking), increasing the cow's comfort and making sure that all cows can eat simultaneously (Nordlund, 2013). With proper transition cow management, it is likely that both the risk for mortality associated with the early lactation and the likelihood of diseases can be minimised.

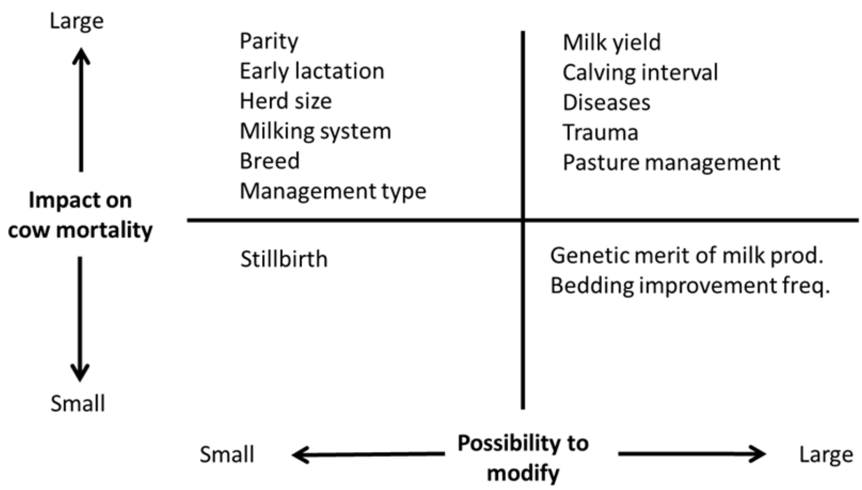

Figure 7. Some of the characteristics in the studies found to be associated with cow mortality, categorised by their impact on mortality and the possibility of modification.

The population attributable fraction (Table 2) is one way to demonstrate where efforts are most efficient in reducing mortality at the population level. Thus, because the risk associated with increasing parity was high and there were reasonably many older cows, parity would be the factor with the largest impact on mortality risks at the population level. Now, parity may not be an easily modifiable risk factor and thus not the first choice for action, and neither is a missing test-milking information in the first part of the lactation stage (indicating a sick cow). However, management type and breed are modifiable, because farmers could convert to organic and select cows of the SR breed, and a change would have significant impact on the mortality risk in the population. For the individual cow, however, other factors may be more important. Thus, experiencing a traumatic event will increase the mortality risk at the individual cow level significantly, but there are only few cows that experience traumatic events and trauma is therefore not found in Table 2. Also, at the individual cow level, being milked in a rotary system is inferior because it increased the mortality risk, but rotary systems are still so rare that this factor has only a minor impact at the population level. Thus, it is necessary to acknowledge that different factors are important to address if looking from the population perspective or from the individual cow level perspective. However, it is important to recognise that the PAF values are only valid if the relationships are indeed causal. With observational studies, as in the case of this thesis, there is no guarantee that all associations shown are causal relationships, and the PAFs should therefore be treated with some caution. However, several of the associations identified are consistent across studies and with other research, and some also have showed strong associations, which is consistent with causal associations according to Hill (1965).

5.6 Methodological considerations

Different study populations and designs have been used to address the aims of this thesis. Common to all papers was that the included herds had to be participating in the SOMRS. Additionally, herds with small herd sizes were excluded in all papers (except in paper IV). This exclusion was done to make the studies more valid in the longer term, as we considered that small herds would not be representative of a future Swedish dairy herd. Small herds were also excluded because the mortality rate would become very high even if only one of the cows in the herd dies, which could give high variation between years.

Herd size seems to be a risk factor with a significant impact on cow mortality under Swedish production conditions. Many management factors are closely associated with the size of the herd, and including herd size in a multivariable model may therefore hide other important factors. One way to avoid this situation could be to use stricter inclusion criteria, e.g. using only Swedish Holstein herds with more than 100 cows in a certain milking system. The drawback with this approach is that it is not possible to evaluate all risk factors (in this example, the effects of herd size, breed and milking system), and the external validity would be limited because it would only be possible to extrapolate the results to other herds with these specific characteristics. In these papers, we chose to use a wider approach as we wanted to get results that should be valid for most Swedish dairy herds.

An important aspect is that dairy cow mortality is a multifactorial problem influenced by a large number of factors. Consequently, it was not feasible to include all potential factors in the analyses. Most importantly, the farmer's attitude and management highly influence the mortality rates.

5.6.1 Bias

Bias indicates when the measure of association between exposure and outcome is systematically wrong (Dohoo, 2014). Several types of bias can occur in observational studies (Sackett, 1979). It is important to be aware of this when drawing inferences from the results. In this section, the potential biases considered in this thesis are discussed.

Selection bias

Selection bias results from systematic differences between characteristics of the study population and the target population. Only herds participating in the SOMRS were included in papers I-III, but because the study population and our target population were the same, this restriction did not introduce any selection bias. In paper II, a questionnaire was sent to selected farmers who had >35 cows per year and either a high or a low mortality rate. This approach introduced a risk of selection bias, as we relied on the willingness of farmers to answer the questionnaire. The response rate was below 35%, and the analysis comparing respondents and non-respondents identified some significant differences in herd-level characteristics that could distort the internal validity. The response rate was also higher for LM herds indicating that LM farmers may have more time and interest in participating in surveys. Still, we consider the study population to be reasonably similar to the target also in this study, so that inferences are valid.

In the telephone interviews (paper IV), there were only a few farmers whom we could not reach or who did not want to participate, so this is not regarded as a potential problem in that study.

Information bias

Information bias (also called misclassification bias) is a type of measurement bias. In this thesis, all four studies included secondary data, which introduced a risk of information bias, as the data could be incomplete or inaccurate. All information in the cattle database has not been validated, so it is not possible to know the magnitude of the potential bias. However, Mörk *et al.* (2009) found under-reporting in the national disease recording system. In Denmark and the USA, farmers' perceptions of the reason for death have been evaluated against the results from necropsy examinations (McConnel *et al.,* 2009; Thomsen *et al.,* 2012). These studies found that a farmer's perception of the reason for death can be seriously flawed. This misperception is most likely also the case for Swedish farmers, which was indicated in the telephone interviews in paper IV, where the reason for unassisted death was unknown in 48% of the cases.

In paper IV, cadavers were examined at the destruction plants and a telephone interview was carried out after the visit. This telephone interview had the purpose of verifying the type of death to reduce misclassification bias, as we knew that the examination at the destruction plants could not differentiate between unassisted death and euthanasia by an overdose of an anaesthetic. The interviews were performed immediately after the visits, to reduce recall bias. Even though only a low number of cows were euthanised with an overdose of an anaesthetic, there was a misclassification of cows as euthanised or not at the destruction plant. We did, however, control for this in the analysis by only including cows where the information from the destruction plant agreed with the information from the farmer.

It is challenging to design a questionnaire. To reduce the risk of using questions that were confusing or could be misunderstood, the questionnaire used in paper II was first pre-pilot-tested on colleagues in the academy and then pilot-tested on 10 dairy farmers. Only after this procedure was the questionnaire sent to the study population. The responses to some questions were nevertheless not possible to include in the analyses owing to a large proportion of missing answers or obvious misunderstandings. Another problem with the questionnaire (and questionnaires in general) was the risk of the respondents answering as they know they should act or as they want to act (instead of how they really act), so the answers may not have fully reflected the true routines on the farm. This could for instance have been the case in the last section of the questionnaire covering recognition and actions when detecting sick or lame cows. These variables were expected to differ between high and low mortality herds, but we did not find any significant differences. It is possible that another type of questionnaire (e.g. based on theory of planned behaviour) could have worked better in this area. Although the drawback with that type of questionnaire is that many questions are needed and we wanted answers to a broader array of questions.

Another important aspect is that the questionnaire was sent to herds that had had either high or low mortality rates for three consecutive years. The inclusion criteria were used to obtain a firmer classification and to reduce random fluctuations in mortality rates. Even though this was done, there is no guarantee that the herds belonged to the intended group in the year the farmers answered the questionnaire. It is also difficult in some cases to differentiate between cause and effect. For example, if some farmers with high mortality herds had taken action and were trying to reduce their high MR, they might have applied new routines that we then would have incorrectly identified as harmful.

6 Conclusions

The hypothesis in this thesis has been answered: there are systematic differences in mortality between herds and individual cows in Sweden. The Swedish mortality rates are high from an international perspective. The good news, however, is that while the average mortality rate is high, there are large differences between herds and many herds are able to obtain low mortality rates. Also, the proportion of euthanasia among cows dying on farm is higher than what has been reported from other countries.

Unfortunately, there is no single simple answer to the problem of high mortality levels in dairy herds. This is a multifactorial problem that is highly affected by, e.g. farmers' attitudes and management practices. However, a few factors that were repeatedly found to be associated with an increased risk for mortality in these studies were the Holstein breed, long calving intervals, a large herd size, a conventional production system (compared with organic), a low milk yield and the summer season.

7 Recommendations

- A national target for on-farm cow mortality is recommended. It would be more motivating for Swedish dairy farmers, herd advisors and the industry to have a specified mortality level to work towards. Farmers need to be aware of the herd's mortality rate and keep proper records on each cow, to be able to prevent future deaths. Awareness of the high mortality rates may per se help to reduce the problem.

- It is of great importance to be able to distinguish between the two types of deaths in dairy recording systems. The cattle database introduced separate reporting codes in 2012, which means that it is now possible to differentiate between unassisted death and euthanasia. However, there is a need to apply the separated codes in the CDB as well.

- In one quarter of the dead cows, farmers could not with certainty state the primary cause of death. The reason could be that signs of illness or other problems go unnoticed or that the cause could not be distinguished due to a combination of several different diseases preceding death. One way to increase the knowledge of what actually causes unassisted death and euthanasia could be to perform more necropsy examinations.

- Most of the cows dying on farm are euthanised (70%), and claw and leg disorders were the most common primary reason for euthanasia. This reinforces the need for preventive action and prompt and effective treatment to improve claw health. This is also valid in other diseases and traumas, as these events increase the mortality risk.

- In addition, as most deaths occur in connection to calving or in early lactation, good management in the transition period is of paramount importance. This would include giving the cows extra care and surveillance in a non-competitive environment - i.e access to the elements they need should be facilitated (feed, water, comfortable lying place, milking).

- Another recommendation is to keep the pasture legislation and work with subsidies and knowledge support, so that a larger proportion of cows could have access to production pastures and not only exercise pastures.

8 Future Research

There is a need for future studies in this area, as on-farm mortality is a complex problem. Here are some examples of future research topics that are advocated:

- We have understood that mortality rates are highly influenced by farmers' attitudes and decision-making. A qualitative approach is needed to increase the understanding of farmers' behaviours. Luckily, we have already started a project to explore this area by using focus group discussions with dairy farmers. This project will hopefully increase the knowledge of motivators and barriers from the farmer's point of view and help to find an appropriate strategy to reduce the problem.

- It would be interesting to use the divided codes for unassisted death and euthanasia (which are currently reported to the cattle database) to evaluate differences in the relative proportions of the two types of death over a number of years. In addition, it would be valuable to use a larger population to identify the potential risk factors for unassisted death (as opposed to euthanasia). A further idea is to study animal welfare in the two types of deaths, to evaluate if the welfare state in general is less compromised in any of the death types.

- In this thesis, we relied on the farmers stated reason for death. To fully understand why dairy cows die on farm, post-mortem examinations are needed as a complement to the information in the cattle database. Currently, post-mortem examinations are only performed on a small proportion of dairy cows. To carry out a necropsy study and compare the causes of death with the results from other countries would be valuable, and the skills of Swedish farmers in determining the cause of death could also be evaluated.

- So far, we have evaluated many risk factors at both the herd and the cow level, but the effects of calf and heifer rearing on cow mortality have not yet been considered.

- It is important to further evaluate risk factors at the cow level, as the associations might be different in different parities.

- Claw and leg disorders were found to be the most common reason for euthanasia. Lameness is a major concern in the dairy industry, and the challenges are increasing as more cows are kept in free-stalls. Extensive information from research is available, but is not applied out on the farms. There is also a need to enhance the utilisation of claw health records and evaluate if they can be used to direct advisory services and in turn reduce the prevalence of claw and leg disorders.

- The results demonstrated differences in mortality between breeds. It is therefore urgent to investigate if some cows are genetically predisposed to end up dying on farm and also to estimate the heritability.

- Another suggestion is to conduct a life cycle analysis to evaluate the complete impact of on-farm cow mortality on the environment.

- Finally, of value would be to identify differences in management practices between large SH herds with either high or low mortality rates.

9 Populärvetenskaplig sammanfattning

9.1 Bakgrund

Svensk mjölkproduktion har genomgått stora förändringar under de senaste årtiondena och är fortfarande i förändring. Bland annat blir antalet besättningar färre, samtidigt som besättningsstorleken ökar, korna har en högre mjölkavkastning, fler kor hålls i lösdriftsystem och det blir allt vanligare med kor av Holsteinras. Dessutom har ny teknologi introducerats vilket har medfört att arbetstiden per ko har minskat.

En genomsnittlig ko slås i dagsläget ut redan vid 61 månaders ålder. Detta innebär att många svenska mjölkkor inte hinner bli lönsamma. De flesta korna skickas till slakt, men en del självdör eller avlivas på gården. En hög andel självdöda och avlivade kor är en indikation på bristande djurvälfärd eftersom de flesta kor som självdör eller måste avlivas ofta har haft något slags problem som orsakat lidande hos djuret. Hög dödlighet leder även till stora ekonomiska förluster för lantbrukarna och är negativt ur en miljömässig aspekt eftersom mindre nötkött levereras. Dessutom blir det kostnader och utsläpp från kadaverhantering och destruktion. Fram till mitten av nittiotalet låg kodödligheten på en nivå under tre procent, men under förra decenniet började vetenskapliga rapporter tyda på att nivåerna kunde vara högre.

Avhandlingens syfte var att undersöka hur den svenska kodödligheten (dvs. självdöda och avlivade kor) förändrats över tid, samt att identifiera riskfaktorer för dödlighet på både besättnings- och konivå i mjölkbesättningar.

9.2 Sammanfattning av studier och resultat

För att undersöka dödligheten i svenska mjölkbesättningar gjordes fyra olika studier. I samtliga studier har datamaterial från kodatabasen använts. Åttio procent av alla Sveriges mjölkbesättningar är anslutna till kokontrollen och har därmed uppgifter i kodatabasen.

I den första studien analyserades datamaterial från åren 2002 till 2010. Här ingick uppgifter från 6898 besättningar som hade över 20 kor. Dessutom gjordes en separat analys för året 2010 eftersom ytterligare besättningsuppgifter fanns tillgängliga för det året. Den senare analysen inkluderade 4252 besättningar. Resultaten visade att dödligheten ökat från 5,1 till 6,6 dödsfall per 100 kor och år mellan 2002 och 2010. På besättningsnivå var dödligheten högre i besättningar med Holsteinras, längre kalvningsintervall och låg mjölkavkastning. Dödligheten var även högre i Norrland jämfört med i Södra Götaland, samt i konventionella besättningar jämfört med ekologiska. I de båda analyserna hittades ett samspel mellan besättningsstorlek och säsong. Generellt ökade dödligheten med ökande besättningsstorlek och var högre under sommaren. Generellt sett minskade dödligheten med ökad avkastningsnivå. I den lägsta avkastningsnivån (<8400 kg ECM) var dödligheten högst för lösdrifter med grop eller karusell. Den lägsta dödligheten hade besättningar med högst avkastningsnivå (>9995 kg ECM) och lösdrift med automatiskt mjölkningssystem.

I den andra studien som genomfördes under hösten 2012, skickades en enkät till 250 besättningar som haft en hög dödlighet och till 194 besättningar som haft en låg dödlighet under de tre senaste åren. Syftet var att fånga upp riskfaktorer om inhysnings- och skötselfaktorer och besvarades av nästan 35% av lantbrukarna. Även här framkom att större besättningsstorlekar och besättningar med rasen Holstein var förknippade med hög dödlighet. Det visade sig också att besättningar som använde rastbete istället för produktionsbete i större utsträckning var besättningar med hög dödlighet. Enkäten visade också att lantbrukare från besättningar med hög dödlighet i större utsträckning avstod från att ange hur ofta de ströade hos korna, i övrigt identifierades inga signifikanta skillnader i ströfrekvens. En tendens till att högdödlighetsbesättningar i större utsträckning använde egen tjur istället för artificiell inseminering kunde också påvisas.

I studie tre undersöktes riskfaktorer för den enskilda kon genom att analysera data från kontrollanslutna kor som kalvat mellan 1 juli 2008 och 30 juni 2009. Dessa kor följdes från kalvning till att de antingen kalvade igen, skickades till slakt eller självdog/avlivades. Resultaten visade att dödligheten ökade med ökat laktationsnummer, var högre i tidig laktation, var högre om kon drabbas av trauma eller sjukdom. Dödligheten var även högre om kon befann sig i en stor besättning eller om hon var av Holsteinras.

Slutligen utfördes en fältstudie för att ta reda på fördelningen av självdöda kor bland de som självdör eller avlivas på gården. Eftersom självdöda och avlivade kor rapporterades till kodatabasen med samma kod var det inte möjligt att avgöra med stöd av data därifrån. Därför besöktes de två stora destruktionsanläggningarna, Mosserud och Krutmöllan, dit de flesta djurkadaver skickas vid tre tillfällen. Besöken gjordes tre dagar i följd under vår, höst och sommar på vardera anläggningen 2011 och 2012. Alla mjölkkor undersöktes och det registrerades om kon hade ett skotthål i pannan eller inte. Efter varje besök på destruktionsanläggningen intervjuades aktuell lantbrukare över telefon. Informationen användes för att verifiera om kon avlivats eller självdött, men även till att få reda på anledningen till att kon dött, samt vilken avlivningsmetod som använts (i de fall avlivning skett). Totalt undersöktes 556 mjölkkor. Av dessa kunde 123 kor inte användas i analyserna av anledningar så som att: de inte ingick i kokontrollen, att lantbrukaren inte gick att nå eller inte ville svara på frågorna, eller på grund av att lantbrukarens uppgifter om självdöd eller avlivad inte överenstämde med vår. Av de 433 kor som därmed ingick i studien hade 30 % självdött och 70 % avlivats. Den anledning till att kon dött som lantbrukaren angav skiljde sig mellan de som självdött och de som avlivats. Den vanligaste orsaken till avlivning var klöv- och benproblem, och den näst vanligaste orsaken var olycksfall. Majoriteten av de avlivade korna hade bedövats med bultpistol och därefter avblodats av djurägaren eller av en anställd på gården. Bland de självdöda korna var dödsorsaken okänd i nära hälften av fallen. Av de kända orsakerna till att korna självdött var den vanligaste angivna orsaken juverrelaterade problem och därefter foderrelaterade problem. Resultaten visade även att självdöda kor i större utsträckning skickats från besättningar som hade en hög årlig spädkalvsdödlighet.

9.3 Slutsatser

Kodödligheten i svenska mjölkbesättningar har ökat under den studerade tidsperioden. Största andelen av korna som dör på gården blir avlivade (70 %). Kodödligheten påverkas av många olika faktorer och skiljer sig mycket mellan olika besättningar. Det kan inte fastställas att den ökade dödligheten har något samband med den intensifiering som skett inom mjölkindustrin, även om vissa fynd tyder på detta. Resultaten visar till exempel att dödligheten är associerad med större besättningar, Holsteinras och rastbete. För en fjärdedel av korna som självdör eller avlivas kan lantbrukaren inte uppge någon dödsorsak. Dödligheten var högre i samband med kalvning och i tidig laktation vilket belyser att det är viktigt att ta extra bra hand om korna under veckorna innan och efter kalvning för att förhindra kalvningsrelaterade problem och metaboliska sjukdomar. Det är även viktigt att förbättra klövhälsan eftersom klöv- och benproblem var den vanligaste orsaken till avlivning. En mycket viktig aspekt som inte studerats i så stor omfattning är lantbrukarens inställning och förhållningssätt. Genom att fatta rätt beslut vid rätt tidpunkt och genom att upptäcka och behandla sjuka och skadade kor i ett tidigt skede kan det undvikas att korna självdör eller måste avlivas. Detta skulle kunna leda till en bättre djurvälfärd och troligtvis även en ökad ekonomisk lönsamhet för lantbrukaren.

References

Anonymous (2000). Regulation (EC) No 1760/2000 of the European Parliament and of the council of 17 July 2000, establishing a system for the intensification and registration of bovine animals and regarding the labelling of beef and beef products.

Anonymous (2001). Regulation (EC) No 1760/2000 of the European Parliament and of the council of 22 May 2001, laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies.

Anonymous (2004). Regulation (EC) No 854/2004 of the European Parliament and of the council of 29 April 2004, laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption..

Agger, J.F. & Alban, L. (1996). Welfare in Danish dairy herds 3. Health management and general routines in 1983 and 1994. *Acta Veterinaria Scandinavica,* 37(1), pp. 79-97.

Albright, J.L. (1987). Dairy Animal Welfare: Current and needed research. *Journal of Dairy Science,* 70(12), pp. 2711-2731.

Alvåsen, K., Thomsen, P.T., Sandgren, C.H., Jansson Mörk, M. & Emanuelson, U. (2014). Risk factors for unassisted on-farm death in Swedish dairy cows. *Animal Welfare,* 23(1), pp. 63-70.

Barfoot, L.W., Cote, J.F., Stone, J.B. & Wright, P.A. (1971). Economic appraisal of a reventative medicine program for dairy herd health management. *Canadian Veterinary Journal,* 12(1), pp. 2-10.

Batra, T.R., Burnside, E.B. & Freeman, M.G. (1971). Canadian dairy cow disposals 2. Effect of herd size and production level on dairy cow disposal patterns. *Canadian Journal of Animal Science,* 51(1), pp. 85-87.

BCVA (2010). British Cattle Veterinary Association, Guidance for veterinary surgeons on the emergency slaughter of cattle, BCVA Office, Gloucestershire.

Bendixen, P.H., Vilson, B., Ekesbo, I. & Åstrand, D.B. (1986). Disease frequencies in Swedish dairy cows. I. Dystocia. *Preventive Veterinary Medicine,* 4(4), pp. 307-316.

Bendixen, P.H., Vilson, B., Ekesbo, I. & Åstrand, D.B. (1987). Disease frequencies in dairy cows in Sweden. II. Retained placenta. *Preventive Veterinary Medicine,* 4(5-6), pp. 377-387.

Bendixen, P.H., Vilson, B., Ekesbo, I. & Åstrand, D.B. (1988). Disease frequencies in dairy cows in Sweden. V. mastisis. *Preventive Veterinary Medicine,* 5(4), pp. 263-274.

Burow, E., Thomsen, P.T., Sørensen, J.T. & Rousing, T. (2011). The effect of grazing on cow mortality in Danish dairy herds. *Preventive Veterinary Medicine,* 100(3-4), pp. 237-241.

Coignard, M., Guatteo, R., Veissier, I., Lehébel, A., Hoogveld, C., Mounier, L. & Bareille, N. (2014). Does milk yield reflect the level of welfare in dairy herds? *The Veterinary Journal,* 199(1), pp. 184-187.

Cook, N.B. & Nordlund, K.V. (2004). Managing the transition cow to optimize health and productivity. *Veterinary Clinics of North America: Food Animal Practice,* 20(3), pp. xi-xii.

de Vries, M., Bokkers, E.A.M., Dijkstra, T., van Schaik, G. & de Boer, I.J.M. (2011). Invited review: Associations between variables of routine herd data and dairy cattle welfare indicators. *Journal of Dairy Science,* 94(7), pp. 3213-3228.

Dechow, C.D. & Goodling, R.C. (2008). Mortality, culling by sixty days in milk, and production profiles in high- and low-survival Pennsylvania herds. *Journal of Dairy Science,* 91(12), pp. 4630-4639.

Dechow, C.D., Smith, E.A. & Goodling, R.C. (2011). The effect of management system on mortality and other welfare indicators in Pennsylvania dairy herds. *Animal Welfare,* 20(2), pp. 145-158.

del P. Schneider, M., Strandberg, E., Emanuelson, U., Grandinson, K. & Roth, A. (2007). The effect of veterinary-treated clinical mastitis and pregnancy status on culling in Swedish dairy cows. *Preventive Veterinary Medicine,* 80(2-3), pp. 179-192.

Dematawewa, C.M.B. & Berger, P.J. (1998). Genetic and phenotypic parameters for 305-day yield, fertility, and survival in Holsteins. *Journal of Dairy Science,* 81(10), pp. 2700-2709.

Dohoo, I., Martin, W. & Stryhn, H. (2009). *Veterinary Epidemiologic Research*. 2nd. ed. VER Inc. Charlottetown, Prince Edward Island, Canada.

Dohoo, I.R. (2014). Bias—Is it a problem, and what should we do? *Preventive Veterinary Medicine,* 113(3), pp. 331-337.

Emanuelson, U. (1988). The national swedish animal-disease recording-system. *Acta Veterinaria Scandinavica*, pp. 262-264.

Emanuelson, U. & Egenvall, A. (2014). The data – Sources and validation. *Preventive Veterinary Medicine,* 113(3), pp. 298-303.

Emanuelson, U., Oltenacu, P.A. & Gröhn, Y.T. (1993). Nonlinear mixed model analyses of five production disorders of dairy cattle. *Journal of Dairy Science,* 76(9), pp. 2765-2772.

Esslemont, R.J. & Kossaibati, M.A. (1997). Culling in 50 dairy herds in England. *Veterinary Record,* 140(2), pp. 36-39.

Faye, B. & Perochon, L. (1995). Mortality of dairy-cows in an ecopathological survey in Brittany. *Veterinary Research,* 26(2), pp. 124-131.

Fetrow, J., Nordlund, K.V. & Norman, H.D. (2006). Invited review: culling: nomenclature, definitions, and recommendations. *Journal of Dairy Science,* 89(6), pp. 1896-1905.

Gardner, I.A., Hird, D.W., Utterback, W.W., Danayeelmi, C., Heron, B.R., Christiansen, K.H. & Sischo, W.M. (1990). Mortality, morbidity, case-fatality, and culling rates for california dairy-cattle as evaluated by the national animal health monitoring-system, 1986-87. *Preventive Veterinary Medicine,* 8(2-3), pp. 157-170.

Garry, F. (2011). Rethink your dairy cow mortality rates and their cost. *Progressive dairyman* (Dairy basics - herd health).

Garry, F. & McConnel, C. (2013). Why cows die on dairy farms. *Proceedings of the 22nd Tri-State Dairy Nutrition Conference,* Fort Wayne, Indiana, USA, 23-24 April 2013, pp. 1-7.

Grandin, T. (2010). Slaughter plants: behavior and welfare assessment. In: Breed, M.D. & Moore, J. (eds) *Encyclopedia of Animal Behavior*. Oxford: Academic Press, pp. 197-202. Available from: http://www.sciencedirect.com/science/article/pii/B9780080453378000838

Granström, K. (2009) Hantering vid avlivning av nötkreatur, *Jordbruksinformation 4.* Jordbruksverket.

Grummer, R.R., Mashek, D.G. & Hayirli, A. (2004). Dry matter intake and energy balance in the transition period. *Veterinary Clinics of North America: Food Animal Practice,* 20(3), pp. 447-470.

Hare, E., Norman, H.D. & Wright, J.R. (2006). Survival rates and productive herd life of dairy cattle in the United States. *Journal of Dairy Science,* 89(9), pp. 3713-3720.

Harris, B.L. (1989). New Zealand dairy-cow removal reasons and survival rate. *New Zealand Journal of Agricultural Research,* 32(3), pp. 355-358.

Hertl, J.A., Schukken, Y.H., Bar, D., Bennett, G.J., González, R.N., Rauch, B.J., Welcome, F.L., Tauer, L.W. & Gröhn, Y.T. (2011). The effect of recurrent episodes of clinical mastitis caused by gram-positive and gram-negative bacteria and other organisms on mortality and culling in Holstein dairy cows. *Journal of Dairy Science,* 94(10), pp. 4863-4877.

Hill, A.B. (1965). The environment and disease: association or causation? *Proccedings of the Royal Society of Medicine,* 58, pp. 295-300.

Karuppanan, P., Thurmond, M.C. & Gardner, I.A. (1997). Survivorship approaches to measuring and comparing cull rates for dairies. *Preventive Veterinary Medicine,* 30(2), pp. 171-179.

Kelly, P.C., More, S.J., Blake, M. & Hanlon, A.J. (2011). Identification of key performance indicators for on-farm animal welfare incidents: possible tools for early warning and prevention. *Irish Veterinary Journal,* 64.

Kelly, P.C., More, S.J., Blake, M., Higgins, I., Clegg, T. & Hanlon, A. (2013). Validation of key indicators in cattle farms at high risk of animal welfare problems: a qualitative case-control study. *Veterinary Record,* 172(12).

Kendall, P.E., Nielsen, P.P., Webster, J.R., Verkerk, G.A., Littlejohn, R.P. & Matthews, L.R. (2006). The effects of providing shade to lactating dairy cows in a temperate climate. *Livestock Science,* 103(1-2), pp. 148-157.

KRAV (2014). http://www.krav.se, accessed 2014-02-02.

Laaksonen, M.A., Knekt, P., Harkanen, T., Virtala, E. & Oja, H. (2010). Estimation of the Population Attributable Fraction for Mortality in a Cohort Study Using a Piecewise Constant Hazards Model. *American Journal of Epidemiology,* 171(7), pp. 837-847.

Löf, E., Emanuelson, U. & Gustafsson, H. (2007). Data management affects reproductive performance indicators in Swedish dairy herds. *Acta Agriculturae Scandinavica Section a-Animal Science,* 57(2), pp. 73-80.

Mayer, M.W. & Kammel, D.W. (2010). Dairy modernization works for family farms. *Journal of Extension,* 48(5), pp. 5-7.

McConnel, C.S. (2010). Dairy cow mortality. *Colorado State University,* Fort Collins.

McConnel, C.S., Garry, F.B., Hill, A.E., Lombard, J.E. & Gould, D.H. (2010). Conceptual modeling of postmortem evaluation findings to describe dairy cow deaths. *Journal of Dairy Science,* 93(1), pp. 373-386.

McConnel, C.S., Garry, F.B., Lombard, J.E., Kidd, J.A., Hill, A.E. & Gould, D.H. (2009). A necropsy-based descriptive study of dairy cow deaths on a Colorado dairy. *Journal of Dairy Science,* 92(5), pp. 1954-1962.

Menzies, F.D., Bryson, D.G., McCallion, T. & Matthews, D.I. (1995). A study of mortality among suckler and dairy cows in Northern Ireland in 1992. *Veterinary Record,* 137(24), pp. 531-536.

Milian-Suazo, F., Erb, H.N. & Smith, R.D. (1988). Descriptive epidemiology of culling in dairy cows from 34 herds in New York State. *Preventive Veterinary Medicine,* 6(4), pp. 243-251.

Milian-Suazo, F., Erb, H.N. & Smith, R.D. (1989). Risk factors for reason-specific culling of dairy cows. *Preventive Veterinary Medicine,* 7(1), pp. 19-29.

Miller, R.H., Kuhn, M.T., Norman, H.D. & Wright, J.R. (2008). Death losses for lactating cows in herds enrolled in dairy herd improvement test plans. *Journal of Dairy Science,* 91(9), pp. 3710-3715.

Mulligan, F.J. & Doherty, M.L. (2008). Production diseases of the transition cow. *The Veterinary Journal,* 176(1), pp. 3-9.

Mörk, M., Lindberg, A., Alenius, S., Vågsholm, I. & Egenvall, A. (2009). Comparison between dairy cow disease incidence in data registered by farmers and in data from a disease-recording system based on veterinary reporting. *Preventive Veterinary Medicine,* 88(4), pp. 298-307.

Mörk, M.J., Wolff, C., Lindberg, A., Vågsholm, I. & Egenvall, A. (2010). Validation of a national disease recording system for dairy cattle against veterinary practice records. *Preventive Veterinary Medicine,* 93(2–3), pp. 183-192.

Nordlund, K. (2013). Transition cow needs space and comfort. *Proceedings of the cow longevity conference*, Tumba, Sweden, pp. 166-177.

Nyman, A.K., Ekman, T., Emanuelson, U., Gustafsson, A.H., Holtenius, K., Waller, K.P. & Sandgren, C.H. (2007). Risk factors associated with the incidence of veterinary-treated clinical mastitis in Swedish dairy herds with a high milk yield and a low prevalence of subclinical mastitis. *Preventive Veterinary Medicine,* 78(2), pp. 142-160.

Nyman, A.K., Lindberg, A. & Sandgren, C.H. (2011). Can pre-collected register data be used to identify dairy herds with good cattle welfare? *Acta Veterinaria Scandinavica,* 53(Suppl. 1), p. S8.

Nørgaard, N.H., Lind, K.M. & Agger, J.F. (1999). Cointegration analysis used in a study of dairy-cow mortality. *Preventive Veterinary Medicine,* 42(2), pp. 99-119.

Olsson, S.-O., Baekbo, P., Hansson, S., Rautala, H. & Osteras, O. (2001). Disease recording systems and herd health schemes for production diseases. *Acta Veterinaria Scandinavica,* 42(Suppl 1), pp. S51 - S60.

Pinedo, P.J., De Vries, A. & Webb, D.W. (2010). Dynamics of culling risk with disposal codes reported by Dairy Herd Improvement dairy herds. *Journal of Dairy Science,* 93(5), pp. 2250-2261.

Raboisson, D., Cahuzac, E., Sans, P. & Allaire, G. (2011). Herd-level and contextual factors influencing dairy cow mortality in France in 2005 and 2006. *Journal of Dairy Science,* 94(4), pp. 1790-1803.

Sackett, D.L. (1979). Bias in analytic research. *Journal of Chronic Diseases,* 32(1–2), pp. 51-63.

Sandgren, C.H., Lindberg, A. & Keeling, L.J. (2009). Using a national dairy database to identify herds with poor welfare. *Animal Welfare,* 18(4), pp. 523-532.

SJVFS (2008). Statens jordbruksverks författningssamling. Föreskrifter om ändring i Statens jordbruksverks föreskrifter och allmänna råd (SJVFS 2007:77) om slakt och annan avlivning av djur. SJVFS 2008:69, saknr: L22.

SJVFS (2010a). Statens jordbruksverks författningssamling. Föreskrifter om ändring i Statens jordbruksverks föreskrifter och allmänna råd (SJVFS 2006:84) om befattning med animaliska biprodukter, och införsel av andra produkter, utom livsmedel, som kan sprida smittsamma sjukdomar till djur och människor. SJVFS 2010:59.

SJVFS (2010b). Statens jordbruksverks författningssamling. Statens jordbruksverks föreskrifter och allmänna råd om djurhållning inom lantbruket m.m. Saknr L100.

SJVFS (2013). Statens jordbruksverks författningssamling. Statens jordbruksverks föreskrifter om operativa ingrepp samt skyldigheter för djurhållare och för personal inom djurens hälso- och sjukvård. Saknr D8 och L41.

Smith, J.W., Ely, L.O. & Chapa, A.M. (2000). Effect of region, herd size, and milk production on reasons cows leave the herd. *Journal of Dairy Science,* 83(12), pp. 2980-2987.

Stevenson, M.A. & Lean, I.J. (1998). Descriptive epidemiological study on culling and deaths in eight dairy herds. *Australian Veterinary Journal,* 76(7), pp. 482-488.

Svensk Lantbrukstjänst (2014). Svensk Lantbrukstjänst AB, http://www.svensklantbrukstjanst.se/prislista/index.html, accessed 2014-02-02.

Swedish Board of Agriculture (2014). http://www.jordbruksverket.se/amnesomraden/djur/djurhalsopersonal/djursjukdata/rapportering.4.67e843d911ff9f551db80001823.html, accessed 2014-01-15.

Takashima, N., Miura, K., Hozawa, A., Kadota, A., Okamura, T., Nakamura, Y., Hayakawa, T., Okuda, N., Fujiyoshi, A., Nagasawa, S.-y., Kadowaki, T., Murakami, Y., Kita, Y., Okayama, A., Ueshima, H. & Grp, N.D.R. (2010). Population attributable fraction of smoking and metabolic syndrome on cardiovascular disease mortality in japan: a 15-year follow up of NIPPON DATA90. *Bmc Public Health,* 10.

Thomsen, P.T., Dahl-Pedersen, K. & Jensen, H.E. (2012). Necropsy as a means to gain additional information about causes of dairy cow deaths. *Journal of Dairy Science,* 95(10), pp. 5798-5803.

Thomsen, P.T. & Houe, H. (2006). Dairy cow mortality. A review. *Veterinary Quarterly,* 28(4), pp. 122-129.

Thomsen, P.T., Kjeldsen, A.M., Sørensen, J.T., Houe, H. & Ersboll, A.K. (2006). Herd-level risk factors for the mortality in Danish dairy herds. *Veterinary Record,* 158(18), pp. 622-626.

Thomsen, P.T., Kjeldsen, A.M., Sørensen, J.T. & Houe, H. (2004). Mortality (including euthanasia) among Danish dairy cows (1990-2001). *Preventive Veterinary Medicine,* 62(1), pp. 19-33.

Thomsen, P.T. & Sørensen, J.T. (2008). Euthanasia of Danish dairy cows evaluated in two questionnaire surveys. *Acta Veterinaria Scandinavica,* 50(33), p. 33.

Thomsen, P.T. & Sørensen, J.T. (2009). Factors affecting the risk of euthanasia for cows in Danish dairy herds. *Veterinary Record,* 165(2), pp. 43-45.

Thrusfield, M. (1999). *Veterinary Epidemiology*. 2nd. ed. Blackwell Science Ltd, Oxford, United Kingdom.

Toft, N., Houe, H. & Nielsen, S. S. (2004). Sample size and sampling methods. In: Houe, H., Ersbøll, A. K. & Toft, N. (eds.), Introduction to veterinary epidemiology. Biofolia, Frederiksberg, Denmark.

USDA (2007). Dairy 2007, Part II: Changes in the U.S. dairy cattle industry, 1991-2007. US Department of Agriculture. Fort Collins, USA.

Växa Sverige (2013). Cattle statistics 2013.

Winblad von Walter, L., Engelbrekts, E., Jansson Mörk, M., Carlsson J. & Oskarsson, M. (2012) Economy function in the Swedish tool ”animal welfare signals”. *Proceedings of the the first dairy cattle welfare symposium*, Guelph, Ontario, Canada.

Yeates, J. (2010). Death is a Welfare Issue. *Journal of Agricultural and Environmental Ethics,* 23(3), pp. 229-241.

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