Economic Impact of Mastitis in Dairy Cows

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Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2009

Acta Universitatis agriculturae Sueciae
2009:29

Cover illustration by Anny Toftkær Nielsen

ISSN 1652-6880
ISBN 978-91-86195-76-2

Print: SLU Service/Repro, Uppsala 2009

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Abstract

This thesis aims to assess the economic loss associated with clinical (CM) and subclinical (SCM) mastitis under current Swedish farming conditions.

Stochastic simulation was used to investigate the impact of mastitis on technical and economic results of a 150-cow dairy herd. The yearly avoidable cost of mastitis, assuming that the initial incidence (32 and 33 cases of CM and SCM per 100 cow-years, respectively) could be reduced by 50%, was estimated at €8 095. This figure corresponded to 5% of the economic net return for the herd given the initial incidence of mastitis. Expressed as an average per cow/year, the avoidable cost of mastitis was estimated at €54.

The economic loss associated with mastitis could not be reduced by discarding milk with high somatic cell count, because this resulted in a substantial decrease of the volume of sold milk which was not offset by the increase in milk price.

Cases of CM and SCM were on average associated with an average economic loss of €275 and €60, respectively. Reduced milk production constituted the major cost component of the economic loss caused by mastitis.

The magnitude of yield loss associated with mastitis occurring in different stages of lactation was assessed using mixed linear models. The dataset was collected in a research herd between 1987 and 2004, and consisted of weekly test-day records sampled in 1200 lactations. The most extensive yield loss was estimated when CM developed in early lactation and when SCM (modelled by means of increased somatic cell count) occurred in late lactation. The 305-day yield loss associated with CM varied between 0 and 705 kg milk in primiparous cows and between 0 and 902 kg milk in multiparous cows, depending on lactation week at onset. Most cases of CM developed in the first week of lactation and resulted in a yield loss of 578 and 782 kg milk in primiparous and multiparous cows, respectively. Daily yield loss at an SCC of 500 000 cells/ml ranged from 0.7 to 2.0 kg milk in primiparous cows and from 1.1 to 3.7 kg milk in multiparous cows. The yield loss in an *average* 305-day lactation affected by SCM was 150 and 450 kg milk in primiparous and multiparous cows, respectively.

Keywords: dairy cow, mastitis, somatic cell count, yield loss, dairy herd, economic performance, discarding milk

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Till Birgitta
Jag önskar du hade fått vara med

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 Hagnestam, C., Emanuelson, U. and Berglund, B. (2007). Yield Losses Associated with Clinical Mastitis Occurring in Different Weeks of Lactation. *Journal of Dairy Science* 90(5), 2260-2270.

II Hagnestam-Nielsen, C. and Østergaard, S. (2009). Economic Impact of Clinical Mastitis in a Dairy Herd Assessed by Stochastic Simulation using Different Methods to Model Yield Losses. *Animal* 3(2), 315-328.

III Hagnestam-Nielsen, C., Emanuelson, U., Berglund, B. and Strandberg, E. (2009). Relationship Between Somatic Cell Count and Milk Yield in Different Stages of Lactation. *Journal of Dairy Science*, accepted, doi:10.3168/jds.2008-1719.

IV Hagnestam-Nielsen, C., Emanuelson, U., Strandberg, E., Andersson, H., Berglund, B. and Østergaard, S. Economic Consequences of Mastitis and Discarding Milk with High Somatic Cell Count (manuscript).

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Abbreviations

BTSCC	bulk tank somatic cell count
CM	clinical mastitis
SCC	somatic cell count
SCM	subclinical mastitis
SEK	Swedish krona
TD	test day

Introduction

The dairy sector is subjected to increasing international competition. Economically effective herds are thus a prerequisite to maintain a sound Swedish dairy industry. Economic margins of dairy herds are, however, narrow. Optimization of the economic results, therefore, becomes important, and the need for cost minimization at every level of production is accentuated. A means of reducing the costs of production is to decrease the incidence of production disorders, as such are associated with reduced production, veterinary costs, and increased replacement rate, and, consequently, give rise to economically less efficient herds. Mastitis is of considerable interest because of its high incidence and the extensive costs associated with the disease. In 2007, the average incidence of veterinary-treated clinical mastitis (CM) in herds participating in the Swedish milk recording scheme was 16% (Swedish Dairy Association, 2008). The incidence of mastitis can however be expected to be even higher, because there is considerable under-reporting of CM (Mörk *et al.*, 2009). Udder disease, including udder disorders and high somatic cell count (SCC), constitutes the most common reason for culling of Swedish dairy cows (Swedish Dairy Association, 2008). In 2007, 26% of cullings was attributed to udder disease, and 10% of the total cow population was, consequently, culled because of udder disorders and high SCC. Indeed, mastitis is the most costly disease in dairy production (Seegers *et al.*, 2003 (review); Kossaibati & Esslemont, 1997; Degraves & Fetrow, 1993 (review)).

Clearly, mastitis control is of paramount importance. The incidence of mastitis can be reduced by implementation of preventive measures. These are, however, associated with extra costs for the farmer in terms of investments and labour, and interventions will only be made if the resulting increase in revenue can be expected to offset the incurred costs. Information about the economic loss associated with mastitis is, therefore, crucial when evaluating the viability of different preventive measures. The economic loss incurred by mastitis is also an essential part of other management decisions, such as treating infected udder quarters, culling mastitic cows, and discarding milk with high SCC in order to obtain a higher milk price.

The frequency of mastitis in the dairy cow population can also be decreased by breeding for cows with better ability to resist udder disease. Udder health is unfavourably genetically correlated with milk yield (Carlén *et al.*, 2004; Heringstad *et al.*, 2000 (review); Emanuelson *et al.*, 1988), and selecting only for increased production, which traditionally has been the focus of dairy cattle breeding in many countries, will therefore result in deterioration of udder health. This can be counteracted by applying a broad breeding goal, like the one used in the Nordic countries, which includes not only production traits, but functional traits such as mastitis resistance. The genetic progress in a trait is partly determined by the relative weight put on it in the total merit index of bulls. In order to assign proper economic weight to mastitis resistance, accurate estimates of the economic loss caused by mastitis are necessary.

This thesis aims at assessing the economic loss associated with mastitis under current Swedish farming conditions, in order to provide estimates that can support decisions regarding mastitis control in individual herds and facilitate derivation of appropriate economic weight of mastitis resistance in the breeding goal.

Background

What is Mastitis?

Mastitis is defined as an inflammatory reaction of the mammary gland (International Dairy Federation, 1987). It is induced when pathogenic microorganisms enter the udder through the teat canal, overcome the cow's defence mechanisms, begin to multiply in the udder, and produce toxins that are harmful to the mammary gland. Mammary tissue is then damaged, which causes increased vascular permeability. As a result of this, milk composition is altered: there is leakage of blood constituents, serum proteins, enzymes, and salts into the milk; decreased synthesis of caseins and lactose; and decreased fat quality (Østerås, 2000; Harmon, 1994). The extent of these changes is determined by the severity of the infection (Pyörälä, 2003; Harmon, 1994; International Dairy Federation, 1987).

Mastitis is a multifactorial disease. As such, its incidence depends on exposure to pathogens, effectiveness of udder defence mechanisms, and presence of environmental risk factors, as well as interactions between these factors (Oviedo-Boyso *et al.*, 2007; Suriyasathaporn *et al.*, 2000).

Severity and Duration

Mastitis can be either clinical or subclinical. Clinical cases give rise to visible symptoms. Mild CM causes flakes or clots in the milk, whereas severe cases are associated with heat, swelling and discolouration of the udder, as well as abnormal secretion. Severe CM can also exhibit systemic reactions, such as fever and loss of appetite. Mastitis can exist in the absence of visible signs of infection, and is then referred to as subclinical mastitis (SCM). SCM is the most prevalent form of mastitis (Akers, 2002). In practice, whether a case of mastitis is classified as clinical or subclinical often depends on how carefully the cow is observed when diagnosis is made (International Dairy Federation, 1987). SCM can be diagnosed by presence of pathogens in bacteriological cultures of milk, but bacteriological sampling is not practically feasible as a routine test. The current standard method of detecting SCM is to measure SCC. Other inflammatory parameters, such as electrical conductivity, lactose, lactate dehydrogenase, acute phase proteins, etc. (Åkerstedt *et al.*, 2007; Hamann, 2005; Pyörälä, 2003), have been proposed as indicators of SCM, and some have the potential of being adapted to in-line use.

The duration of infection further classifies mastitis as acute or chronic manifestations, where a sudden onset defines acute cases and chronic mastitis is characterized by an inflammatory process that lasts for months and results in progressive development of fibrous tissue (International Dairy Federation, 1987; Jain, 1979).

Somatic Cell Count

Milk always contains a certain amount of somatic cells. These consist of various cell types, and their relative proportions depend on the health status of the udder. In a healthy lactating mammary gland, the major proportion of somatic cells is constituted by leukocytes (white blood cells) (Östensson *et al.*, 1988). These are primarily macrophages and lymphocytes, but a small fraction consists of neutrophils and epithelial cells (Harmon, 1994; Kehrli & Shuster, 1994). Microbial infection results in rapid accumulation of large numbers of somatic cells in the udder, and these are predominantly neutrophils (Harmon, 1994; Kehrli & Shuster, 1994; Östensson *et al.*, 1988). The increase in SCC constitutes an important part of the cow's immune response, and SCC is, therefore, a widely used indicator of mastitis.

Infection status has been recognized as the main factor affecting SCC (Schepers *et al.*, 1997; Sheldrake *et al.*, 1983; Dohoo & Meek, 1982), and SCC often exceeds 1 000 000 cells/ml in milk produced by mastitic cows (Kehrli & Shuster, 1994). Compositional changes of milk are, however, significant from 100 000 cells/ml, and are observed already at an SCC as low as 50 000 cells/ml (Hamann, 2002; Reichmuth, 1975). In bacteriologically negative milk cultures of udder quarter foremilk, an average SCC of 68 000 cells/ml has been reported (Djabri *et al.*, 2002). Laevens *et al.* (1997) found an SCC of 49 000 cells/ml in composite milk sampled in lactations from which no pathogens had been isolated. Presently, an SCC threshold of 100 000 cells/ml in quarter foremilk is internationally accepted (Hamann, 2005; 2003). In composite milk, an SCC above 50 000 cells/ml is considered indicative of SCM (Hortet & Seegers, 1998a (review)).

Pathogens

The magnitude of increase in SCC partly depends on the causative pathogen (Djabri *et al.*, 2002; Lam *et al.*, 1997; Schepers *et al.*, 1997). The primary mastitis causative microorganism is bacteria. These have traditionally been categorized into major or minor pathogens, depending on the magnitude of inflammatory response associated with infection. Major pathogens most often cause CM (Djabri *et al.*, 2002), and give rise to the most extensive changes of milk composition (Harmon, 1994). These infections are most often due to *Staphylococcus aureus, Streptococci* (*agalactiae, dysgalactiae, uberis*), *Escherichia coli* and *Klebsiella* spp. Minor pathogens, including *Corynebacterium bovis* and coagulase-negative staphylococci, cause only moderate infection and are most often associated with SCM (Djabri *et al.*, 2002; Harmon, 1994). These pathogens have been reported to have a protective effect against major pathogens (Lam *et al.*, 1997; Matthews *et al.*, 1991), and the reason has been suggested to be competitive growth, antagonism, induced leukocytosis or an increased immunity of the cow (Black *et al.*, 1972).

Depending on the vector of transmission, bacteria are considered either contagious or environmental pathogens. *Staph. aureus* and *Strep. agalactiae* are contagious pathogens, for which udders of infected cows serve as the major reservoir. Contagious pathogens spread from cow to cow, primarily during milking, and tend to result in chronic subclincal infections with flare-ups of clinical episodes (Harmon, 1994). Environmental pathogens include *E. coli*, *Klebsiella* spp., *Strept. dysgalactiae* and *Strept. uberis*., and have bedding, manure and soil as their primary sources. The majority of infections caused by environmental pathogens are clinical and of short duration (Harmon, 1994).

In Sweden, the most common pathogens isolated in cases of CM are *Staph. aureus*, *Strept. dysgalactiae*, and *E. coli* (Persson Waller *et al.*, 2009).

Risk Factors

Several features of individual cows can be identified, which might indicate an increased risk of developing mastitis.

Multiparous cows are generally at higher risk of developing CM (Rajala-Schultz *et al.*, 1999b; Emanuelson *et al.*, 1993; Bendixen *et al.*, 1988), except in the very early stages of lactation where the relationship is the opposite (Steeneveld *et al.*, 2008; Barkema *et al.*, 1998). In multiparous cows, the risk of developing CM increases with increasing parity (Steeneveld *et al.*, 2008). There is also consistency in the literature as regards higher SCC in older cows (Harmon, 1994; Reneau, 1986; Dohoo & Meek, 1982).

The risk of developing CM is highest in early lactation (Persson Waller *et al.*, 2009; Steeneveld *et al.*, 2008; Barkema *et al.*, 1998), whereas the risk of SCM increases with increasing days in milk (Busato *et al.*, 2000).

Mastitic cows tend to have higher milk yield than non-mastitic cows before they develop CM (Gröhn *et al.*, 2004; Wilson *et al.*, 2004; Rajala-Schultz *et al.*, 1999b), indicating that high milk yield is a risk factor for CM.

Previous occurrences of mastitis, CM or high SCC, substantially increased the risk of a cow developing a new case of CM (Steeneveld *et al.*, 2008; Bendixen *et al.*, 1988). Other disorders, such as dystocia; milk fever; retained placenta; metritis; ketosis; and lameness, are also known to increase the risk of CM (Svensson *et al.*, 2006; Emanuelson *et al.*, 1993; Gröhn *et al.*, 1990b; Bendixen *et al.*, 1988).

Cows of certain breeds are more prone to mastitis. Among the Swedish breeds, national statistics (Swedish Dairy Association, 2008), as well as several studies (Persson Waller *et al.*, 2009; Nyman *et al.*, 2007; Emanuelson *et al.*, 1993), show that Swedish Red cows have a lower incidence of mastitis than Swedish Holstein cows.

The incidence of mastitis is influenced by managerial and environmental factors, such as housing of cows, milking equipment, feeding regime, hygienic quality of feed and water, cleanliness of cows, implementation of preventive measures, and general practices related to, for instance, drying-off (Nyman *et al.*, 2007; Schreiner & Ruegg, 2003; Peeler *et al.*, 2000; Barkema *et al.*, 1999; Elbers *et al.*, 1998). Season also affects the incidence of mastitis, and the incidence of CM has been reported to be highest during the winter months (Steeneveld *et al.*, 2008; Olde Riekerink *et al.*, 2007a; Bendixen *et al.*, 1988).

Consequences of Mastitis

Mastitis is of great economic importance to milk producers, because the disease has negative impact on several important aspects of cow and herd performance. Incurred costs are of both direct and indirect nature (Kossaibati & Esslemont, 1997). Direct costs include veterinary costs, increased labour requirement, discarded milk (during the course of treatment), and reduced milk yield and quality. Indirect costs are those that are not always obvious to the milk producer, and are therefore referred to as hidden costs. They include increased risk of subsequent disorders, reduced fertility (extra services per conception and, as a result of this, an extended calving interval), increased risk of culling, and, occasionally, mortality. The total cost of mastitis can, consequently, be much higher than the direct cost

(Kossaibati & Esslemont, 1997). The cost associated with each component is likely to vary between herds; partly because of differences in performance parameters (yield level, fertility, etc.) and partly because of different preferences of farmers influencing, for instance, their inclination to contact a veterinarian when mastitis is detected.

Yield Loss

The extent of yield loss depends on severity, causative pathogen, parity of cow, and the stage of lactation at which mastitis develops. In primiparous cows, yield loss is most severe when CM is caused by *Staph. aureus*, *E. coli*, and *Klebsiella* spp., whereas, in multiparous cows, *Streptococcus* spp., *Staph. aureus*, *E. coli*, *Klebsiella* spp., *and A. pyogenes* are responsible for the largest yield loss (Gröhn *et al.*, 2004). Multiparous cows suffer more severe yield loss than primiparous cows (Bennedsgaard *et al.*, 2003; Hortet *et al.*, 1999; Rajala-Schultz *et al.*, 1999b). CM occurring before peak yield results in the most extensive yield loss (Rajala-Schultz *et al.*, 1999b; Hortet & Seegers, 1998b (review)), whereas SCM occurring in late lactation is associated with the highest yield loss (Bennedsgaard *et al.*, 2003; Hortet *et al.*, 1999).

There is substantial variation as regards estimates of the magnitude of lactational yield loss in the literature. Discrepancies are due to differences in management, breed and yield level, as well as the analytical method used.

CM is associated with yield loss at the time of diagnosis, and, more importantly, yield loss often persists throughout lactation (Wilson *et al.*, 2004; Rajala-Schultz *et al.*, 1999b; Houben *et al.*, 1993). In the latest review on the subject, Hortet and Seegers (1998b) summarised a lactational yield loss of 300 to 400 kg (4 to 6%) in multiparous cows and 200 to 300 kg in primiparous cows. Cases of CM are of different severity, and 40% of CM cases can be expected to be associated with negligible yield loss, 30% with a lactational yield loss of 150 ± 250 kg, and 30% with a lactational yield loss of 950 ± 1050 kg (Hortet & Seegers, 1998b). Before diagnosis, mastitic cows have a production advantage over their non-mastitic herd mates (estimated at 2.6 kg by Wilson *et al.* (2004)). As most studies use the yield level of non-mastitic cows as reference for yield in healthy cows, the reported losses probably underestimate the true yield loss associated with CM.

The reduction in milk yield associated with SCM has been summarised as 80 kg (1.3%) and 120 kg (1.7%) per 2-fold increase in SCC above 50 000 cells/ml in primiparous and multiparous cows, respectively (Hortet & Seegers, 1998a).

The economic damage caused by yield loss is to some extent alleviated by reduced feed cost (Yalcin, 2000). This effect of local CM is small, but systemic CM has been reported to reduce dry matter intake by 30 kg over a period of 117 days (Bareille *et al.*, 2003). Still, reduced milk yield is the major component of the cost associated with both CM and SCM (Huijps *et al.*, 2008; Hortet & Seegers, 1998b (review); Degraves & Fetrow, 1993 (review)).

Milk Composition

Mastitis decreases the synthetic capacity of the mammary gland, which leads to decreased concentrations of fat and caseins in the milk (summarized by Pyörälä, 2003 and Akers, 2002). Indeed, in reviews by Hortet & Seegers (1998a; 1998b) CM and SCM were found to cause somewhat lower fat content in the milk, and, on lactational level, estimates of the absolute fat yield loss due to CM varied between 3 and 22 kg (1.5 to 7.5%). Results from previous studies indicate slightly increased protein content in milk produced by mastitic cows (Hortet & Seegers, 1998a; 1998b). This is due to a higher content of inflammatory, non-coagulating proteins and whey proteins, but, at the same time, a decreased proportion of casein (Urech *et al.*, 1999; Auldist *et al.*, 1996; Barbano *et al.*, 1991). In the studies reviewed by Hortet & Seegers (1998b), the absolute protein yield loss following a case of CM ranged from 0 to 15 kg (0 to 8.5%). Milk composition changes caused by mastitis can be neglected in economic calculations (Seegers *et al.*, 2003), because milk produced in connection with diagnosis is discarded due to treatment and later losses are proportional to the milk loss.

The bacterial count is increased by mastitis, but the elevation can be neglected after the withdrawal period (Seegers *et al.*, 2003).

The only changes in milk composition that are of economic importance to the dairy producer are those that affect the milk price, i.e. components that are part of the milk payment scheme. The largest dairy association in Sweden, Arla Foods, pays a premium when bulk tank somatic cell count (BTSCC) is below 300 000 cells/ml, and incurs a penalty when BTSCC exceeds 401 000 cells/ml. In a specific herd, the bulk tank SCC and the amount of milk produced influence whether a single case of mastitis will affect the milk price or not, because those factors impact on the extent to which the milk from the mastitic cow is "diluted" in the bulk tank (Østerås, 2005).

In practice, if BTSCC has been too high for a period of time, a cow with high SCC might be culled in order to bring down BTSCC and avoid payment penalties. Culling does, however, incur a cost of replacement, and might, in fact, be more costly than accepting milk quality penalty (Dekkers et al., 1996). An alternative approach to reduce BTSCC and limit the impact of mastitis on herd profit is to sort out milk with high SCC. Milk-sorting decisions have traditionally been based on SCC information obtained from the milk recording scheme. Such information is obtained on a monthly basis, resulting in crude decisions. Recent technological advancements now allow SCC to be recorded in-line, and thus provide means to make decisions on whether or not the milk from a certain cow is to be delivered to the dairy in connection with each milking. The profitability of discarding poor quality milk based on the results of an in-line SCC indicator can, however, be expected to depend on how accurately SCC can be recorded. If uncertainty is high, there would be a risk of classifying milk with low SCC as poor quality milk and discard it and vice versa, resulting in lower economic benefit of discarding milk with high SCC as compared to if the true SCC could be measured.

Veterinary and Treatment Costs

In Sweden, only veterinarians may prescribe drugs for treatment of mastitis. Milk producers consulting a veterinarian for treatment of a case of CM are, on average, charged €119[1] (1 200 SEK, exchange rate of 18 November 2008, Paper IV) for starting fee, travel costs, labour, and drugs. Veterinary costs are partly subsidised in Sweden.

Veterinary costs are easily identified, and are often perceived by farmers as the full cost of mastitis. In a study of Norwegian dairy herds, it has, however, been shown that there is only marginal association between treatment rate of mastitis and gross margin, indicating that treatment costs constitute only part of the total cost of mastitis and that most costs are hidden (Østerås, 2000). Østerås (2000) therefore suggested that treatment costs should be regarded as an investment to decrease the hidden costs.

Discarded Milk

Milk produced when a cow shows signs of mastitis, or while a cow is treated with antibiotics, is discarded. The withdrawal period includes the days when a cow actually receives drugs and a waiting time, usually consisting of some additional days, when there is a risk of antibiotic residues in the milk. The length of the withdrawal period depends on the production system (i.e. conventional or organic), and the drug used.

The cost of discarded milk is comparable to that of milk loss, but with one important difference: discarded milk is produced by the cow and is

[1]Thomas Svensson, Swedish Board of Agriculture, personal communication

therefore associated with feed costs. The cost per unit of discarded milk is thus higher than the corresponding cost of milk not produced (Halasa *et al.*, 2007; Hogeveen & Østerås, 2005).

Some herds feed discarded milk to calves, and, when this is practised, discarded milk should be assigned an alternative value corresponding to that of the amount of milk replacer that would otherwise have been needed. Feeding milk produced by mastitic cows or cows being treated with antibiotics to calves is, however, not recommended by Swedish veterinarians.

Extra Labour

CM is associated with extra labour requirement, for instance in form of attendance of the visit by the veterinarian and administration of medicine. Also, CM may affect the order in which cows are milked, and thus gives rise to less efficient milking routines. The time requirement associated with a case of CM is likely to amount to two hours[2]. The amount of time needed to treat SCM can be expected to be less than that associated with CM, because SCM is not always detected, and, when detected, is not always treated.

Extra labour requirement should be valued based on the opportunity cost of labour, i.e. the value of the next best alternative foregone as the result of having to assign time to mastitis. Opportunity cost of labour in agriculture is often difficult to assess, and is likely to differ between farms (Halasa *et al.*, 2007; Hogeveen & Østerås, 2005). Opportunity cost is readily calculated if labour is of external source; because the value of time spent on preventing mastitis can be estimated as hours times hourly wage. If labour is of internal source, i.e. the farmers own time, opportunity cost is zero, or the value that the farmer assigns to his or her free time. If, however, the farmer spends less time on other tasks consequential upon having to deal with mastitis, then opportunity cost is the decreased income resulting from spending less time on these other tasks.

Subsequent Disorders

Cows having experienced one case of CM often develop a subsequent case of CM later in lactation (Rajala & Gröhn, 1998; Houben *et al.*, 1993). Also, as contagious pathogens use the udder of infected cows as reservoir, having mastitic cows in a herd increases the risk of spreading infection to healthy cows. Mastitis is associated with increased risk of lameness (Peeler *et al.*, 1994; Dohoo & Martin, 1984a), and CM has been reported to be associated

[2]Charlotte Hallén-Sandgren, Swedish Dairy Association, personal communication

with concurrent or subsequent diagnosis of ketosis, displaced abomasum, and non-parturient paresis (Gröhn *et al.*, 1989). CM is not a risk factor for reproductive disorders (Gröhn *et al.*, 1990a), but both CM and SCM are known to adversely affect reproductive performance (Petersson *et al.*, 2006; Maizon *et al.*, 2004; Schrick *et al.*, 2001).

When other disorders or fertility disturbances occur as a consequence of mastitis, it has been argued that their economic cost should be included in the total cost of mastitis (Halasa *et al.*, 2007; Hogeveen, 2005). A complicating factor is, however, that the causative relationships between mastitis and other disorders are somewhat obscure, and care must, therefore, be taken in assigning costs of other disorders to mastitis as this might result in overestimation of the total cost of mastitis.

Culling

CM increases the risk of culling (Schneider *et al.*, 2007; Rajala-Schultz & Gröhn, 1999a; Gröhn *et al.*, 1998), as well as mortality (Bar *et al.*, 2008a). The extent to which CM affects the risk of culling depends on lactation stage at clinical onset (Schneider *et al.*, 2007; Beaudeau *et al.*, 1995; Dohoo & Martin, 1984b). It is also influenced by reproductive status, and open cows are at greatest risk of being culled due to CM if they are diagnosed in early lactation, whereas, pregnant cows are subjected to a relatively similar risk of being culled because of CM irrespective of when in lactation they are diagnosed (Schneider *et al.*, 2007). Once cows are pregnant, the risk of being culled as a consequence of CM drops sharply (Gröhn *et al.*, 1998). SCC above 300 000 cells/ml has been reported to increase the risk of culling in primiparous cows (Beaudeau *et al.*, 1995), and, in late lactation, SCM is the most important disease influencing culling decisions regardless of parity of the cow (Dohoo & Martin, 1984b).

The cost associated with involuntary culling as a consequence of mastitis is an important component of the total cost of mastitis. Like milk loss, increased risk of culling imposes a hidden cost, which is not always obvious to the farmer. Involuntary cullings are associated with replacement costs, and hence include costs of rearing or buying a heifer. If a heifer is not available at the time a cow is culled, capacity utilization is reduced as a stall will be empty while the fixed costs remain the same. Further economic loss can be expected as milk yield of primiparous cows is lower than that of multiparous cows, and because there is a risk that the yield level of a heifer might be disappointing (Halasa et al., 2007; Hogeveen, 2005; Østerås, 2005). Economic cost also arise as cows culled due to mastitis do not reach their full production potential (Østerås, 2005). On the other hand, additional returns from meat are obtained if a mastitic cow can be sold to slaughter.

Economic assessment of the impact of increased risk of culling is not straightforward. Culling results from a management decision taken by the farmer, which is based not only on presence or absence of mastitis but also on milk yield, pregnancy status, parity, stage of lactation, and presence of other diseases (Gröhn *et al.*, 1998). Cows are culled when replacement is judged to be the economically optimal alternative. At what point in time it is optimal to replace a mastitic cow is, indeed, determined by the above mentioned factors (Houben *et al.*, 1994). Furthermore, it also depends on mastitis incidence and critical price parameters (Stott & Kennedy, 1993).

Other Effects

Any kind of pathology involves some degree of poor animal welfare (Broom, 2006). Mastitis is a very painful condition and is one of the major welfare problems of dairy cows (Broom & Fraser, 2007; Webster, 1999). Even mild cases of CM cause increased responsiveness to pain and affected cows become hypersensitized to stimuli normally considered innocuous (Fitzpatrick et al., 1998).

In European countries, there is a high level of consumer concern for animal welfare (Harper & Henson, 2001; Moynagh, 2000), which results in major public demand for improvements in animal welfare. Indeed, consumers are prepared to pay considerably more for welfare-friendly production practices (Moynagh, 2000). If milk is produced from cows with high incidence of mastitis, consumers' acceptance of dairy production, and thereby their willingness to buy dairy products, may be adversely affected.

There are no known, direct threats to public health associated with consuming dairy products made from high SCC milk (Hogan, 2005). Potential food safety risks do, however, arise from ingestion of human pathogens, bacterial toxins, and antibiotic residues; factors that are associated with high SCC in milk (Hogan, 2005).

Mastitis in cattle is the main reason for use of antibiotics in Swedish animal production (Swedish Board of Agriculture, 2008b). Exposure of animals to antibiotics is an important factor contributing to development of resistant bacteria (Mevius *et al.*, 2005), which is considered to be one of the major public health threats.

Economic Assessment of Mastitis

The total economic cost of disease consists of two distinct components; production loss and control expenditures (McInerney *et al.*, 1992). Losses include benefits that are taken away and benefits that are not realized. The former can be exemplified by milk that must be discarded following treatment with antibiotics and the latter by milk that is never produced as a result of disease. Expenditures are extra inputs needed to limit losses, either by reducing the impact of an unplanned event, such as treatment of a mastitic cow, or by preventing such events from occurring, as in the case of investments into preventive measures. It has been argued that it is the relationship between losses and expenditures that is of importance if estimates of the cost of disease are to be used as input in decision-making (McInerney *et al.*, 1992), not the economic loss associated with disease *per se* (Østerås, 2005; Dijkhuizen *et al.*, 1995; Schepers & Dijkhuizen, 1991).

The primary purpose of economic analyses is to support decisions regarding mastitis control. The economic losses in situations where nothing is done to limit the impact of mastitis should, therefore, be compared with the economic loss in situations where mastitis control is practised (Hogeveen, 2005). When such assessments reveal that mastitis management is economically profitable, interventions can be justified. Mastitis control can be practiced at different levels; udder quarter, cow, herd, or national. The cost of mastitis can be estimated at all of these levels, and the level of choice depends on the nature of the decision that is to be supported.

At udder-quarter level, decisions are concerned with whether or not to dry off an infected udder quarter. Cow-level decisions are directed at managing occurrences of mastitis, and the options are no treatment, treatment or culling. Treatment decisions impact also on herd level, as treatment reduces spread of infection to healthy cows. In the same way, culling might serve to reduce the overall incidence of mastitis in the herd. Mastitis control at herd level aims at reducing the incidence of mastitis, and consists of various proactive and reactive measures. Information on the national consequences of mastitis is needed to answer whether subsidized veterinary services and targeted research are necessary in order to reduce the incidence of mastitis. Other contexts in which estimates of the impact of mastitis is essential are when milk payment schemes are designed to motivate producers to produce milk of desired quality, and when breeding programs are dimensioned with respect to mastitis resistance.

The economic viability of different measures to control mastitis can only be assessed if reliable estimates of the economic loss brought about by the disease are available (Seegers *et al.*, 2003). Before management strategies are compared, the magnitude of economic loss must be addressed (Hogeveen, 2005), because mastitis management needs to be based on insight into the costs associated with CM and SCM (Hogeveen & Østerås, 2005). Huirne (2003) emphasized that calculations of the economic loss resulting from mastitis is central, as they aid in providing a better overall view of the impact of the disease, as well as contribute to better understanding of the extent to which the loss can be reduced. It is the latter, the avoidable cost, that is of importance in mastitis control, because complete elimination of disease is not feasible (McInerney *et al.*, 1992) and calculation of the economic loss against a situation with zero incidence would thus encourage overestimation of the economic damage associated with mastitis.

Previous estimates of the cost of mastitis show large variation (reviewed by Halasa *et al.*, 2007; Degraves & Fetrow, 1993; and Schepers & Dijkhuizen, 1991). Some reasons for this variation seem to be origin of data, definition of mastitis, differences in sources of loss included, and analytical approach applied. Furthermore, studies have been conducted in different spatiotemporal contexts, which can be assumed to influence the results as circumstances of production and price levels vary between countries and over time. Differences as regards the economic consequences of mastitis can also be expected between farms, because of differences in incidence of mastitis, pathogen frequency, severity of mastitis cases, number of cases per affected cow and management routines. Additionally, the impact of mastitis upon the economic performance of individual cows will be influenced by their production level, age and reproductive status, and this will, in turn, affect decisions regarding mastitis management on cow level (Hogeveen & Østerås, 2005). The external validity of results might, therefore, be questioned, and any generalizations must be made with caution. In order to support decisions regarding mastitis management in individual herds, evaluations of the economic loss associated with mastitis must be as specific as possible (Hogeveen, 2005; Hogeveen & Østerås, 2005). Preferably, they should be conducted for a specific herd and in a specific economic context (Seegers et al., 2003).

The level at which the impact of mastitis has been estimated obviously affects the results. Even though it has been suggested that the herd-level cost of mastitis can be obtained by aggregating the costs at cow level (Østerås, 2005), this might impose bias on the results. Several of the direct costs of mastitis, such as treatment, discarded milk, increased labour and decreased milk production, can readily be assessed in individual cows. Indirect consequences, however, frequently arise through herd dynamics, and often reflect management decisions taken by the farmer. Increased risk of culling and thus increased replacement costs, as well as penalties or loss of premiums connected with increased SCC in the bulk tank milk, are good examples of dynamic factors. The decision to cull a mastitic cow, in order to increase the average milk yield per cow and decrease BTSCC, incurs a replacement cost, and illustrates the way in which dynamics within the herd impact on herd-level economy. Some herd-level effects can therefore not be assessed simply by summing up the cow-level effects, and this type of dynamics require the economic impact of mastitis to be addressed at herd level (Seegers *et al.*, 2003).

Methods of Economic Analysis of Animal Disease

There are several analytical approaches that can be applied in the assessment of economic effects of disease and disease control. Which one that is most suitable for a certain analysis depends on the nature of the decision problem; the complexity of the disease and its effects; the data available; the intended use of the model and the preferences and capabilities of the model builder and/or decision maker; and the resources available (Bennett, 1992). A brief description of the methods most frequently applied in economic analyses of the economic loss associated with mastitis is given below.

Partial Budgeting

Partial budgeting can be used for rather simplistic economic comparisons of different situations, such as high or low incidence of mastitis or changes associated with implementation of a new control measure. It is a marginal approach, i.e. it is concerned with changes in costs and returns due to an actual decision or a disease event. Consequently, the analysis considers variable costs (such as veterinary costs, labour, milk yield), but typically ignore fixed costs (for instance maintenance costs and interest). Establishing a partial budget requires information on:

1. Additional returns (returns that will not be received unless the change is undertaken)
2. Reduced costs (costs present in the initial situation that will be avoided if the change is made)
3. Returns foregone (returns received in the initial situation that will not be received if the change is made)
4. Extra costs (costs associated with the change that are not present in the initial situation)

If the sum of additional returns and reduced costs is greater than that of returns foregone and extra costs, the change can be economically justified.

Advantages of using partial budgeting are that the method is a fairly uncomplicated and time effective. Drawbacks are that it cannot account for stochastic events nor involve development over time (Dijkhuizen *et al.*, 1995).

Simulation

Simulation is a more sophisticated method to analyse the impact of disease. A simulation model is a simplified mathematical model of the unit of concern (for instance a dairy herd), which can be manipulated by modification of input parameters and, thus, adjusted to various real-life situations. Simulation is well suited to investigate the impact of strategies before they are applied, or as an alternative to intervention studies where such would be time consuming or associated with great costs. Simulation models can be either static or dynamic. Static models do not include time as a variable, whereas dynamic models do. Dynamic models are, thus, capable of modelling the development of the system over time. Models are further classified as deterministic or stochastic. Deterministic models make definite predictions of quantities, whereas stochastic models account for uncertainty in the behaviour of the system (i.e. the same conditions can give different outcomes), and, thus, reflect biological variation.

Dynamic and stochastic simulation models can account for complicated interactions, and are thus capable of mimicking the dynamics taking place in a dairy herd. Indeed, stochastic simulation has been suggested to be the most relevant method to use when studying the effects of disease in a system (Allore & Erb, 1999; Dijkhuizen *et al.*, 1995). Disadvantages of stochastic simulations are that the methodology requires an extensive amount of input, lots of computational power, and is rather time consuming.

Aims of Thesis

The overall aim was to assess the economic loss associated with mastitis under current Swedish farming conditions. More specifically, the objectives were to:

- Estimate the yield loss associated with CM and SCM occurring in different stages of lactation
- Assess the consequences of mastitis on the results of a dairy herd, and to estimate the economic gain following a reduction of the current incidence of mastitis
- Investigate whether recognition that yield loss varies depending on when in lactation CM occurs results in an evaluation of the economic loss caused by CM that differs from that derived when the lactational timing of CM is ignored
- Study the impact of discarding milk with high SCC on herd net return

Summary of Investigations

Material and Methods

Detailed descriptions of studied materials and applied methods are given in Papers I to IV. Here, a condensed version is presented.

Data from Research Herd

Papers I and III were based on test-day records collected at weekly intervals in the research herd of the Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences. Data sampled between September 1987 and April 2004 were available. Cows were of the Swedish Red and Swedish Holstein breeds, and had an average yearly production of 8 900 and 10 600 kg milk, respectively, in 2004. The research herd was kept at two locations during the study period. Before 1992, the herd was kept on a farm with tie-stall housing. The current farm has a free-stall barn (n = 50) and a tie-stall barn (n = 50). All cows were milked twice daily. In 2004, the median BTSCC was 150 000 cells/ml.

Cases of CM were detected by the milkers by presence of abnormal milk in the first milk streams or by signs of inflammation in one or more udder quarters. All cases were diagnosed by a veterinarian. Not all cases were necessarily treated. Treatment decisions were made according to a Standard Operating Protocol based on stage of lactation as well as possible designation for culling. Affected udder quarters were sampled and the milk cultured to determine the pathogens present. Additional samples were taken two and five weeks after a completed treatment. Milk samples for bacteriological culture were also taken from cows with composite milk SCC > 180 000 cells/ml on two subsequent test days (TD). Furthermore, milk samples were routinely cultured from each udder quarter in the fourth week of lactation, as well as two weeks before a cow was dried off. From the autumn of 1997 until the autumn of 2000, milk samples were also taken in the first week of lactation. From 1993 to 2004, milk samples were taken from 1 560 udder quarters and 40% of the samples had positive cultures. Table 1 shows the pathogens present in the culture-positive milk samples.

Table 1. *Pathogens present in culture-positive milk samples (n = 624) taken from mastitic udder quarters as well as by routine (Paper I)*

Pathogen	Frequency (%)
Mixed culture	25
Staphylococcus aureus[1]	10
Staphylococcus aureus[2]	1
Coagulase-negative Staphylococci[1]	12
Coagulase-negative Staphylococci[2]	6
Streptococcus agalactiae	0
Streptococcus dysgalactiae	11
Streptococcus uberis	7
Other *Streptococcus* spp.	1
Escherichia coli	16
Klebsiella	5
Arcanobacterium pyogenes	3
Other pathogens	3

[1]*Sensitive to penicillin*

[2]*Resistant to penicillin*

The lactational incidence risk (lactations with at least one case of CM divided by the total number of lactations at risk) of CM was 19.9 and 28.9% in primiparous and multiparous cows, respectively (Paper I). Cases of CM most often developed in the first week of lactation (Figure 1). The overall recurrence rate of CM was 23%, and the average number of cases per lactation was 1.3.

The geometric mean SCC on TD free of CM was 55 000 and 95 000 cells/ml in primiparous and multiparous cows, respectively (Paper III). Median-values of SCC on TD free of CM, sampled in different stages of lactation, are given in Table 2.

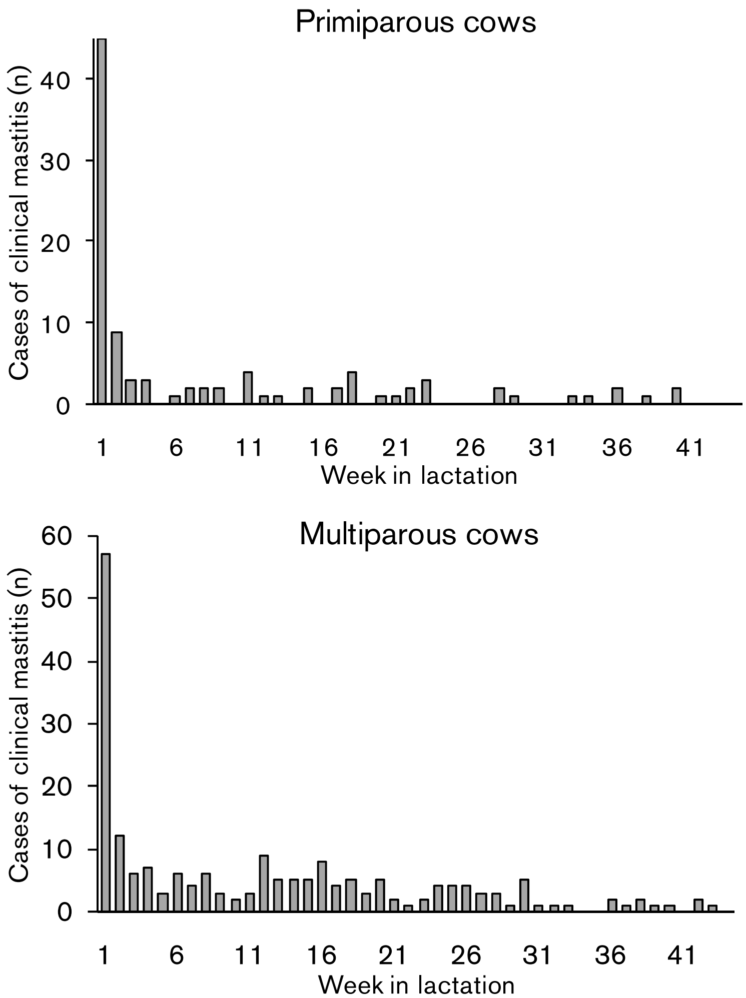

Figure 1. Number of cases of clinical mastitis in each week of lactation in primiparous and multiparous cows (Paper I).

Table 2. *Median-values of somatic cell count (x 10^3 cells/ml) in different stages of lactation on test days free of clinical mastitis (Paper III)*

	Lactation weeks					
	1-2	3-8	9-16	17-24	25-32	33-44
Primiparous cows	133	46	35	37	43	59
Multiparous cows	114	48	51	77	109	164

Paper I was based on 38 535 test-day records sampled from 307 Swedish Red and 199 Swedish Holstein cows. Out of 1 192 lactations, 298 were affected by at least one case of CM. The first lactational incidence of CM, irrespective of causative pathogen, was studied.

Test-day records without information on SCC were discarded in Paper III, leaving data sampled between November 1989 and April 2004 from 303 Swedish Red and 194 Swedish Holstein cows. Two datasets were created. Dataset A excluded test-day records sampled on days where cows were affected by CM, and a case of CM was assumed to last for eight days following diagnosis. It comprised 36 117 test-day records collected in 1 155 lactations. A subset of dataset A (dataset B) was created by excluding all lactations in which CM occurred. Dataset B contained 27 753 test-day records sampled in 863 lactations.

Simulated Data

The impact of mastitis on technical and economic results in a Swedish 150-cow dairy herd was studied by means of simulation (Papers II and IV). Scenarios were simulated over ten (Paper II) and twenty (Paper IV) years, but only the average annual results from the latter half of the period was used in the analyses. For each scenario, 250 replicates were performed.

The effect of mastitis on milk yield was not modelled in the same manner in the two studies. In Paper II, the effect of CM on milk yield was modelled directly (based on results from Paper I), and no effect of SCC on milk yield was included in the model. The estimated average economic loss per case of CM, therefore, included possible correlated effects of CM on SCM, because the drop in production some weeks prior to diagnosis as well as part of the lactation-long impairment of milk yield subsequent to CM, may be due to SCM. It, thus, expressed the total economic loss caused by mastitis in lactations where CM occurred. In Paper IV, we were interested in the entire effect of mastitis on herd economy, and thus modelled both CM and SCM. Because of programming considerations (mastitis is modelled as one trait with different severities in SimHerd), the effect of mastitis on milk yield was mediated primarily through its effect on SCC, i.e. as an indirect effect. Mastitis started to affect SCC on the day of diagnosis. Cases of CM were supplemented with a direct effect on milk yield, because it has been reported that CM gives rise to a larger yield loss than what can be explained simply by the increase in SCC (Bennedsgaard *et al.*, 2003). In Paper IV, recurrent cases of mastitis were allowed to develop within the same lactation.

In Paper II, results given the initial incidence of CM (26 cases per 100 cow-years, first lactational incidence) were studied, together with the consequences of reducing the incidence of CM by 50% and 90% throughout lactation and the consequences of reducing the incidence by 50% and 90% only before peak yield. Different approaches to model yield loss subsequent to CM were compared; a conventional modelling strategy - i.e. one employing a single yield-loss pattern irrespective of when, during the lactation, the cow developed CM - and a new modelling strategy in which CM was assumed to affect production differently depending on its lactational timing (based on the results obtained in Paper I). The effect of choice of reference level when estimating yield loss was investigated by combining the modelling strategies with two different reference levels; the potential yield of mastitic cows, had they not developed CM, and the yield of non-mastitic cows.

The full effect of mastitis, including both CM and SCM, was estimated in Paper IV. In the initial scenario, a CM incidence of 32 cases per 100 cow-years (multiple cases could occur within the same lactation), based on the incidence of CM in the research herd studied in Papers I and III, was modelled. According to the distribution between clinical and subclinical cases of mastitis in a study by De Haas et al. (2002), the probability of a case becoming clinical was assumed to be 47%. In the initial scenario, an incidence of SCM of 33 cases per 100 cow-years was, consequently, modelled. Herd results given the initial incidence of mastitis were studied, together with the consequences of reducing and increasing the incidence of mastitis by 50% and the consequences of modelling no CM while the incidence of SCM was kept constant, and vice versa.

Paper IV also included an assessment of the economic benefit of discarding milk with high SCC in order to obtain a higher price for the delivered milk. This was done by comparing results obtained when no milk with high SCC was discarded with results given different strategies for deciding when sorting of milk was to be initiated. When the decision of whether to discard milk with high SCC was based on herd-level information, sorting of milk was initiated when bulk tank SCC exceeded 220 000, 200 000 and 180 000 cells/ml, respectively, whereas when the decision was based on cow-level information, milk was discarded when SCC in individual cow's milk exceeded 1 000 000, 750 000, and 500 000 cells/ml, respectively. The impact of uncertainty in the measurement of SCC on the consequences of discarding milk with high SCC was investigated by simulating different levels of uncertainty; high, low, or none.

Statistical Approaches

The effects of CM and SCC on test-day yield were estimated using mixed linear models in SAS 8.2 and 9.1, respectively (PROC MIXED, SAS Institute Inc., Cary, USA). Due to different shapes of their lactation curves, primiparous and multiparous cows were analyzed separately. Dependent variables in the models were test-day milk (Papers I and III), and fat and protein yield (Paper I). The general model used in Papers I and III included fixed effects of parity, breed, pregnancy status, year-season of calving, and various disorders. Additionally, fixed effects of season of test-day and housing system were included in Paper III. Variables with P-value ≤ 0.05 were considered statistically significant and were kept in the final models. Model validation was conducted by visual examination of normal probability plots of residuals against standardized residuals (q-q plots).

Yield loss associated with CM occurring in different stages of lactation (Paper I) was investigated by including an interaction term between a mastitis index and lactation stage in the general model. The mastitis index was used to distinguish between cows with and without CM, as well as to indicate time (test day) with respect to day of diagnosis. The clustered nature of test-days, and declining correlation between test-days as the time interval between them increased, were accounted for by specifying an auto-regressive residual correlation structure within lactations (Paper I). Least-squares means of the interaction term were used as estimates of daily yield in a certain week of lactation at a certain time with respect to diagnosis, and 305-day yields were extrapolated from the daily estimates. Yield loss was expressed relative to the yield of non-mastitic cows.

The association between SCC and daily milk yield in different stages of lactation in cows free of CM was investigated in Paper III. Fixed linear, quadratic and cubic regressions of $\log_2$-transformed and centered SCC were nested within lactation stage. The shape of the lactation curve was described by two fixed effects; lactation stage and weeks in milk. Moreover, a random regression, which modelled the deviation of individual lactations from the general lactation curve, was fitted. Daily milk yield at different SCC, in different stages of lactation, was calculated based on the estimated regression coefficients. Daily yield loss was expressed relative to milk yield on test-days free of SCM, defined as having SCC below 50 000 cells/ml in lactation weeks 2 to 44 and below 175 000 and 200 000 cells/ml, respectively, in primiparous and multiparous cows in the first week of lactation. Lactational (305-day) milk loss caused by SCM was calculated based on the regression coefficients. Affected TD were assigned SCC corresponding to the week-specific geometric mean of TD with SCC above the thresholds, whereas healthy TD were assigned SCC corresponding to the week-specific geometric mean of TD with SCC below the thresholds. Lactational milk loss in an average lactation affected by SCM was obtained by comparing the sum of weekly yields in affected cows, weighted by the prevalence of SCM in each week of lactation, with the 305-day yield of healthy cows.

The SimHerd Model

SimHerd is a dynamic bio-economic model with stochastic elements. It simulates production and associated events in a dairy herd over time through weekly time-increments. The simulation unit in the model is the individual animal. Herd-level production is simulated through the changes in state and production of individual animals. The state of an animal in each week is defined by age, parity, lactation stage, milk yield, body weight, reproductive status (oestrus and pregnancy) and disease status. Discrete events, such as oestrus detection, conception, sex and viability of the calf, disease occurrences, non-voluntary culling and mortality, are triggered stochastically. The modelling of mastitis within a lactation in Paper IV is summarized in Figure 2.

The impact of different scenarios on herd net return was evaluated by applying Swedish market prices to the results. A treatment cost of €119 (1 200 SEK, exchange rate of 18 November 2008, Paper IV) per incidence of CM, including veterinary fees and antibiotics, was assumed in Paper IV. Results were expressed as averages of 250 replicates, and were analyzed by univariate ANOVA. Simultaneous pair-wise comparisons of scenarios were conducted using t-tests ($P < 0.05$).

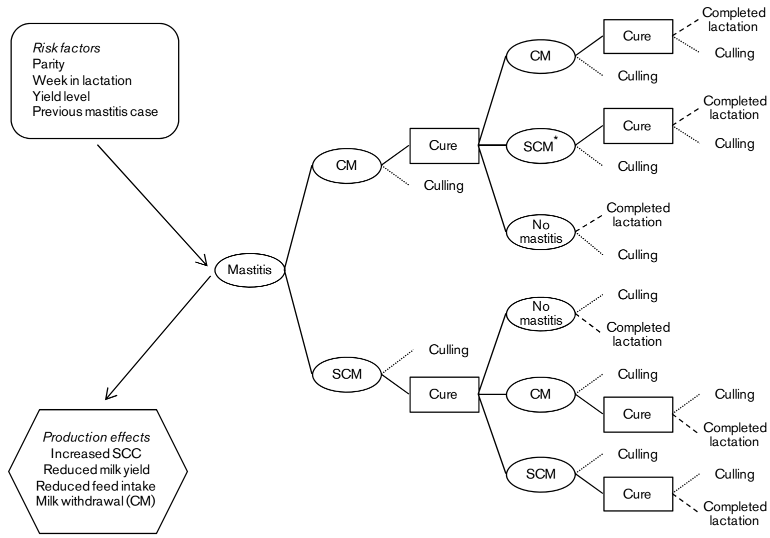

Figure 2. A simplified description of the modelling of mastitis in SimHerd (Paper IV). Mastitis only affected culling indirectly (....). Subclinical mastitis (SCM*) could only occur after clinical mastitis (CM) if the yield loss incurred by SCM was higher than the current yield loss caused by the earlier occurrence of CM. There was no upper limit as regards the number of mastitis cases in a lactation (indicated with --- in the figure).

Main Results

Yield Loss caused by Mastitis

The magnitude of the yield loss was affected by the stage of lactation in which the cow developed mastitis. CM gave rise to the most extensive yield loss when cows were diagnosed in early lactation (Paper I), whereas increased SCC caused greatest loss when it occurred in late lactation (Paper III). Multiparous cows generally suffered more severe yield loss than primiparous cows (Papers I and III). Cows developing CM generally had a higher initial milk yield than non-mastitic cows (Paper I).

Daily milk yield tended to decline 2 to 4 weeks prior to CM, and, after a case of CM, milk yield was suppressed throughout lactation (Paper I). At the time of diagnosis, daily milk loss in primiparous cows was close to 5 kg in Paper I, whereas it ranged from 1 to 8 kg in multiparous cows. On test-days free of CM, daily milk loss at an SCC of 500 000 cells/ml was estimated at 0.7 to 2.0 and 1.1 to 3.7 kg in primiparous cows and multiparous cows, respectively (Paper III). The higher figures applied to TD sampled in lactation weeks 33 to 44. In Paper III, an increase in SCC had a certain relationship with daily milk yield in primiparous cows irrespective of whether the cow developed CM in the lactation or not. In multiparous cows, on the other hand, an increase in SCC was associated with a higher milk loss in lactations where the cow did *not* develop CM.

The relative yield loss associated with CM occurring in different weeks of lactation is illustrated in Figure 3. On 305-day basis, primiparous cows affected by CM suffered a yield loss in the range of 0 to 705 kg (0 to 9%), depending on the week of lactation in which the cow was diseased (Paper I). The most severe yield loss occurred when primiparous cows developed CM in lactation week six. Most cases of CM occurred in the first week of lactation, and yield loss in primiparous cows diagnosed at this point in time amounted to 578 kg milk. In multiparous cows, lactational yield loss varied from 0 to 902 kg (0 to 11%). The highest yield loss applied to multiparous cows developing CM in lactation week three. When CM occurred in the first week of lactation, yield loss in multiparous cows was estimated at 782 kg milk.

In an average lactation affected by SCM, primiparous cows suffered a yield loss of 155 kg milk, which corresponded to 2% of their 305-day yield (Paper III). Milk yield of multiparous cows was substantially more affected, and, in an average lactation affected with SCM, yield loss in multiparous cows amounted to 445 kg milk (5%).

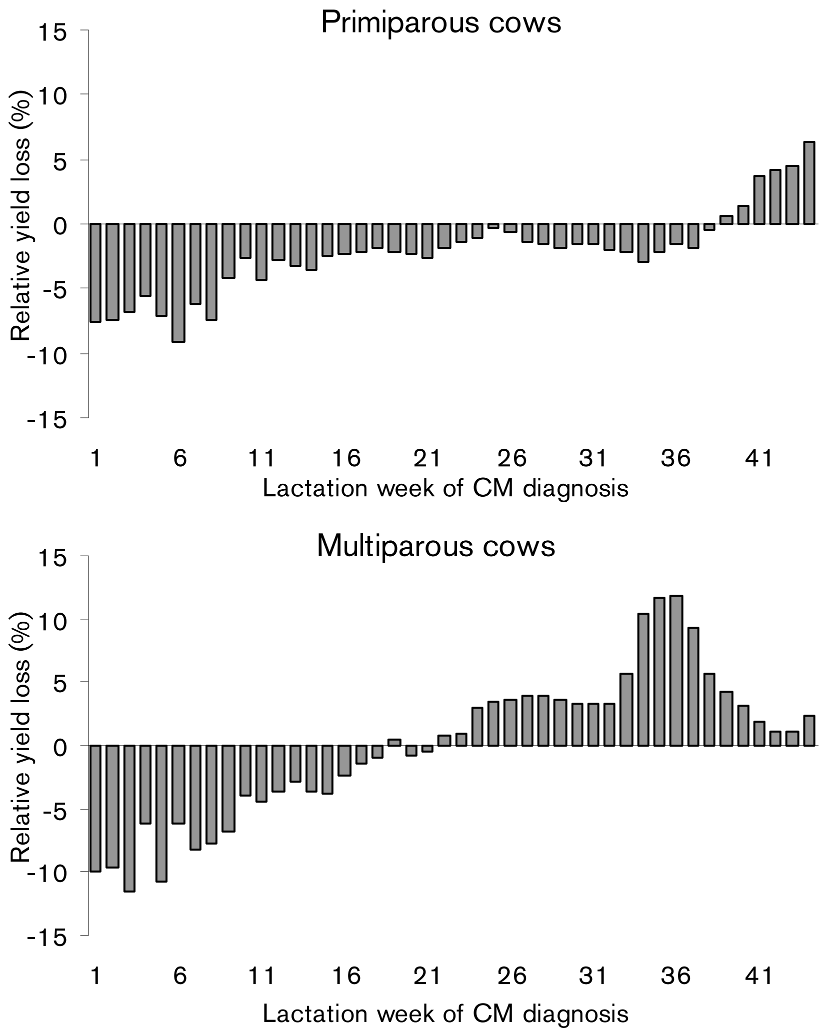

Figure 3. Proportional change in 305-day milk yield in primiparous and multiparous cows diagnosed with clinical mastitis in different weeks of lactation, expressed relative to milk yield of non-mastitic cows (Paper I).

Economic Loss associated with Mastitis

The maximum avoidable cost of CM (i.e. the increase in net return if the initial incidence could be reduced by 90%) in a Swedish 150-cow dairy herd was estimated at €14 504 per year (Paper II). In Paper IV, the yearly avoidable cost of mastitis (CM and SCM) in a herd of the same size was estimated at €8 095, under the assumption that the initial incidence of mastitis could be reduced by 50%. Assuming that the relationship between mastitis incidence and herd net return was linear, which appeared to be the case in Paper II, this would correspond to a maximum avoidable cost of €14 571. The avoidable cost of mastitis estimated in Paper IV corresponded to 5% of the herd net return given the initial incidence of mastitis. Figure 4 shows the changes in various cost items that resulted from the 50% reduction of the initial incidence of mastitis in Paper IV.

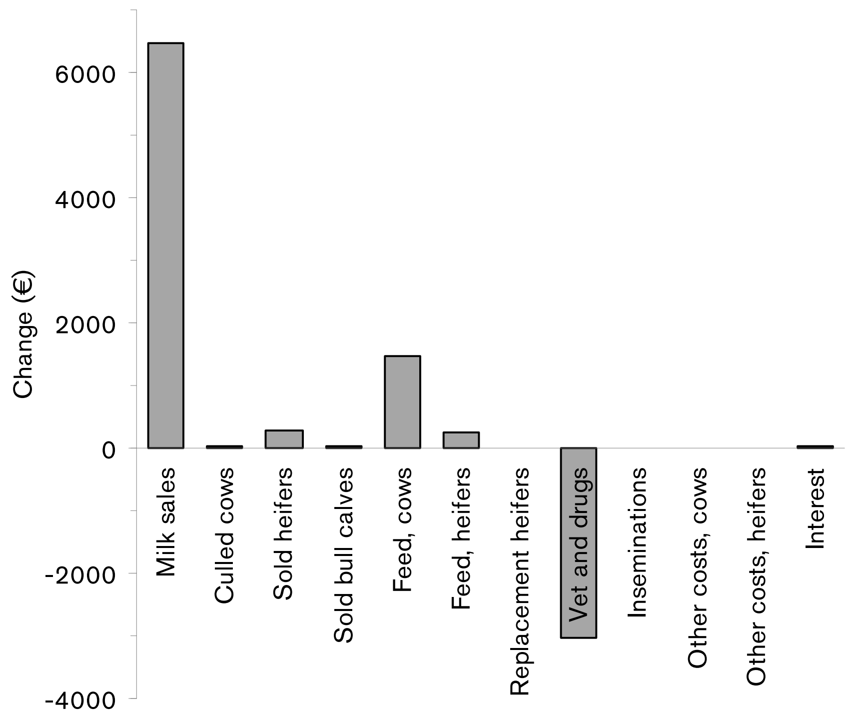

Figure 4. Changes in various cost components as a consequence of a 50% reduction of the initial incidence of mastitis (Paper IV).

When the economic consequences of CM were investigated, an average economic loss of €428 per case was arrived at (Paper II). In Paper IV, where the economic impact of CM and SCM were assessed simultaneously, an estimate of €275 was obtained. These figures are not comparable, because the estimate from Paper II accounts for correlated effects of CM on SCM, whereas the estimate from Paper IV does not. The average economic loss per case of SCM was estimated at €60 (Paper IV).

The average economic loss per case of CM was only slightly affected by the strategy for modelling yield loss when mastitic cows' own yield level, had they not developed CM, was used as the reference for production in healthy cows when the yield loss was estimated. When the same reference level for yield in healthy cows was used, applying specific yield-loss patterns for different periods in lactation did not have any substantial impact on herd results, as compared to using just one yield-loss pattern irrespective of the lactational timing of CM. Neither did the modelling strategy affect the response to a reduction of the risk of CM. Differences between modelling strategies were more pronounced when yield of non-mastitic cows was used as the reference for production in healthy cows.

Discarding Milk with High SCC

Discarding milk with high SCC was never profitable, because sorting of milk generated a substantial amount of milk withdrawal that was not offset by a sufficient increase in milk price. The most negative impact of discarding milk with high SCC on net return per cow-year was, consequently, observed when high incidence of mastitis was simulated. Milk sorting based on SCC measured with low uncertainty reduced the amount of withdrawn milk, and thus had less negative effect on net return per cow-year as compared with when SCC was measured with high uncertainty.

General Discussion

It is generally accepted that mastitis is the most costly disease in dairy production. The results of this thesis clearly emphasize the economic importance of mastitis, and stress the need for strategies to limit the impact of the disease. In the following, the most important findings will be discussed in detail.

Yield Loss caused by Mastitis

Severity

Clinical mastitis was associated with higher milk loss than SCM (Papers I and III). In primiparous cows, CM occurring in early lactation gave rise to a yield loss that was three times the size of the milk loss in an average lactation affected by SCM. In multiparous cows, the reduction in milk yield following CM in early lactation was twice as large as that estimated in an average lactation affected by SCM.

CM is the more severe form of mastitis, and a higher yield loss resulting from CM as compared with SCM is, thus, a logic finding. CM is associated with a larger amount of affected udder tissue, which results in more severe udder damage with decreased synthetic capacity of the mammary gland as a consequence.

Lactation Stage

The timing of mastitis in lactation had profound impact on the magnitude of yield loss (Papers I and III). Milk yield in cows developing CM before peak yield was most severely affected (Paper I). Partly, this can be expected to be due to the effects of CM being experienced over a longer period of time. Udder-tissue damage caused by CM in early lactation will, thus, suppress milk yield throughout lactation (in accordance with the findings in Paper I). Also, it may be speculated that CM in early lactation obstructs the differentiation of secretory cells, which takes place in this period and is responsible for the increase in milk yield until peak lactation (Capuco *et al.*, 2001), thus resulting in more severe reduction of milk yield. Another explanation of the high yield loss associated with early occurrences of CM is related to that, in this stage of lactation, milk yield is increasing. High production can cause impairment of the immune system due to metabolic stress (Knegsel et al., 2007). When cows are in negative energy balance, body fat is converted to ketone bodies, and hyperketonemia has been suggested to be one of the most important factors causing impairment of the udder defence mechanisms (Janosi *et al.*, 2003; Suriyasathaporn *et al.*, 2000). It is likely that the impaired immune system in cows in early lactation results in reduced ability to battle infection, which contributes to the more severe depression of milk yield associated with CM. Cows are in negative energy balance until approximately weeks 7 to 9 of lactation (Suriyasathaporn et al., 2000), which coincides with the stage of lactation in which CM gives rise to the most extensive yield loss.

Increased SCC had the most detrimental effect on milk yield in late lactation. It has been suggested (Hortet et al., 1999), that poorer udder health status, caused by increased exposure to pathogens, increased prevalence of infection, and subsequent permanent glandular damage from previous infections, is responsible for the higher milk loss associated with an increase in SCC in late lactation. In Paper III, this explanation was tested using a sub-dataset containing only test-day records sampled in lactations in which CM did not occur and that were not immediately preceded by a lactation affected by CM. The obtained regression coefficients were similar to those estimated in the original analyses, and it was, therefore, concluded that milk loss related to an increase in SCC was highest towards the end of lactation, irrespective of whether cows had a history of CM or not. A different explanation for the higher yield loss associated with high SCC in late lactation was proposed: the fact that the udder is in a catabolic state. The degenerative process taking place might influence both the udder's ability to repair itself after infection and the compensatory ability of uninfected quarters. The compensatory ability of uninfected quarters has, indeed, been found to be lower in late than in early lactation (Hamann & Reichmuth, 1990). Hamann and Reichmuth (1990) argued that the potential for yield compensation is related to the number and activity of secretory cells, supporting the above reasoning.

Parity

Parity of the cow was another important determinant of the extent of yield loss caused by mastitis (Papers I and III). Multiparous cows consistently suffered more severe yield loss than primiparous cows. This might be explained by multiparous cows having a higher yield level, and that they, simply, have more milk to lose. The relative yield loss was, however, also larger in multiparous cows, which indicates that this is not the full explanation. It may be hypothesized that the immune system becomes less efficient as cows get older, which might result in less complete cure of mastitis, with more extensive tissue damage and more severe yield loss as a consequence.

Production Level

Cows that developed CM tended to have higher initial milk yield than cows without CM (Paper I). The fact that high-yielding cows are more likely to develop CM further adds to the economic damage of the disease, and might suggest that the estimates reported in Paper I possibly underestimated the actual yield loss caused by CM. In Paper I, yield loss was expressed relative to the production level of cows without CM. Cows that developed CM in lactation weeks 1 to 8 and 9+ produced 2.5 and 0.8 kg ECM per day, respectively, more milk than their non-mastitic herd mates prior to three weeks before diagnosis (Paper II). Considering that most cases of CM develop in early lactation, these figures correspond well with the production advantage of mastitic cows of 2.6 kg milk reported by Wilson *et al.* (2004). In view of this, it might actually be reasonable to assume that another 2.5 kg milk could be added to the daily yield loss estimated in Paper I without overestimating the yield loss caused by CM.

Most cows in a herd are in second or later lactations. Considering that most CM cases occurred in multiparous cows (Paper I), and that the median SCC in later parts of lactation in multiparous cows was more than twice the size of that in primiparous cows (Paper III), it can be concluded that the majority of milk loss caused by mastitis in a herd is suffered by multiparous cows. Furthermore, most of this yield loss is likely to occur in early and late stages of lactation.

Importance of Mastitis to Herd Profit

The yearly avoidable cost of mastitis in a Swedish 150-cow herd, assuming that the initial incidence of mastitis could be reduced by 50%, corresponded to 5% of the herd net return in the initial situation (Paper IV). Mastitis was thus of considerable importance to the economic performance of the herd, confirming findings of Hansson (2007) who reported that average milk production per cow-year and incidence of mastitis were the only significant indicators of economic efficiency in Swedish dairy herds among several investigated predictors (incidence of mastitis, average milk production per cow-year, average protein content of milk, average herd fertility, and involuntary culling rate).

Main components of the increase in net return when the incidence of mastitis was reduced were increased income from milk sales, because of higher production per cow-year and higher milk price as a result of an increased proportion of delivered milk with an SCC below 200 000 cells/ml, and reduced veterinary costs (Paper IV, Figure 4). When all cases of CM were eliminated, income from milk sales increased substantially more than when no SCM cases were modelled. Also, CM was always associated with veterinary costs, and, when all cases where eliminated, these costs were avoided. It is thus clear from Paper IV that CM is more influential on herd profit than SCM.

Implications for Mastitis Control

The impact of mastitis on herd-level economy can be reduced by various interventions, which are of proactive or reactive nature. Measures aiming at preventing new cases of mastitis from occurring include breeding, improvement of milking hygiene, implementation of post-milking teat disinfection, regular controls of the milking equipment, implementation of milking order, and improvement of bedding material. Antibiotic treatment protocols, dry cow therapy, and culling regimes are examples of actions that are taken in order to limit the impact of mastitis once it has occurred. Discarding milk with high SCC, in order to increase the price of the delivered milk, can also be regarded as a means to reduce the economic damage caused by mastitis.

Prioritization between Cows

The most extensive yield loss occurred in multiparous cows diagnosed with CM in early lactation. To make matters worse from an economic point of view, most cases of CM developed in this category of cows (Paper I). Preventive measures should, therefore, focus on reducing the incidence of mastitis in multiparous cows at early stages of lactation. This can be attempted by enhanced mastitis control in primiparous cows, because cows that have suffered a previous case are at substantially increased risk of developing subsequent cases (Steeneveld *et al.*, 2008; Bendixen *et al.*, 1988).

Economic Framework

Mastitis control incurs additional costs for the milk producer in terms of investments and extra labour requirement. Estimates of the avoidable cost of mastitis, which expresses the maximum viable expenditure on preventive measures per year, are thus necessary to determine the amount of money that can be invested into mastitis control. In a Swedish 150-cow herd with initial incidences of CM and SCM of 32 and 33 per 100 cow-years, respectively, € 8 095 could be spent on mastitis control on a yearly basis, if that investment results in a 50% reduction of the incidence of mastitis (Paper IV). This amount of money equates to 1.2 hours of external labour per day (at a cost of €17.8 per hour (Agriwise, 2008), which can be spent on improving management routines. Alternatively, €57 000 could be invested in improved milking equipment which might contribute to better udder health status, or be invested in technical tools, such as an in-line SCC indicator, which would facilitate monitoring of udder health in the herd. The maximal investment is calculated by the annuity method, with an interest rate of 7% per year and a depreciation period of ten years.

The costs associated with implementation of different preventive measures differ. Moreover, different preventive measures are not equally effective in reducing the incidence of mastitis. The profitability of a certain control strategy is thus determined by the difference between its cost and the value of the reduction in mastitis incidence that it can achieve. To further complicate matters, the efficiency of different approaches to control mastitis varies depending on milking system. For example, Yalcin *et al.* (1999) showed that dry-cow therapy reduced SCC in herds milking in parlour, but not in herds with tie-stalls. Further studies are therefore needed to answer which preventive measures are most appropriate in the context of a specific herd.

Control expenditures arise as a consequence of a mastitis problem and should therefore be attributed to mastitis (McInerney *et al.*, 1992). Thus, in order to obtain an estimate of the total economic cost of mastitis, costs of prevention should be added to the estimates of economic loss proposed in this thesis.

Different Estimates Support Decisions at Different Levels

Mastitis control is practiced at different levels. The nature of the decision that is to be supported determines which estimate of the economic loss associated with mastitis that is of interest in a certain situation.

Cow-level decisions most often concern which actions that should be taken after a case of mastitis has been confirmed. In this case, the economic loss per case is the most relevant estimate. The expected extent of yield loss must then be taken into consideration, because it constitutes the major component of economic loss caused by mastitis.

The avoidable cost of mastitis at herd level is pertinent when the economic viability of mastitis control programs is to be assessed.

When economic weights of traits in the breeding goal are calculated, it is the avoidable economic cost associated with mastitis per cow-year that is the most appropriate input. It can be debated whether yield loss should be included in the economic loss caused by mastitis in this context, because if yield loss is already part of the genetic evaluation for milk yield, i.e. the milk yield of an affected cow is considered her production potential, then including yield loss also when deriving the economic weight of mastitis would double-count this effect. Milk loss is, however, a consequence of mastitis, and neglecting it in the genetic evaluation might underestimate the economic importance of mastitis.

Economic Loss per Case of Mastitis

Inconsistency of Estimates

Considerably different estimates of the average economic loss per case of CM were obtained in Papers II and IV. These figures are, however, not directly comparable. The model in Paper IV was a development of that in Paper II and there were, consequently, some differences in the underlying assumptions. All of these contributed to the lower estimate of average economic loss per case of CM obtained in Paper IV.

The cost of extra labour requirement associated with treatment of CM was included in the fixed economic loss per case of CM (veterinary and treatment costs) in Paper II, but not in Paper IV. Which approach that is most correct depends on the assumed opportunity cost of labour, which, in turn, depends on the source of labour. Whether or not extra labour has been included in the economic loss caused by mastitis in previous studies has, indeed, varied (Table 4). SimHerd does not consider labour as a variable cost (Østergaard *et al.*, 2005), and we, therefore, found it most suitable not to include extra labour requirement in the economic loss associated with CM when the economic parameters were updated for the analyses conducted in Paper IV.

Milk sorted out due to high SCC was produced by cows without CM, and such milk was modelled to be fed to calves, thus, reducing the need for milk replacer. It was, consequently, assigned alternative value. SimHerd did not distinguish between this milk and milk not sold due to treatment of CM. As a result of this, milk produced in the withdrawal period was assigned alternative value in Paper IV, but not in Paper II. In this context, it needs to be stressed that feeding milk produced by cows receiving treatment to calves is not a recommended practice, because it increases antibiotic resistant bacteria in the lower gut of calves (Langford *et al.*, 2003).

Another, and probably the most important, explanation for the differences is that Paper II addressed the impact of the first lactational incidence of CM whereas Paper IV considered recurrent cases within the same lactation. When multiple cases developed, yield loss was defined based only on the impact of the most recent case. For instance, if a cow developed CM in lactation week two, and then again in lactation week four, the yield loss in lactation week five would be related only to the case occurring in lactation week four. The case developing in lactation week two would, thus, only incur yield loss in lactation weeks two and three. As a consequence, the average yield loss *per case* of CM was lower in Paper IV, 551 kg ECM, as compared with 797 kg ECM in Paper II. Considering that the average price per delivered kg ECM was €0.288 in Paper IV, the value of a 246 kg ECM lower yield reduction equates to €71. If the average yield loss would have been the same in Paper IV as in Paper II, €71 should be added to the estimated average economic loss per case of CM, and a new estimate of €346 (compared with €428 in Paper II) would be arrived at. Also, yield loss in the weeks before clinical onset was attributed to CM in Paper II. This effect was assumed to be caused by SCM in Paper IV and was, thus, not included in the yield loss caused by CM.

Based on these arguments, it is relatively safe to assume that the actual average economic loss per case of CM lies somewhere between €275 and €428. The former estimate was, however, derived from a more complete model, where recurrent cases of CM as well as SCM were adjusted for. The importance of representing effects of both CM and SCM when assessing the impact of mastitis in a dairy herd is stressed by the fact that estimates of net return per cow-year are highly sensitive to the severity of mastitis cases (Østergaard *et al.*, 2005), and by subclinical cases being responsible for a large proportion of the total economic loss associated with mastitis (Huijps *et* *al.*, 2008; Yalcin, 2000). The estimate obtained in Paper IV is, consequently, likely to be more correct and the average economic loss of a case of CM will, in the remaining sections, be assumed to be €275.

Consistency with Previously Published Estimates

Estimates of the cost per case of mastitis, published since 1990, are summarized in Table 3. The average estimate is presented when studies reported several estimates. Studies based on old data (e.g. McInerney *et al.*, 1992) or concerning non-lactating cows (Hillerton *et al.*, 1992) are not included. Estimates have been adjusted for the effect of inflation by the use of consumer price indices (Organization for Economic Co-operation and Development, 2009) and are expressed in the price level of 2007, which agrees with the price level applied in Paper IV. Estimates originally expressed in other currencies have been converted to Euro (exchange rate of 18 November 2008, Paper IV) to facilitate comparison of results.

Table 3. *Estimates, published since 1990, of the cost per case of clinical (CM) and subclinical mastitis (SCM) in lactating cows*

Reference	Country	Severity	Method	Cost per case (€)
Paper IV	Sweden	CM	SS[1]	275
Paper II	Sweden	CM	SS	413
Bar *et al.* (2008b)	US	CM	DP[2]	146
Huijps *et al.* (2008)	The Netherlands	CM	PB[3]	205
Wolfová *et al.* (2006)	Czech Republic	CM	PB	71
Østergaard *et al.* (2005)	Denmark	CM[4]	SS	360
Kossaibati & Esslemont (1997)	UK	CM[5]	PB	519
Sandgren & Emanuelson (1994)	Sweden	CM	PB	350
Miller *et al.* (1993)	US	CM	PB	142
Belotti (1991)	Sweden	CM[4]	PB	420
Paper IV	Sweden	SCM	SS	60
Steeneveld *et al.* (2007)	The Netherlands	SCM[6]	SS	115[7]
Swinkels *et al.* (2005a)	The Netherlands	SCM[8]	PB	116
Swinkels *et al.* (2005b)	The Netherlands	SCM[6,9]	PB	130

[1]*Stochastic simulation;* [2]*dynamic programming;* [3]*partial budget;* [4]*assuming that SCM is a natural part of CM;* [5]*severe case;* [6]*Streptococcus uberis;* [7]*without treatment;* [8]*Staphylococcus aureus;* [9]*Streptococcus dysgalactiae.*

The cost per case of mastitis differed between studies: estimates of the cost of a case of CM ranged between €71 and €519. Thus, compared to findings in the literature, the average economic loss of €275 per case of CM obtained in Paper IV is a relatively intermediate value.

Cost components included in the total cost of mastitis differed widely between studies (Table 4), which probably explains a substantial part of the large variation in estimates. Veterinary costs, drugs, discarded milk, yield loss, and culling were frequently included, whereas other cost components, such as effects on milk composition, mortality, and spread of infection to healthy cows, were more infrequently accounted for. None of the reviewed studies considered increased risk of subsequent disorders (other than mastitis) or reduced fertility.

Table 4. *Cost components considered in studies, published since 1990, estimating the cost of mastitis in lactating cows*

	Considered consequences of mastitis											
Reference	Vet	Drugs	Discarded milk	Yield loss	SCC	Feed	Extra labour	Mortality	Culling	New case	Contagiousness	Prevention
Paper IV[1]	X	X	X	X	X	X		X	X	X		
Paper II	X	X	X	X	X	X	X	X	X			
Bar *et al.* (2008b)		X	X	X			X	X	(X)[2]	(X)[2]		
Huijps *et al.* (2008)	X	X	X	X		X	X		X			
Wolfová *et al.* (2006)	X	X	X				X					X[3]
Østergaard *et al.* (2005)	X	X	X	X	X	X		X	X	X		
Kossaibati & Esslemont (1997)	X	X	X	X					X			
Sandgren & Emanuelson (1994)	X	X	X				X		X			
Miller *et al.* (1993)	X	X	X	X			X	X	X			
Belotti (1991)	X	X	X	X		X	X		X			
Paper IV[4]				X	X	X		X	X	X		
Steeneveld *et al.* (2007)[5]	X[6]	X[6]	X[6]	X					X		X	
Swinkels *et al.* (2005a)		X[6]	X[6]	X					X			
Swinkels *et al.* (2005b)				X					X		X	

[1]Clinical mastitis; [2]not included in cost, but accounted for in model; [3]dry-cow therapy; [4]subclinical mastitis; [5]without treatment; [6]applicable to clinical flare-up.

Earlier Swedish studies have arrived at higher estimates of the economic loss per case of CM than Paper IV. These investigations used a simpler analytical approach, partial budgeting, and herd dynamics were, consequently, neglected. Differences are likely to arise as a consequence of dissimilar analytical approaches applied. It has been pointed out (Bar *et al.*, 2008b), that static models, such as partial budgets, often overestimate the economic loss associated with an average case of mastitis. The cost of mastitis is not the same in all cows, even if they are of the same parity and develop mastitis in the same stage of lactation. Mastitis affecting a cow that should be replaced anyway is, in practice, associated with a lower cost, whereas mastitis in cows of high future expected income is more costly (Bar *et al.*, 2008b). The expected value of a mastitic cow will influence whether she receives treatment, which, in turn, will affect the magnitude of yield loss suffered. Dynamic models, therefore, often include a lower average yield loss per case of mastitis. Culling of mastitic cows is, to a large extent, a voluntary decision made by the farmer, and depends on the lactational timing of CM and pregnancy status of the cow (Schneider *et al.*, 2007). Such interactions are not easily accounted for in static models. Static models attributing treatment costs, yield loss, and costs associated with increased risk of culling to every case of mastitis might, thus, overestimate the economic loss.

It is difficult to make unbiased inferences about the impact of methodology on estimated cost per case of mastitis based on the summarized studies, because most of them obtained their estimates by means of partial budgeting. Studies applying stochastic simulation or dynamic programming arrived at estimates that fell within the range of estimates in studies using partial budgeting, and variability was thus larger within a specific analytical approach than between analytical approaches. Other factors, such as the economic value assigned to each component of loss included in the cost per case of mastitis, therefore seemed to be more important than the analytical approach applied.

Estimates of the cost per case of CM in Western Europe were higher than those in the US, which was somewhat unexpected due to the absence of a milk-quota system in the US. Mastitis is more costly in a non-quota situation, because the reduction in milk yield subsequent to mastitis directly affects herd net returns by means of reduced milk sales. Where a quota system is in place, farmers usually compensate the lower average production brought about by mastitis with keeping cows in the herd beyond their intended culling date (Swinkels *et al.*, 2005a). In Papers II and IV, no milk quota was modelled even though it is well known that the economic loss associated with mastitis depends on the presence or absence of a milk quota, and despite the fact that milk is produced under a quota system in Sweden. The amount of milk produced in Sweden is, however, not enough to fill the quota (Swedish Dairy Association, 2009), and Swedish milk production, thus, functions as if no milk quota was present.

Differences between studies conducted in different spatiotemporal contexts can, at least to some extent, also be explained by different pathogen frequencies. For instance, CM caused by environmental pathogens (primarily *E. coli*) have been reported to be more costly than CM caused by contagious pathogens (Miller *et al.*, 1993). Swinkels *et al.* (2005a; 2005b) did, however, estimate relatively similar cost per case of SCM, irrespectively of whether *Staph. aureus*, *Strept. uberis* or *Strept. dysgalactiae* was the causative agent.

Different circumstances of production, management routines, and attitudes towards the use of antibiotics are other factors likely to contribute to differences between estimates obtained in different countries. Likewise, prices and costs can be expected to differ. Indeed, the cost per case of CM has been found to depend on exogenous factors, primarily the milk price (Bar *et al.*, 2008b): when a 20% higher milk price was modelled an 18% higher cost per case of CM was reported.

All reviewed studies investigating the cost per case of SCM originated from the Netherlands and were conducted closely in time (Table 3). They also arrived at very similar estimates. The estimate of €60 per average case of SCM obtained in Paper IV was about half the size compared with those calculated by Steeneveld *et al.* (2007) and Swinkels *et al.* (2005a; 2005b). These studies investigated the cost of SCM caused by specific pathogens, whereas Paper IV did not take the causative pathogen into account. More importantly, different definitions of SCM were applied. In the three Dutch studies, SCM was defined as two out of three consecutive milk samples, taken at 3 or 4-week intervals, with SCC > 250 000 cells/ml. This definition requires that SCC is elevated for at least seven weeks, and, if it were to be applied in Paper IV, no cases of SCM would have occurred in primiparous cows because of the insufficient response in SCC. Modelled cases of SCM in Paper IV were, consequently, milder than those investigated by Steeneveld *et al.* (2007) and Swinkels *et al.* (2005a; 2005b), and a lower estimate of average economic loss per case is, thus, reasonable.

Economic Loss caused by Mastitis in Sweden

There are 350 000 dairy cows in Sweden (Swedish Board of Agriculture, 2008a). Considering the estimated avoidable cost of mastitis of €54 per cow-year (Paper IV), the national avoidable cost can roughly be estimated at €19 millions per year. This figure does not include costs of prevention and costs that mastitis incurs to the processing industry. It is thus not an estimate of the total cost of mastitis, and, as such, it must be interpreted with care.

The proposed estimate does, however, give a hint of the extent of the economic damage caused by mastitis each year.

No comparison of the national economic costs due to different production diseases in cattle has been conducted under Swedish circumstances of production. A British study (Bennett *et al.*, 1999) has, however, investigated the economic impact of numerous diseases simultaneously, and came to the conclusion that mastitis, because of its high incidence and high financial impact per affected cow, had the largest economic impact on cattle production in the UK.

Discarding Milk with High SCC

The possibility that discarding milk with high SCC could reduce the economic loss associated with mastitis in dairy herds was refuted in Paper IV. Discarding milk with high SCC was never profitable in herds with average BTSCC between 158 000 and 236 000 cells/ml, because substantial amounts of milk had to be discarded. That generated an economic loss that was not offset by the increase in the milk price. It should be pointed out that discarding milk with high SCC was not economically justified, even though the discarded milk was assigned alternative value and extra labour costs were neglected. If discarded milk were not fed to calves, or if sorting of milk would require some monitoring, then the impact of discarding milk with high SCC would have been even more negative.

The results of Paper IV suggest that the quality of delivered milk has less impact on herd net return than the amount of delivered milk, supporting the findings of Hansson (2007) who concluded that milk quality was not a significant indicator of economic performance in Swedish dairy herds whereas milk yield per cow was. The current Swedish milk-pricing system does, consequently, not serve as a strong motivation to discard milk with high SCC. Premiums and penalties are, however, an important motivation for farmers to improve udder health management (Valeeva *et al.*, 2007), and the current milk-pricing system is, thus, likely to stimulate efforts to reduce BTSCC. Some concerns regarding the current milk-pricing system are, nevertheless, raised by the fact that the impact of discarding milk with high SCC on net return per cow-year was most negative when the incidence of mastitis was high. The extra premiums received when delivering milk with lower SCC did not compensate for the economic loss incurred by discarding milk. If the milk-pricing system is supposed to serve as an incentive to farmers to improve the quality of delivered milk, then premiums and penalties need to be revised. This, of course, invokes the issue of designing a new milk-payment scheme that would make it profitable to discard milk with high SCC. It needs to be stressed that it is not recommended to proceed with making changes in the milk-pricing system until scientifically supported regulatory limits have been proposed.

Methodological Issues

Reference Level for Yield in Healthy Cows

Cows that develop CM tend to have a production advantage over non-mastitic cows before diagnosis (Gröhn *et al.*, 2004; Wilson *et al.*, 2004; Rajala-Schultz *et al.*, 1999b). In Paper I, the seemingly higher 305-day yields of cows developing CM in mid or late lactation were most certainly a consequence of mastitic cows producing above the level of non-mastitic cows to such an extent that their cumulative 305-day yields were higher, even though they had suffered from CM towards the end of lactation. Therefore, using the yield of non-mastitic cows as the reference for production in healthy cows will underestimate the true yield loss caused by CM.

In future studies aiming at assessing the impact of mastitis on milk yield, it is recommended to account for the higher initial milk yields of mastitic cows. One means to do this is to express yield loss relative to cows' pre-mastitic milk yield. This approach does, however, impose problems because most cases of CM develop in early lactation where no information on pre-mastitic yield is available. This can, to some extent, be overcome by using the yield level in the previous lactation(s) for multiparous cows, and accounting for the expected yield change to this lactation. An appealing possibility would be to correct for a cow's genetic and permanent environmental effect for milk-yield in the models, and, thus, obtain estimates that are less biased due to the relation between milk yield and mastitis.

Recurrent Cases of CM

Cows that have suffered from a case of mastitis are at increased risk of developing subsequent cases (Rajala & Gröhn, 1998; Houben *et al.*, 1993). Still, the average number of CM cases per lactation was only 1.3 in the dataset studied in Paper I. Only the impact of the first lactational incidence of CM was, however, studied. By only including the first incidence, the entire lactational yield loss was attributed to just one case. Thus, in lactations with recurrent cases, the loss assigned to the first case will be overestimated. To obtain less biased estimates of the yield loss caused by a single case of

CM, lactations with multiple cases could have been excluded from the analyses.

Estimates of Yield Loss Obtained from One Herd

Yield losses estimated in Papers I and III were based on a dataset sampled in only one herd. In comparison with average Swedish figures, the herd has low BTSCC but high incidence of CM. The studied herd was, however, a research herd, and the surveillance of animals was probably more extensive than what can be expected in commercial dairy herds. As a consequence of this, more CM cases than normally were likely detected. Also, some of the reported cases were presumably milder than those reported by practicing veterinarians, which might have influenced the size of the estimated yield loss. The estimates obtained in Paper I can, therefore, be utilized in decision-support without any risk of overestimating the yield loss caused by CM.

Among the pathogens present in culture-positive milk samples taken in the research herd, a relatively large proportion was of environmental origin. As different pathogens give rise to different extent of yield loss, it might be argued that the estimates are not applicable in the average Swedish herd, where environmental pathogens, generally, are less frequent (Persson Waller *et al.*, 2009). The sampling procedure in the research herd can, however, not be compared with that applied in commercial herds. Milk samples for bacteriological culture were collected by routine at pre-determined weeks in lactation, and not only when clinical symptoms were observed or when cows were suspected to be subclinically infected. It may be speculated that the bacteriological findings do, indeed, represent a pattern of infection that is representative also in other herds, but that is currently undetected due to the way in which sampling normally is conducted.

Definition of SCM

From a management perspective, estimates of the lactational yield loss caused by SCM occurring in different stages of lactation would have been of great interest, because such information could provide insight into the expected economic benefit that could be achieved if proper actions were taken. In order to obtain such estimates, however, a definition of a case of SCM would have been required. Subclinical mastitis does, by definition, not give rise to visible symptoms, and cannot be diagnosed by the milkers. Instead, SCM is defined based on SCC or other indicators. SCC is measured on a continuous scale, and, even though SCM is a dynamic condition, different threshold values are usually used to distinguish between healthy and affected cows.

In Paper III, a threshold of 50 000 cells/ml was used to distinguish between healthy TD and TD affected by SCM in lactation weeks 2 to 44. This threshold was suggested by Hortet and Seegers (1998a), and was based on a review of studies on SCC in bacteriologically negative cultures; i.e. Laevens et al. (1997) who reported an SCC of 49 000 cells/ml in composite milk samples and Schepers et al. (1997) who found SCC around 14 000 cells/ml in udder quarter foremilk samples. Higher thresholds of 175 000 and 200 000 cells/ml in primiparous and multiparous cows, respectively, were applied in the first week of lactation (Paper III), because SCC is elevated in the colostrum period irrespective of whether the cow is affected with mastitis or not (Dohoo & Meek, 1982). These thresholds were defined based on bacteriological cultures of milk samples, taken by routine in the research herd in the first week of lactation from the fall of 1997.

A threshold of 200 000 cells/ml is commonly applied to distinguish between healthy cows and cows affected by SCM. With respect to the findings of the previously mentioned studies, such a threshold is far too high. Also, the results obtained in Paper III indicate that milk yield is reduced on TD with an SCC of 200 000 cells/ml, as compared to TD with an SCC of 50 000 cells/ml. Applying a threshold of 200 000 cells/ml will, consequently, result in that the importance of SCM is underestimated, and that proper measures are not taken to avoid unnecessary milk loss in affected cows.

A clear drawback with a definition of SCM based only on SCC at a single TD is that SCC is affected by a number of factors. Infectious status of the mammary gland is clearly the most important one, but season, stress and management mishaps also assert an effect on SCC (Reneau, 1986; Dohoo & Meek, 1982). Individual TD results are therefore rather inconclusive.

In order to increase the accuracy of diagnosis, it has been suggested (De Haas *et al.*, 2004; Reneau, 1986; Dohoo & Meek, 1982) that SCM should be defined based on measurements of SCC taken over a series of consecutive TD. In Sweden, "udder disease status", based on SCC measured at three monthly test milkings, is used as a prognostic tool to identify individual cows that are likely to be affected by infectious mastitis (Brolund, 1985). De Haas et al. (2004) derived the SCC-patterns of clinically infected cows based on 3 to 5 TD results, recorded with intervals of three or four weeks. With such long sampling intervals, actually detecting an increased SCC will depend on when, with respect to sampling, infection occurred, but also on the duration of the increase in SCC, as pointed out by

De Haas et al. (2004). If this method were to be applied to SCM, subclinical infections could cure spontaneously or turn into a clinical infection before diagnosis based on a completed SCC-pattern could be made. A shorter time interval between TD is, thus, preferable if diagnosis of SCM is to be based on SCC-patterns. Patterns should preferably be based on daily observations, because SCC fluctuates from day to day (Reneau, 1986), and even between between milkings on the same day (Olde Riekerink *et al.*, 2007b).

Strategies for Modelling Yield Loss

Using specific yield-loss patterns for different periods in lactation or just one yield-loss pattern, irrespective of the lactational timing of CM, only marginally affected the estimated economic impact of CM (Paper II). This was particularly evident when mastitic cows' own yield level, had they not developed CM, was used as reference for production of healthy cows when yield losses were estimated. The lack of effect of modelling strategy on average economic loss per case of CM was probably due to that the average yield loss did not change much as most CM cases were modelled to occur in early and late lactation. In these periods, yield loss modelled by specific yield-loss patterns in different periods of lactation was higher and lower, respectively, compared with the yield loss modelled when one yield-loss pattern was used throughout lactation. This is likely to have evened out any difference between the modelling approaches.

The results of Paper II, consequently, suggest that using one yield-loss pattern, irrespective of when in lactation CM occurs, is good enough, and that this approach to assess yield loss is adequate for application into decision-support systems.

Method of Economic Analysis

The analytical approach is often suggested to be one of the reasons for the variation in estimates of cost of mastitis obtained in different studies. The aim of the studies reviewed earlier was to estimate the cost of mastitis, and none of them, therefore, investigated a possible impact of methodology on the result. Stochastic modelling is suggested to be the most relevant method for assessment of economic impact of disease in dairy cattle because of its capability to account for herd dynamics. Simulation models are, however, not transparent, and are therefore not a very appealing tool for advisors. Partial budgets, on the other hand, are transparent, but are sometimes argued not to provide reliable estimates because of their inability to account for stochastic or dynamic elements.

Paper II provided estimates of the average economic loss per case of CM estimated by stochastic simulation. To provide some insight into the impact of methodology on economic loss per case of CM, the economic loss of a case of CM will now be calculated using a simple partial budgeting approach. As far as possible, cost components will be assigned the same values as in Paper II. The estimate obtained in Paper II applied to an average case of CM. The extent of yield loss caused by CM shows large variation depending on in which week of lactation the cow is diseased (Paper I). In the partial budget analysis it is therefore assumed that CM occurred in the first lactation week, because this was the week in which most cows developed CM in the dataset used in Paper I. Furthermore, as most cows in Paper II (65%) were simulated to be in their second or later parity, the economic loss of a case of CM in a multiparous cow is estimated.

Extra Costs

When a cow is diagnosed with CM and treatment is necessary, a veterinarian is consulted (required by Swedish legislation). An average fixed cost of €133 per case, including extra labour requirement, veterinary costs and drugs, was assumed. Clinical mastitis increases the risk of culling, and, thus, incurs replacement costs. In previous studies, it has been assumed that 15 to 20% of CM cases result in culling (Huijps *et al.*, 2008; Sandgren & Emanuelson, 1994). The cost of culling can, roughly, be estimated as the cost of a replacement heifer minus the slaughter value of the culled cow. The value of a heifer is €952, and the meat from a slaughtered cow generates an income of €0.86 per kg live weight. Assuming that 15% of CM cases leads to culling and that live weight is 630 kg, extra costs associated with increased culling can be calculated as 0.15 x (€952 - €0.86 x 630) = €62. Extra costs associated with a case of CM in a multiparous cow in lactation week one are, consequently, €133 + €62 = €195.

There are a couple of other aspects as regards culling due to mastitis that ought to be considered. Replacement animals are almost exclusively heifers, and primiparous cows have lower lactational milk yields than multiparous cows. By replacing an older cow with a younger, the production advantage of the older cow is lost. The value of the extra volume of milk that would have been produced if the older cow had not been culled should be included in the economic loss caused by CM. On the other hand, a heifer is on average genetically superior to the culled cow. Finally, a heifer is not always available when a cow must be replaced. If so, a stall will be empty and the production potential of the herd will not be fully utilized. It might be argued that the loss in income as a consequence of reduced capacity utilization should be attributed to CM. These considerations will, however, be ignored for reasons of simplicity.

Returns Foregone

A multiparous cow developing CM in the first week of lactation suffers a yield loss of 782 kg milk (Paper I). Considering an average price per kg milk of €0.29, the economic loss caused by reduced milk yield amounts to €227. When the cow is diagnosed with mastitis, she receives antibiotics. Neither the milk produced during the treatment period nor the milk produced during the waiting period following treatment can be sold. The total withdrawal period subsequent to treatment usually lasts for eight days. The average daily milk yield in a multiparous cow diagnosed with CM in the first week of lactation is about 17 kg (Paper I), and the cost of the discarded milk is, consequently, €39. This is actually an underestimation of its economic value, because discarded milk is produced by the cow and is, consequently, associated with feed costs. The value of discarded milk is, thus, higher than that of lost milk yield. In spite of this, all milk not delivered will now be assigned the same value, resulting in an economic loss caused by returns foregone of €227 + €39 = €266.

Additional Returns

Milk produced in the withdrawal period is sometimes fed to calves. In this case, the discarded milk has an alternative value corresponding to the value of the milk replacer saved. The economic loss associated with discarded milk would then, obviously, be less. Feeding milk produced by cows treated with antibiotics is, however, not recommended and discarded milk will not be assumed to have an economic value.

Reduced Costs

When cows are affected by CM, feed intake is reduced (Bareille *et al.*, 2003). Østergaard *et al.* (2005), for instance, modelled a reduction of feed intake of 7, 5, and 2%, respectively, in the three weeks following CM diagnosis. The amount of money saved from reduced feed intake is, however, difficult to assess, because it will depend on the feedstuffs used, and will be neglected here.

Consequences Not Considered

Extra labour requirement and the increased risk of mortality caused by CM are not accounted for, and these factors were also not included in Paper II. Effects of CM on milk composition were not included, because it has been argued (Seegers *et al.*, 2003) that changes in fat and protein content can be neglected in economic calculations as milk produced in the withdrawal period is discarded and losses occurring later in lactation are proportional to the milk loss. Also, increased SCC is not considered as BTSCC and the amount of milk produced in the herd will influence whether or not a case of CM affects milk price (Østerås, 2005).

In this simple partial budgeting approach, an economic loss of €461 per case of CM was estimated. This figure is similar to the estimate of €428 obtained in Paper II, supporting the notion that the value assigned to each cost component is more influential on the estimate than the analytical approach. A well-parameterized partial budget is, therefore, able to provide reliable estimates of the economic loss associated with production disorders.

Main Conclusions

The yearly avoidable cost of mastitis in a Swedish 150-cow dairy herd, assuming that the initial incidence (32 and 33 cases of CM and SCM per 100 cow-years, respectively) can be reduced by 50%, is slightly more than €8 000. This figure corresponds to 5% of the net return given the initial incidence of mastitis. Expressed per cow/year, the avoidable cost of mastitis is €50.

The economic loss associated with mastitis cannot be reduced by discarding milk with high SCC, because this resulted in a substantial decrease of the volume of sold milk, which was not offset by the increase in milk price. Under the current milk-pricing system, it is, consequently, more profitable for farmers to sell a larger volume of milk with higher SCC than to discard high SCC milk in order to obtain a higher average milk price.

The average economic loss per case of CM and SCM are €275 and €60, respectively. Reduced milk production constitutes the major cost component of the total economic loss caused by mastitis. The magnitude of yield loss is determined by the stage of lactation in which the cow develops mastitis: milk yield is most severely affected when CM occurs in early and when SCM occurs in late lactation. The lactational yield loss associated with CM varies between 0 and 705 kg in primiparous cows and between 0 and 902 kg in multiparous cows, depending on lactation week at clinical onset. Most cases of CM develop in the first week of lactation and results in a yield loss of 578 and 782 kg milk in primiparous and multiparous cows, respectively. This yield loss is, most likely, underestimated, because it is expressed relative to the production level of non-mastitic cows, and cows developing CM tends to have a production advantage over non-mastitic herd mates before becoming diseased. Daily milk loss at an SCC of 500 000 cells/ml amounts to 0.7 to 2.0 kg in primiparous cows and 1.1 to 3.7 kg in multiparous cows in different stages of lactation. SCM is difficult to define accurately, and the impact of SCM on milk yield was, therefore, assessed in terms of increased SCC. No estimates of the lactational yield loss caused by *a case* of SCM could, consequently, be obtained. The yield loss in *an average 305-day lactation* affected by SCM is, however, 150 and 450 kg milk in primiparous and multiparous cows, respectively.

Practical Implications

This thesis clearly demonstrates that the economic performance of dairy herds can be improved by reducing the incidence of mastitis. A lower incidence of mastitis can be achieved by implementation of mastitis control programs. In order to make scientifically supported decisions regarding mastitis control in dairy herds, however, accurate estimates of the avoidable cost of mastitis are a necessary prerequisite. These are provided in this thesis.

The negative economic consequences of mastitis can be reduced either by preventing new cases from occurring or by strategies aiming to limit the impact of mastitis once it has occurred. It is demonstrated that prevention is preferred over discarding milk with high SCC, because a reduction of the incidence of mastitis resulted in significantly increased net return per cow-year, whereas the effects of discarding milk with high SCC seemed to be poor. Farmers are, therefore, recommended to invest in preventive measures rather than in milk-sorting equipment.

The largest proportion of economic loss associated with mastitis arises from reduced milk production. Yield loss is, however, a hidden cost and it is not always obvious to farmers. It is, therefore, the task of advisors to communicate the relative economic importance of lost milk production, as compared to veterinary costs, and to convey that veterinary costs are to be regarded as a means to limit the potentially more severe economic loss caused by reduced milk production.

Considering that most cows in a herd are of second or later parities and that the incidence of CM, as well as the proportion of TD with increased SCC, is highest in multiparous cows, the majority of the production loss caused by mastitis is likely to be experienced by multiparous cows. Special emphasis should, therefore, be put on reducing the incidence of mastitis in multiparous cows. This can be attempted by enhanced mastitis control in primiparous cows, because cows that have suffered from mastitis are more likely to develop subsequent cases. Attention should be paid to cows in early and late stages of lactation. During these periods, the incidence of mastitis is highest and yield losses are most severe, but, by taking proper actions, unnecessary milk loss can be avoided. High-yielding cows should be given priority, because they are at increased risk of developing CM.

Partial budgets are relatively easy to construct and are able to provide accurate estimates of the economic impact of disease. If reliable information on the effects of disease and the value of cost components are available, they can be used by advisors and farmers to support decisions regarding animal health management.

The incidence of mastitis can be reduced by breeding for increased mastitis resistance. Genetically, CM is not the same trait over time and this should be considered in the genetic evaluation for mastitis resistance (Carlén, 2008). Based on the findings of this thesis, it might be economically wise to use a selection criterion which attaches more weight to CM in early lactation.

The substantial economic loss associated with mastitis is a powerful incentive to improve the udder health of dairy cows, encouraging farmers to put effort into mastitis prevention. In a long-term perspective, this thesis can, therefore, result in improved welfare of dairy cows as it sheds light on the economic importance of mastitis.

Future Research

The presented estimates of yield loss caused by mastitis were based on data sampled in a single herd, where production records sampled at weekly intervals were available. The validity of the results in herds with other production characteristics should be verified by repeating the analyses on data sampled in herds with different incidences of mastitis, yield levels, and pathogen frequencies.

In Papers I and III, production records sampled at weekly intervals were used to estimate the magnitude of yield loss associated with mastitis. The obtained estimates were, consequently, more fine-tuned as compared with those presented in the literature, where similar studies usually have been conducted based on datasets collected at monthly samplings. As milking systems are becoming more and more technologically advanced, data collected even more frequent is becoming readily available. Based on data recorded on a daily basis, or even at individual milkings, the impact of mastitis on milk yield could be further dissected. Estimates obtained in such analyses would improve mastitis management, because farmers could make more well-informed decisions.

An interesting topic to examine is a possible breed difference in the extent of yield loss suffered due to mastitis. Swedish Red cows have lower incidences of diseases than Swedish Holstein cows, which might indicate differences in innate immune function between the breeds. It may be speculated that a better immune function in Swedish Red cows can contribute also to less yield loss due to faster, and more complete, cure. The economic loss associated with mastitis might, consequently, not be the same in both breeds. Therefore, it is worth studying whether economic considerations actually favour the somewhat lower producing, but more robust, Swedish Red cow.

All strategies of mastitis control are not equally effective as regards their ability to increase the economic performance of dairy herds. The profitability of a certain preventive measure is determined by the cost of its implementation and the value of the reduction in mastitis incidence that it can achieve. In order to improve decision support concerning whether individual herds ought to invest in preventive measures and to facilitate prioritization between different strategies, the expected economic viability of different preventive measures should be investigated.

There are technological tools, such as Herd Navigator®, available on the market that enable detection of SCM at an early stage of infection and, thus, allow for early intervention. With early treatment of mastitis, cure rate can be expected to be higher and the economic loss can thereby be reduced. In theory, such equipment has the potential to revolutionize udder-health management. It is, however, associated with an investment of considerable magnitude, and research is required to assess the economic viability of this kind of technology. Preferably, economic calculations should consider the consequences of a, possibly, increased usage of antibiotics resulting from more cases of mastitis being detected.

Discarding milk with high SCC was not an effective strategy to increase herd net return under the current milk-pricing system. The simulated herds did, however, have a relatively low BTSCC, and the impact of sorting of milk in herds with higher BTSCC and higher incidence of CM must also be looked into. If such studies confirm that discarding milk with high SCC is not profitable, an important task for research is to demonstrate the reduced product value of high-SCC milk. Such information can support decisions regarding whether the premium and penalty system needs to be revised, or if new regulatory limits with respect to SCC should be proposed, so that farmers are motivated not to deliver milk of poor quality.

Because mastitis is considered the most costly disease affecting dairy cows, it is often prioritized in herd-health management. Other production-related disorders, such as lameness, might as a result receive less attention, although they are responsible for substantial economic loss. In order to achieve correct on-farm prioritizations regarding disease control, effects of all disorders must be considered simultaneously. To take a comprehensive approach to herd-health management, the economic impact of lameness, metabolic disorders, reproductive disorders, and calving-related disorders, therefore, need to be assessed. In order to facilitate comparison between the obtained results and our estimates of economic loss caused by mastitis, such studies should be performed under Swedish production circumstances.

Ekonomisk betydelse av mastit hos mjölkkor

Bakgrund

Mjölksektorn är utsatt för hårdnande internationell konkurrens. Ekonomiskt effektiva besättningar är därför en förutsättning för att en livskraftig svensk mjölkproduktion ska kunna upprätthållas. Detta medför att det blir allt viktigare att optimera produktionens alla delar och behovet av kostnadsminimering accentueras i takt med att produktvärdet minskar. Ett sätt att minska produktionskostnaderna är att reducera förekomsten av produktionssjukdomar, då dessa leder till reducerad avkastning, kostnader för veterinär och behandling samt ökad utslagning. I detta sammanhang är mastit (juverinflammation) av stor betydelse, eftersom sjukdomen är vanligt förekommande och ger upphov till stora ekonomiska förluster. I besättningar anslutna till kokontrollen förekommer mastit i 16 % av alla laktationer. Sjukdomen kan dock antas vara betydligt vanligare än så eftersom antalet mastiter som upptäcks av djurägare visat sig vara 33 % högre än antalet mastiter i djursjukdata. Juversjukdom, inklusive höga celltal (ett mått på den immunologiska aktiviteten i juvret), utgör den vanligaste utslagsorsaken bland svenska mjölkkor; i drygt en fjärdedel av fallen då kor gallras ut anges juversjukdom som orsak. Detta innebär att 10 % av den svenska mjölkkopopulationen årligen slås ut på grund av juversjukdom.

Förutom rent ekonomiska förluster ger mastit upphov till ett flertal andra negativa påföljder. Sjukdomen medför en ökning av mjölkens celltal, vilket leder till sämre processegenskaper. Vidare förknippas mastit med försämrad djurvälfärd och ökad användning av antibiotika, vilket påverkar konsumenternas attityd gentemot mjölkproduktionen negativt.

De ekonomiska konsekvenserna av mastit kan minskas genom åtgärder som syftar till att förebygga nya fall av mastit eller begränsa effekterna av mastiter då de inträffat. Sådana åtgärder innebär dock extra kostnader för mjölkproducenten i form av produkter och arbete. En förutsättning för att investeringar ska göras är därför att dessa kan förväntas generera ökade intäkter som överstiger kostnaderna. Kunskap om den ekonomiska betydelsen av mastit är därför avgörande när lönsamheten av att investera i mastitprevention ska utvärderas. Vidare påverkar sådan information andra skötselbeslut i en besättning, t.ex. om en ko med mastit ska behandlas, sinläggas eller slås ut, samt om mjölk med högt celltal ska sorteras bort för att på så vis få ett högre pris för den levererade mjölken. På nationell nivå är uppgifter om kostnaden avgörande för t.ex. investeringar i bättre registreringar av mastit i kokontrollen och för att ge mastit rätt ekonomisk vikt i avelsmålet.

Syftet med denna avhandling är att skatta kostnaden för mastit under svenska produktionsförhållanden.

Sammanfattning av avhandlingens delarbeten

Avkastningsförlusternas storlek

Avkastningsförlustens storlek beror på när i laktationen kon får mastit. Klinisk mastit orsakar störst produktionsbortfall då korna insjuknar i början av laktationen, medan förhöjt celltal ger upphov till störst avkastningsförlust när det inträffar i slutet av laktationen. Avkastningsförlusterna är konsekvent högre hos äldre kor än hos förstakalvare.

Klinisk mastit uppträder oftast i första laktationsveckan. Förstakalvare och äldre kor som diagnosticeras med klinisk mastit under den perioden drabbas av ett produktionsbortfall på 578 respektive 782 kg mjölk. Mjölkförlustens storlek varierar mellan 0 och 705 kg (0 till 9 %) hos förstakalvare och mellan 0 och 902 kg (0 till 11 %) hos äldre kor, beroende på när mastiten uppträder. Den dagliga avkastningsförlusten vid ett celltal på 500 000 celler/ml uppgår till 1 till 2 kg mjölk hos förstakalvare och 1 till 4 kg mjölk hos äldre kor, beroende på i vilket laktationsstadium som kon befinner sig. I en genomsnittlig laktation där subklinisk mastit förekommer reduceras avkastningen med 150 och 450 kg mjölk hos förstakalvare respektive äldre kor.

Kostnad per fall

Varje fall av klinisk mastit är i genomsnitt förknippat med en ekonomisk förlust motsvarande 2 800 kr, vilken i huvudsak utgörs av reducerad mjölkproduktion. Ett fall av subklinisk mastit värderas i medeltal till 600 kr.

Besättningsekonomiska konsekvenser

Om den nuvarande förekomsten av mastit i en genomsnittlig svensk 150-kors besättning halverades skulle täckningsbidraget öka med 80 000 kr per år, vilket motsvarar 5 % av täckningsbidraget. Detta belopp motsvarar den maximala årliga investeringen i mastitförebyggande åtgärder, och kan innebära t.ex. ytterligare 1,2 timmars lönekostnad per dag eller en investering om 580 000 kr i ny teknik.

Sortering av mjölk för att sänka tankcelltalet

Ett tänkbart sätt att reducera de besättningsekonomiska effekterna av mastit skulle kunna vara att sortera bort mjölk med högt celltal för att på så vis undvika betalningsavdrag. Flera olika tröskelvärden för sortering har undersökts, men samtliga hade negativ inverkan på täckningsbidraget eftersom en avsevärd mängd mjölk sorterades bort. Under det nuvarande mjölkbetalningssystemet är den levererade mjölkens kvantitet av större betydelse för besättningens ekonomiska resultat än dess kvalitet.

Kostnaden för mastit i Sverige

I Sverige finns ungefär 350 000 mjölkkor. Täckningsbidraget per ko och år är 550 kr lägre än vad det skulle ha varit om mastitfrekvensen hade varit hälften så hög som idag. På nationell nivå uppgår alltså den motsvarande ekonomiska förlusten på grund av mastit till 192 miljoner kr. Denna siffra innefattar inte kostnader för förebyggande åtgärder mot mastit. Om dessa hade inkluderats, vilket skulle varit mer korrekt, skulle den totala kostnaden för mastit varit högre.

Slutsatser

De viktigaste resultaten från avhandlingen kan summeras enligt följande:

- Mastit kostar årligen Sveriges mjölkproducenter 192 miljoner kr
- Kostnaden för mastit uppgår i genomsnitt till ca 550 kr per ko och år
- En klinisk mastit kostar i genomsnitt ca 2 800 kr medan en subklinisk mastit i medeltal kostar ca 600 kr
- De ekonomiska förlusterna p.g.a. mastit kan inte reduceras genom att mjölk med högt celltal sorteras bort
- Den största kostnadsposten i samband med mastit är reducerad avkastning

- Klinisk mastit ger upphov till större avkastningsförlust än subklinisk mastit
- Klinisk mastit orsakar högst avkastningsförluster hos kor som insjuknar tidigt i laktationen
- Subklinisk mastit reducerar dygnsavkastningen mest då kor drabbas sent i laktationen
- Mastit orsakar större avkastningsförlust hos äldre kor än hos förstakalvare
- Kor drabbas oftast av klinisk mastit i första laktationsveckan
- Hög mjölkproduktion är en riskfaktor för klinisk mastit

Praktisk tillämpning av resultaten

Det är tydligt att besättningars ekonomiska resultat kan förbättras genom att förekomsten av mastit reduceras. I en genomsnittlig svensk besättning kan 550 kr per ko och år investeras i mastitprevention, under förutsättning att dagens mastitfrekvens därigenom halveras. Det inte lönsamt för lantbrukare att sortera bort mjölk med högt celltal. Lantbrukare rekommenderas därför istället att investera i mastitförebyggande åtgärder. Särskild vikt ska läggas vid att förhindra mastiter i tidig och sen laktation, eftersom flest kor insjuknar i dessa perioder och avkastningsförlusterna är som störst då.

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Acknowledgements

The majority of the work underlying this thesis was performed at the Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences, Uppsala. The analyses in Papers II and IV were conducted within the group of Herd Health and Production Management, Faculty of Agricultural Sciences, Aarhus University. The Swedish Farmers' Foundation for Agricultural Research is gratefully acknowledged for funding the project. Financial support was also provided by the department. The SLU fund for internationalization of postgraduate studies funded my stay in Denmark and provided travel grants for participation in a conference.

A lot of people has supported me during my time as a PhD-student. I would like to express my sincere thanks to all of you, and give special credit to some of you:

My supervisors, Erling Strandberg, Ulf Emanuelson, Britt Berglund, Jan Philipsson, Hans Andersson, and Søren Østergaard, it has been a pleasure to work within a group with such a diverse field of knowledge. Thanks a lot for fruitful discussions and all your support!

Erling, min huvudhandledare, för det stora intresse du visat för projektet! Tack för att du på ett så ypperligt sätt bidragit till att lyfta diskussionen på handledarmötena och för dina finurliga tankegångar som har förbättrat mina manuskript.

Uffe, du har varit en ovärderlig support under hela min doktorandtid! Tack för engagemang, snabb feedback och kloka åsikter. Du är min idol i forskarvärlden!

Britt, för att du alltid trodde på min förmåga och aldrig tvivlade på att jag skulle ro projektet i land. Tack för att du hjälpte mig att utvecklas till en självständig forskare!

Jan, det var du som fick mig att hoppa på projektet från allra första början. Det har jag inte ångrat! Tack för all uppmuntran och alla samtal om smått och stort.

Hans, du lyckades med konststycket att övertyga mig om att ekonomi inte är så tokigt ändå. Det är jag väldigt tacksam över nu! Tack också för alla tänkbara (och otänkbara!) anekdoter som kryddade handledarmötena.

Søren, for at du uden tøven involverede dig i mit projekt! Tak for at du introducerede mig for simuleringens forvirrende verden og et endnu større tak for din tålmodighed, når jeg ganske tydeligt ikke havde nogen ide om hvad du snakkede om! Jeg har virkeligt sat stor pris på at arbejde sammen med dig, og dit input i projektet har været uvurderlig!

Tack alla ni som arbetar på Hgen för att ni bidragit till att skapa en trivsam arbetsmiljö som gjort att det har varit roligt att gå till jobbet!

Monica, **Bijan**, **Harriet, Helena, Siw** och **Jörgen**, för att ni håller ordning på institutionen och alltid har hjälpt till när det behövts!

Dan och **Stickan**, för all hjälp med min krånglande dator (men mest tack för fredagsmejlen och dörröppnandet!).

Gudrun och **Lena**, för att ni samlat in allt data i Jällabesättningen och tålmodigt försett mig med allt som jag efterfrågat.

Jörgen (igen!), min livscoach och extrapappa! Tack för alla råd vad gäller jobb, relationer och kärleksliv! Och tack för att din dörr alltid är öppen!

Alla **doktorander** på Hgen, nuvarande och före detta, tack för att ni gjort vardagen på institutionen roligare! Jag kommer att sakna att vara en av er (fast kanske inte så mycket att vara doktorand…).

Doktorandmaffian: **Jessica**, **Sofia**, **Jennie**, **Therese**, **Anna O**, **Emma C** och **Emelie**, tack för allt som inte hade med jobbet att göra! Tiden på institutionen hade inte varit densamma utan er!

Johanna, jag uppskattar våra små pratstunder mycket och ser fram emot att ni snart (!) flyttar hem till Sverige så att vi kan ses lite oftare.

Emma TH, tack för all peppning under slutet av min doktorandtid och för att du lånar ut Ellin till mig. Stunderna i stallet har hjälpt mig att hålla mig över ytan under de sista stressiga månaderna.

Karl-Johan, för givande diskussioner om Jälladata, SAS (du är ett SAS-geni!) och allt annat som hört doktorerandet till.

Gruppen på Foulum, tak for jeres varme modtagelse og for at I fik mig at føle mig som en del af gruppen, på trods af at mine ophold var korte!

Johanna, **Bart**, **Tina**, **Jehan**, **Elise** og **Kirstine**, fordi I sørgede for at jeg havde et socialt liv under mine ophold på Foulum!

Personalen på **Wapnö**, för att ni tog er an ”den där hästtjejen” och på riktigt väckte mitt intresse för kor! Ett särskilt tack till **Jörgen** för att du var fast besluten att lära mig allt som har med en mjölkbesättning att göra!

Anette, dig kan jag lita på! Tack för att du tog hand om Myran i vått och torrt och för att du alltid ställt upp för mig oavsett vad det gällt!

Birgitta, min inspirationskälla framför alla andra! Du väckte mitt intresse för god djurhållning redan i unga år och hejade ivrigt på mig i mitt yrkesval, övertygad om att jag skulle lyckas förändra världen. Jag önskar att du hade fått vara med på min stora dag!

Mamma och **pappa**, för att ni alltid uppmuntrade mitt djurintresse när jag var liten och lät allt från hamstrar till hästar bli fullvärdiga familjemedlemmar. Ofantligt tack för att ni har varit barnvakter åt Buster och Linus i sex (!) år!

Per, för att du finns i mitt liv och för att du alltid stöttar mig! Du är det bästa som hänt mig! Jag ser fram emot vårt fortsatta liv tillsammans, utan avhandlingar som ska skrivas…