Epidemiological Studies of Reproductive Performance Indicators in Swedish Dairy Cows

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Abstract

Reproductive efficiency in dairy cows is a key factor for milk producers, and numerous studies have identified impaired reproductive performance as a major cause of reduced production efficiency in the dairy industry. The overall aim of this thesis was to gain knowledge of factors affecting the reproductive performance indicators currently used by herd advisory services and to find other, possibly more efficient, ways to measure reproductive performance in dairy cows.

The studies included in this thesis were based mainly on records from the Cattle Database at the Swedish Dairy Association, but also on data from a simulation model. The records used in the constituent studies of the thesis came from 2728 herds (Paper I), 483 herds (Paper II), 900 simulated herds (Paper III), and 132,721 individual cows (Paper IV). The statistical analyses were performed using multivariable linear and logistic regression models as well as survival analysis.

Many statistically significant associations were found between herd and cow characteristics and reproductive performance. When allocating advisory service resources to improve reproductive performance, the focus should be on easily influenced herd characteristics, such as heat detection efficiency, nutritional status, do-it-yourself inseminations, and health deviations. Herd characteristics were also found to influence the degree of disagreements in reproductive performance indicators when data were updated after six months. Reproductive performance indicators that were adjusted for management strategy were evaluated, and *percentage pregnant after the herd voluntary waiting period plus 30 days* was found to be the best reproductive performance indicator with which to assess both reproductive management and reproductive physiology. Both *percentage pregnant after the herd voluntary waiting period plus 30 days* and *percentage inseminated after the herd voluntary waiting period plus 30 days* could be integrated for use in the herd advisory services. These indicators would be useful in providing information on herd performance and in establishing more efficient benchmarking between herds.

Keywords: dairy, herd characteristics, reproductive performance indicators, voluntary waiting period (VWP)

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To my family

Mamma, när är du klar med korna? Du har ju hållit på i 1000 dagar!
Alexander, 4 år

En doktorsavhandling
Han som sitter där borta hade en doktorsavhandling
som vinden tog hand om
ja, bokstavligen blåste den bort
(någonstans i Tyrolen tror jag).
Tålmodigt hade han arbetat på den
och säkert kändes det svårt
några år framöver, men numera
tar han det stillsamt och filosofiskt.
- Vi behöver nog lite till mans en doktorsavhandling
som blåser bort, säjer han.
Och det krävs inte mer än ett öppet fönster.
Nils Ferlin (Kejsarens Papegoja, 1951)

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 Löf E, Gustafsson H and Emanuelson U (2007). Associations between herd characteristics and reproductive efficiency in dairy herds. *Journal of Dairy Science* 90, 4897–4907.

II Löf E, Emanuelson U and Gustafsson H (2007). Data management affects reproductive performance indicators in Swedish dairy herds. *Acta Agriculturae Scandinavica, Section A – Animal Science* 57, 73–80.

III Löf E, Gustafsson H and Emanuelson U (2012). Evaluation of two dairy herd reproductive performance indicators that are adjusted for voluntary waiting period. *Acta Veterinaria Scandinavica* 54:5.

IV Löf E, Gustafsson H and Emanuelson U (2012). Factors influencing the chance of cows being pregnant 30 days after the voluntary waiting period. (in manuscript).

Papers I–III are reproduced with the permission of the publishers.

Abbreviations

CI	Calving interval
CFI	Calving to first insemination (or service) interval
CLI	Calving to last insemination (or service) interval
SOMRS	Swedish Official Milk Recording Scheme
AI	Artificial insemination
SRB	Swedish Red
SH	Swedish Holstein
DIY	Do it yourself
VWP	Voluntary waiting period
PV30	Proportion of pregnant cows after the herd voluntary waiting period plus 30 days
IV30	Proportion of inseminated cows after the herd voluntary waiting period plus 30 days

1 Introduction

Reproduction in dairy cows is a key factor for milk producers and has been important since the start of domestication. The primitive cow, *Bos primigenius*, has evolved and been selected to become today's high-producing modern dairy cow. This genetic transformation has relied on selection and on allowing cows with the desired traits to reproduce. The birth of a calf is the starting point of a dairy cow's productive life. For the cow to continue to produce milk, it must continue to calve at regular intervals. The fertility of dairy cows – i.e., their ability to become pregnant and carry a pregnancy to term – is therefore indispensable for natural milk production (i.e., without use of hormones for artificially regulating the milk production cycle).

Numerous studies have identified impaired reproductive performance as a major cause of reduced production efficiency in the dairy industry, due to greater costs of herd replacement, internal herd growth, veterinary intervention, and reduced annual milk yield. Herd health and herd production advisory services often have reproductive efficiency as a target, using various measures and indicators to monitor and benchmark reproductive performance in dairy cows and herds.

How dairy cows are held and managed is experiencing ongoing structural change: more farmers are becoming do-it-yourself (DIY) inseminators instead of using professional AI technicians; the number of cows per farm has continued to increase; cows are increasingly being held in free stalls, and the use of automatic milking systems is increasing. These changes could well affect reproductive performance.

The overall aim of this thesis was to gain knowledge of factors affecting the reproductive performance indicators currently used by herd advisory services, and to find other, possibly more efficient, ways to measure reproductive performance in dairy cows.

2 Background

2.1 Reproduction and fertility in general

When this doctoral project started in 2005, several studies had reported declining reproductive performance in dairy cows (Royal *et al.*, 2000; Lucy, 2001). This decline could also be noted in Sweden and, as shown in Figure 1, the reproductive performance indicator *calving interval* (CI) had become extended by almost one month for Swedish Holstein (SH) cows and by about half a month for Swedish Red (SRB) cows between 1985 and 2011. Extended CI is seen as indicating deteriorating fertility, which might not necessarily be true, because a longer CI can be obtained by voluntary decisions. As Figure 1 shows, most of the decline took place between 1985 and 2006. The graph further shows that the CI has stabilized at approximately 13.1 months for SRB cows and at 13.6 months for SH cows between 2006 and 2011.

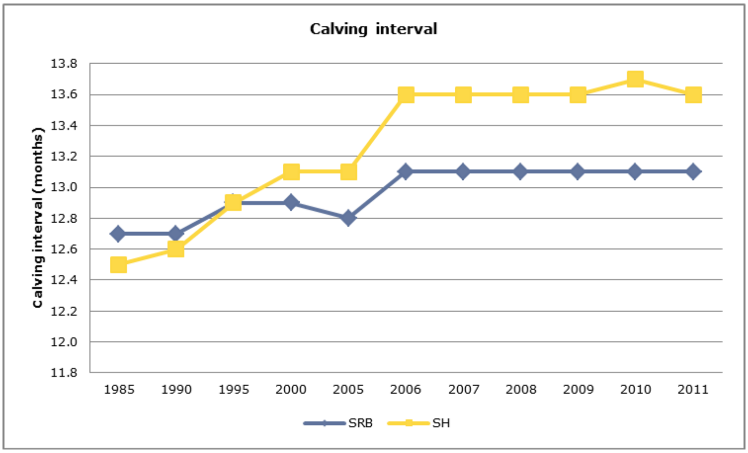

Figure 1. Calving interval in months, 1985–2011, for the breeds Swedish Red (SRB) and Swedish Holstein (SH) (Swedish Dairy Association, 2012b).

2.2 Dairy cows in Sweden

2.2.1 Trends: herd structure

In 2011, 4023 herds comprising 287,606 cows were included in the milk recording database, which is further described in section 2.3.1. This database includes approximately 85% of the total number of cows in Sweden. In 1991, 12,895 herds and 370,067 cows were included in the milk recording database, indicating a rapid structural change in dairy herds in Sweden. Herds are increasing in size: in 1991 the average herd was 28.7 cows, increasing to 68.4 cows as of 2011.

A shift has occurred in how cows are held and milked. By 2011, 53% of cows were held in free stalls and 25% were milked using automatic milking systems – proportions that have been growing over the years. In 1991, no cows were milked using automatic milking systems, since such systems had not yet been approved.

The two predominant breeds in Sweden are SRB and SH. In 2011, the distribution was 41.1% SRB and 51.3% SH cows, while the 1991 distribution was 54.3% and 39.2%, respectively, i.e., the SH population is growing at the expense of the SRB population (Swedish Dairy Association, 2012a).

In general, cows are fed forage-based rations complemented with high amounts of concentrates. Forage consists of grass or grass/clover silage produced on the farm and concentrates consist mainly of grain, protein feed (e.g., rapeseed or soy meal), and by-products from the cereal and sugar industries. Maize silage and by-products from the sugar beet industry may also be used in southern Sweden. By law, all dairy cows in Sweden are held on pasture in the summer months, but grazing does not represent a large proportion of the dry matter intake. Feeding regimens in Sweden are either individualized or grouped based. For individual feeding, the feed advisory service "IndividRam" (www.svenskmjolk.se) can be used. In this service, individual feeding regimes are set up in a management software program and are based on production data such as milk yield. An example of group feeding is the use of total mixed rations (TMRs) in which forage and concentrates are mixed and the feeding regimen is not individualized.

2.2.2 Trends: artificial insemination

In the 2010–2011 administrative year, 252,069 first artificial inseminations (AIs) were performed on cows and 100,340 on heifers (Swedish Dairy Association, 2012a). Herd managers either can use specialized technicians to perform the inseminations or the herd managers (or staff) can be DIY inseminators and perform the inseminations themselves. Currently, three main advisory companies or local livestock organizations provide AI technicians to dairy herds in Sweden. In 2005, the year to which the data in Paper I refer, eight such organizations existed. In addition to these organizations, there are private advisory companies.

The proportion of DIY AI increased from 3.1% in 1991 to 53% as of 2011 (Swedish Dairy Association, 2012a). Some herds might use a bull for natural service for groups of cows or heifers, and 17% of calves born each year were conceived naturally (Nils-Erik Larsson, personal communication, 2012). When a cow is observed to be in heat, the herdsman contacts the local livestock organization, which sends out a technician to perform the insemination and possibly also check for pregnancy. Both AI technicians and DIY inseminators are required to report to the AI recording system within seven days. The reporting involves the unique identity of the animal, insemination date, and identity of the semen used. In Sweden, herd advisors generally suggest that herd managers let the cows have a voluntary waiting period (VWP) of 50–60 days after calving before inseminating them.

2.3 Measuring reproductive performance

2.3.1 Database records in Sweden

The cattle database (CAD; Swedish: *Ko-databasen*) maintained by the Swedish Dairy Association combines records from the Swedish Official Milk Recording Scheme (SOMRS; Swedish: *Ko-kontrollen*), the AI recording system (Swedish: *Seminbokföringen*), the claw trimming database (Swedish: *Klövhälsoregistret*), the central register of bovine animals (CDB; Swedish: *Nötkreatursregistret*), and the National Disease Recording System (NADRS; Swedish: *Djursjukdatabasen*). The data inflow and outflow are depicted in Figure 2.

The SOMRS, AI recording scheme and claw trimming data are maintained by the Swedish Dairy Association. SOMRS, a voluntary service in which dairy herds can choose to enroll, is provided by local livestock organizations as a dairy herd improvement scheme. SOMRS includes test-milking data on milk yield (kg), fat percentage, protein percentage, urea concentration, and somatic cell count. The AI recording system includes records of AI data such as insemination date, pregnancy checks, and pedigree. The AI recording system is also voluntary and enrolment in it does not imply enrolment in SOMRS; however, 95% of herds enrolled in SOMRS are also registered in the AI recording scheme.

CDB is maintained by the Swedish Board of Agriculture and registers compulsory reports of births, deaths, and movements of cattle. NADRS is also maintained by the Board of Agriculture, and veterinarians must report to it disease events in cattle. Both CDB and NADRS cover, at least theoretically, 100% of the herds.

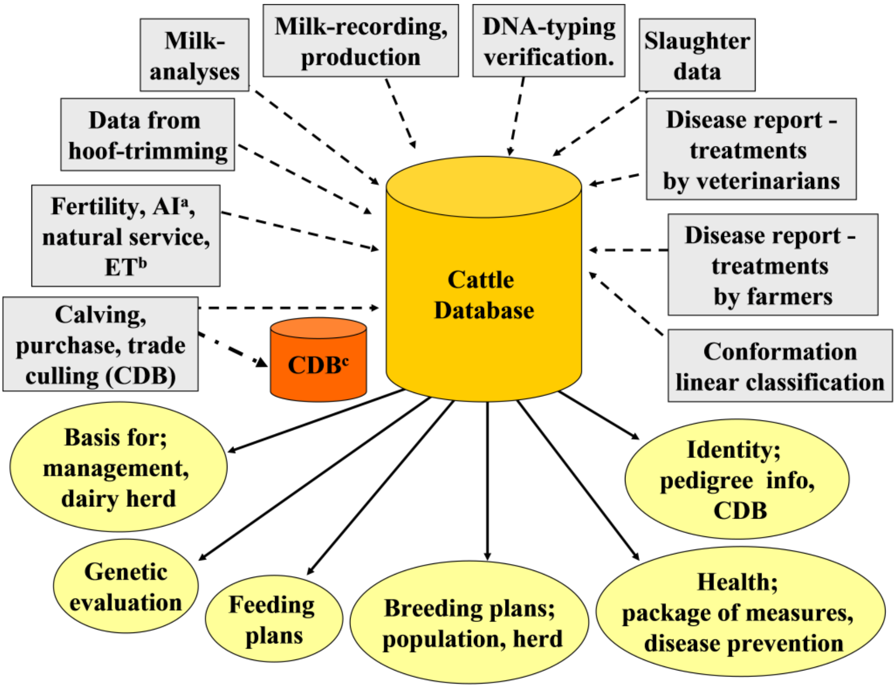

Figure 2. Data inflow and outflow for the Swedish Cattle Database (Nils-Erik Larsson, Swedish Dairy Association, personal communication); [a] Artificial insemination, [b] Embryo transfer, [c] Central register of bovine animals (CDB)

These records and databases serve as the foundation for dairy herd improvement schemes; local livestock organizations provide herd owners with data from the CAD, giving them regular access to information on how they are performing in relation to both their own historical records and benchmarks for other herds. Some herd managers consult advisors for help analysing and prioritizing what should or could be done given the CAD information received. Herd advisory services may deal with feeding optimization, health and reproduction monitoring, and economic calculations.

2.3.2 Various reproductive performance indicators

Internationally, many measures and indices are used to monitor the reproductive performance of dairy herds (Fetrow *et al.*, 2007) and can be used as key performance indicators for fertility and reproduction. These indicators and indices are used for surveillance, status, and trend monitoring in dairy herds and are important tools of herd advisory services. They can be used to evaluate the fertility status of herds (and of cows within herds) and to assess the contributions necessary to improve this status.

In Sweden, the most commonly used indicators are time interval measures such as *calving interval* (CI), *days to first insemination (or service)* (CFI), and *days to last insemination (or service)* (CLI), and frequency measures, such as *number of inseminations per animal submitted* (NINS) and *percent of non-returns in 56 days after AI* (%NR56), which describe conception efficiency. The time intervals measure how many days or months are required for the events of interest.

Figure 3 sets out a schematic view of the reproductive events occurring between two calvings and where the various reproductive indicators can be located in relation to these.

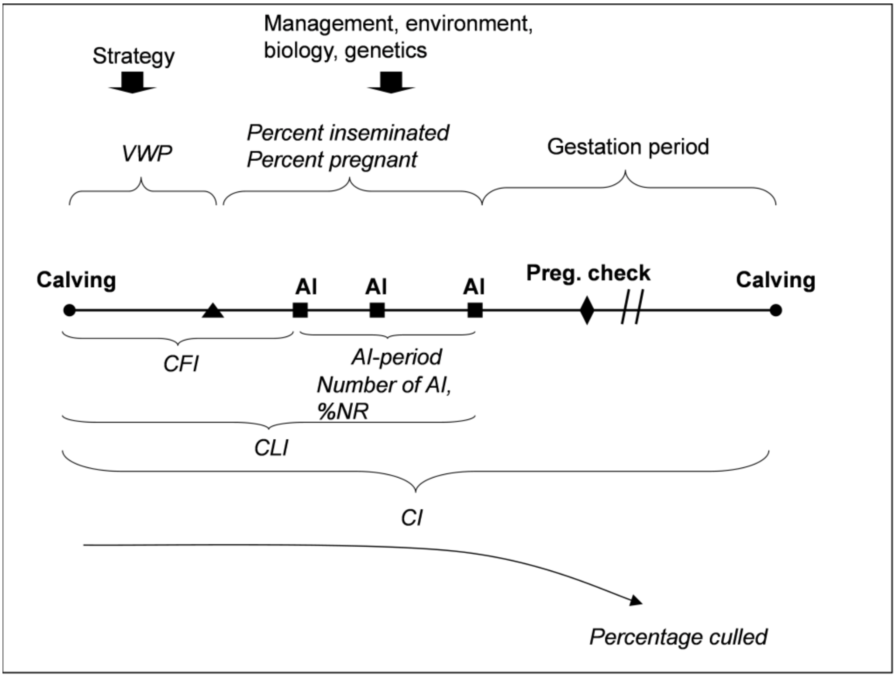

Figure 3. Schematic of the reproductive events and reproductive performance indicators in relation to time between two calvings.

Swedish herd advisory services also use the *fertility index* (FI), a composite measure adapted from de Kruif (1980), which combines several fertility indicators to describe the overall reproductive performance of a herd. The following equation is the formula for FI used in the AI recording system:

$$\text{FI} = \left(\frac{(\%NR56 - (CLI - 125))}{NINS}\right) \times \left(\frac{(Number\ of\ animals\ sub. - Withdrawn\ animals)}{Number\ of\ animals\ submitted}\right)$$

The *number of animals submitted* is calculated as all cows eligible and chosen for insemination. *Withdrawn animals* are animals that have been withdrawn or culled because of reproductive failure or problems.

The *percentage culled due to not pregnant* is another indicator used by herd advisory services. This is reported to SOMRS by herdsman and may contain a certain degree of subjectivity. *Percentage pregnant per insemination*, *percentage pregnant of animals submitted to AI*, and *age at first calving* are other indicators used by herd advisory services.

Table 1 provides an overview of the advantages and disadvantages of indicators used in various parts of the world. Table 2 provides an overview of the advantages and disadvantages of the indicators used by Swedish herd advisory services.

Table 1. *Advantages and disadvantages of reproductive performance indicators used in various parts of the world.*

Reproductive performance indicator	Advantage	Disadvantage
Days open	• easy to calculate	• influenced by management • includes only pregnant animals
First service conception rate	• includes all inseminated cows	• needs pregnancy checks to be valid
InCalf100 [a]	• relates to the whole herd	• influenced by management
NotInCalf200 [b]	• relates to the whole herd	• influenced by management • time lag

[a] InCalf100 = proportion of pregnant cows 100 days after calving

[b] NotInCalf200 = proportion of non-pregnant cows 200 days after calving

Table 2. *Advantages and disadvantages of reproductive performance indicators used by Swedish herd advisory services.*

Reproductive performance indicator	Advantage	Disadvantage
Calving to first service	• easy to calculate • easy to understand	• only calculated for >first-parity cows with at least one service • influenced by management
Calving to last service	• easy to calculate • describes current performance	• only calculated for >first-parity cows with at least one service • influenced by management
Calving interval	• easy to calculate • easy to understand	• only calculated for cows that recalve, i.e., second-parity cows • describes past performance • influenced by management
Number of inseminations/ animal	• easy to understand	• calculated for all animals, not only pregnant ones • depends on heat detection
Percent of non-returns in 56 days	• no pregnancy check needed • describes current performance	• depends on heat detection
Fertility index	• includes culled animals	• complicated to understand
Culled due to reproductive problems		• subjective
Percentage pregnant per insemination	• describes current performance	• calculated only for submitted animals
Percentage pregnant of animals submitted to AI		• calculated only for submitted animals
Proportion CFI >70 days	• relates to the whole herd	• influenced by management
Proportion CLI > 120 days	• relates to the whole herd	• influenced by management
Age at first calving		• time lag

2.3.3 Difficulties with the described indicators

Several difficulties are associated with some of these indicators, related partly to how the indicators are calculated and partly to delays registering information in the database or to lack of information in it.

With respect to how the indicators are calculated, some indicators are constrained by the fact that they can be calculated only for animals that either have calved consecutively or have been inseminated and/or checked for pregnancy (depending on indicator), introducing possible selection bias because they are not completely representative of a herd's reproductive status.

For example, the CI can only be calculated for cows that have calved consecutively, so the indicator omits cows that did not conceive. The indicator therefore captures only the reproductive performance of *fertile* cows. Though a herd might have a huge infertility problem, the CI might indicate otherwise, because the few cows that did get pregnant did so in the shortest possible time, resulting in a short CI. One way to overcome such problems is to use failure-time statistical analyses in which incomplete records contribute to the indicator as censored variables – that is, all cows in the herd contribute to the indicator, not only fertile ones. For example, the proportion of pregnant cows can be measured at specific intervals after the calving date or after a fixed time period. With respect to delay reporting to the database, or lack of information in it, the robustness of an indicator is of course dependent on the data of which it is constructed. The nature of such measures is that they do not always indicate the real "truth", because the data used for the calculations are rarely complete. For example, if herds do not report AI events in time, the indicator CLI might indicate good reproductive performance only because the date of the last insemination is lacking, giving a short value for the indicator. There is an ongoing trend for herds themselves to record various herd and animal parameters, transferring these to the central database for calculations. One example is the increasing number of herds using DIY AI. Although herds enrolled in the Swedish AI recording system are required to report all performed inseminations within seven days, some herds do not report all events while others report them late in batches, affecting the accuracy of the reproductive indicators.

2.4 Factors affecting reproductive performance

2.4.1 General

The fertility of dairy cows is multi factorial, and many factors influence the reproductive performance. Such factors include management regime (Bielfeldt *et al.*, 2006), environment (Windig *et al.*, 2005), genetics (Roxstrom, 2001), nutrition (Butler, 2000), and biological and health status (Fourichon *et al.*, 2000). Successful reproduction, starting with oogenesis and ending with the birth of a calf, relies on complex physiological dynamics and is the result of a chain of events. The resumption of ovarian cyclicity, oestrus, and ovulation are all events that need to precede conception, and failure at one stage results in failure of the whole process (Garnsworthy *et al.*, 2008). Pregnancy should also be maintained, resulting in a living calf.

2.4.2 Management and environment

Some of the above factors are beyond herdsman control, whereas others can be controlled, such as managerial decisions at the farm level. Those factors may influence the outcome of individual cows, i.e., when and if pregnancy will be achieved.

Voluntary waiting period

The voluntary waiting period (VWP) is the time between calving and when herd management decides a cow is ready for breeding. Herd management designates a target number of days postpartum after which cows seen to be in heat are inseminated or served. This period, which allows cows to resume normal ovarian function after calving, can vary in length both between and within herds and can influence reproductive performance (Morton, 2003; Miller *et al.*, 2007). A herd with a long VWP could have a longer CFI or CI than a herd with a short VWP by mathematical definition. However, VWP duration can indirectly affect reproductive performance, because most common metabolic and reproductive disorders occur around parturition or in early lactation (Erb *et al.*, 1984). Given sufficient time, some of these health deviations might resolve, and not interfere with reproduction. For example, Petersson *et al*. (2006b) demonstrated that cows treated for ovarian cysts had higher odds of delayed cyclicity. The length of VWP affects the reproductive performance of these cows and, hypothetically, if these cows were given longer time before first insemination, their reproductive performance might not be affected by this delay in cyclicity.

Heat detection efficiency

The heat detection rate or heat detection efficiency (HDE) is crucial when wanting to impregnate cows. If few cows in heat are detected, few cows will subsequently be inseminated and few cows will become pregnant. Herds with good HDE can achieve better results according to many reproductive performance indicators (Esslemont, 1993; Mayne *et al.*, 2002).

Do-it-yourself inseminations

Herd managers (or staff) who perform inseminations themselves instead of using specialized technicians risk reducing herd reproductive performance. Some researchers (Morton, 2000; O'Farrell & Crilly, 2001; McCoy *et al.*, 2006) have proposed that DIY inseminators contribute to poorer reproductive performance, while others have found no differences in reproductive performance (Buckley *et al.*, 2003a). Poorer performance could be caused by poorer insemination technique, possibly due to lack of training. DIY inseminators might perform inseminations on only a few cows, perhaps infrequently, and consequently be less skilled.

Production intensity

Discussion is ongoing as to whether the high production levels selected for in dairy herds has caused their fertility to decline (Hansen, 2000; LeBlanc, 2010). High-intensity herds have been demonstrated to have a shorter interval from calving to first service but a lower first service conception rate than do low-intensity herds (Windig *et al*., 2005). Windig *et al*. (2005) also found that herds with high average yields had shorter calving to first AI intervals, but also that, within those herds, high-producing cows had longer calving to first AI intervals. Buckley *et al.* (2003b) reported that milk yield at first service was positively associated with the likelihood of pregnancy after 42 days of breeding. Gröhn and Rajala-Schultz (2000) found that the 60-day cumulative milk yield only minimally affected pregnancy and that the highest yielding cows had a slightly lower conception rate.

Season

Seasonal effects have been found involving poorer reproductive performance in the summer months (Gröhn & Rajala-Schultz, 2000; de Vries & Risco, 2005), possibly due to heat stress (Chebel *et al.*, 2004). This may also, at least in Sweden, indicate the effect of cows being outside on pasture, making it difficult to achieve adequate heat detection.

Housing

Free-stall herds have displayed better reproductive efficiency (Valde *et al.*, 1997), and studies have demonstrated that the interval between calving and first ovulation and oestrus is shorter in free-stall than tie-stall herds, enabling earlier insemination in free-stall herds (Petersson *et al.*, 2006a). When examining the effects of automatic milking on fertility, Kruip *et al*. (2002) found that automatic milking increases the number of days to first service. Fahey *et al.* (2002) reported lower calving rates in larger herds, whereas Simensen *et al.* (2010) found that larger herds had better fertility.

2.4.3 Genetics

Reproductive performance is partly influenced by genetics and is often classified as a "functional trait". Since it is partly a genetic trait it is also heritable, though the heritability of reproductive traits is generally low, usually under 5% (Berglund, 2008). Roxstrom (2001) has reported heritabilities of 0.003–0.04 for various reproductive traits. However, studies have found significant genetic variation, so selection for reproductive traits is still possible even though the heritability of such traits is low (Philipsson & Lindhé, 2003). Some estimates also indicate an unfavourable genetic correlation between milk yield and reproductive efficiency (Dematawewa & Berger, 1998; Roxstrom *et al.*, 2001), so selection for milk production *alone* will lead to deterioration in reproductive performance. This has been increasingly realized, and many countries now have selection indices in their breeding programmes that take account of both production and reproduction (Miglior *et al.*, 2005).

2.4.4 Breed

Differences in reproductive efficiency between breeds have been reported by Dillon *et al*. (2003); they compared four breeds, finding that Holstein-Friesian cows had a lower pregnancy rate and longer calving to conception interval than did the others. Friggens and Labouriau (2010) found no differences in the probability of pregnancy between three Danish breeds, though they did find differences in the rate of occurrence of first oestrus, which was higher for the Danish Red than the Danish Holstein breed. Crossbreeding has been evaluated and was found to increase the reproductive performance when comparing pure breed Holsteins to three crossbreeds (Heins *et al.*, 2006).

2.4.5 Nutrition

High-yielding dairy cows have high nutritional requirements, which can put the animals in negative energy balance (NEB) (Butler, 2003), both physiologically and nutritionally affecting follicular growth and ovulation (Butler, 2000; Garnsworthy *et al.*, 2008). NEB will increase the concentration of free fatty acids (FFAs) in the blood, so the FFA concentration is a commonly used indicator of NEB (Butler, 2003). However, FFAs are not routinely measured in milk recording systems. Grieve *et al*. (1986) suggested that the fat/protein ratio in milk could be used as an indicator of the lack of energy supply postpartum, i.e., NEB, as the milk fat concentration tends to increase and milk protein concentration tends to decrease during negative energy balance. Since both milk fat and protein content are regularly measured in milk recording schemes, the ratio between them can easily be used as a marker of NEB. Cows with a high milk fat/protein ratio have also been demonstrated to have poorer reproductive performance (Heuer *et al.*, 1999).

2.4.6 Biological and health status

Lameness

Lame cows have been reported to have poorer reproductive performance. Sprecher *et al*. (1997) found that cows with high lameness scores had longer intervals from calving to first service and to conception and also required more services per pregnancy. In addition, Hultgren *et al*. (2004) found that the first-service conception risk was lower for cows with sole ulcer. Garbarino *et al*. (2004) found that cows classified as lame had 3.5 times greater odds of delayed cyclicity than did cows classified as non-lame.

Reproductive-related disease

Cows with reproductive-related diseases have been associated with impaired reproductive performance (LeBlanc *et al.*, 2002; Dubuc *et al.*, 2011). Oltenacu *et al.* (1990) found that cystic ovarian disease and silent heat syndrome each increased the days open interval by 40 days. They also found that metritis prolonged the interval by 20 days and retained placenta by seven days. Dematawena and Berger (1997) found that cows with dystocia had more days open and needed more services to become pregnant. Cows calving twins are at greater risk of reproductive disorders, including retained placenta, dystocia, and metritis, which increase average days open and services per conception following the subsequent lactation (Nielen *et al.*, 1989). Peake *et al*. (2011) found prolongation of the interval from calving to onset of the first luteal phase for cows with one or more of three production stressors: lameness, subclinical mastitis, and body condition score loss. However, no significant associations were found between disease events and overall reproductive performance.

SCC and mastitis

Both clinical and subclinical mastitis have been associated with poorer reproductive performance (Valde *et al.*, 1997; Barker *et al.*, 1998; Ahmadzadeh *et al.*, 2009). Lavon *et al.* (2011) found that cows with a somatic cell count (SCC) over 150,000 cells mL^{-1} had lowered probability of pregnancy. Hertl *et al.* (2010) demonstrated that clinical mastitis occurring any time between 14 days before and 35 days after AI was associated with a lower probability of conception. Cows with clinical mastitis within the first 45 days of gestation were at 2.7 times greater risk of abortion within the next 90 days than were uninfected cows (Risco *et al.*, 1999). Reduced reproductive performance due to mastitis may be related to extension of the interval from calving to first postpartum AI, reduced pregnancy rate to insemination, prolonged days open, and increased late embryonic mortality after pregnancy diagnosis (Santos *et al.*, 2004). The adverse effects of mastitis on reproductive efficiency are probably mediated by several mechanisms. One example connected to mastitis is the inflammatory process which leads to production of a variety of bioactive molecules that can potentially disrupt reproductive tract tissues. The inflammatory process may also involve elevated body temperature that can affect oocyte competence and embryonic survival (Hansen, 2009). Inflammation may also lead to decreased feed intake which may alter the energy metabolism and consequently influence the reproductive function (Leroy *et al.*, 2008). Rahman *et al.* (2012) reports that decreased fertility of cows with chronic mastitis is caused by effects on the ovary that alters the dynamics of the folliculogenesis, such as reduction of the vascular bed and also lower levels of the growth and differentiation factor-9 (GDF-9).

3 Aim of Thesis

The overall aim of this thesis was to gain knowledge of factors that affect the reproductive performance indicators currently used, or that presumably could be used, by herd advisory services.

The specific aims of the thesis were:

- to study factors associated with the reproductive performance indicators currently used by herd advisory services at the herd level in Swedish dairy herds;
- to investigate whether data management affects the reproductive performance indicators and whether any systematic factors affect indicator accuracy;
- to evaluate reproductive performance indicators that were adjusted for management; and
- to study factors affecting the reproductive performance indicators that were adjusted for management at the cow level.

4 Material and Methods

This section gives a general description of the material and methods used. Detailed descriptions are given in each of the papers I-IV.

4.1 General

Papers I, II, and IV are based on records from the Cattle Database of the Swedish Dairy Association. Herds (and cows, Paper IV) had to be enrolled in SOMRS to be candidates for inclusion. The study reported in Paper III was performed using SIMHERD (www.simherd.com), a simulation model, to construct herds of various reproductive statuses.

4.2 Associations at herd level, Paper I

All farms enrolled in SOMRS and having more than 45 milking cows on average from 1 September 2004 to 31 August 2005 were included in the study, a total of 2728 farms. At that time, 7241 farms were enrolled in SOMRS, representing 86% of all Swedish dairy herds. Reproductive performance indicators were measured as the averages for each herd of calving interval, calving to first AI interval, calving to last AI interval, number of AIs per animal submitted for AI, and culling due to reproductive problems. Available herd characteristics were geographic region, herd breed composition, herd size, 365-d ECM yield, use of advanced feed advisory service, milking system (i.e., pipeline, automatic/robotic, or parlours/rotaries), feeding system (i.e., TMR or unspecified), housing type (i.e., tie stall or free stall), and organic management.

Associations between the outcome and predictor variables were analysed using linear regression models, except for culling due to reproductive problems, which was analysed using a logistic regression model.

4.3 Comparisons of disagreements between datasets, Paper II

The sampling frame for this study was all dairy herds enrolled in SOMRS that contained more than 45 milking cows (n = 2728 at time of sampling). For computational reasons, a 20% random sample was originally selected, although only 483 herds remained in operation when the final data were retrieved in 2006. Data representing the operational year 1 September 2004 to 31 August 2005 were extracted for each herd from the AI recording system on two occasions: in September 2005, which is according to the routine procedures at the Swedish Dairy Association, and in May 2006. Reproductive performance indicators were computed for the same period, i.e., September 2004 to August 2005, on two occasions as described above, producing two sets of data, one with "original" values and another with "updated" values. The latter dataset takes into account changes in the data due to a longer time lag than is commonly used, which allows late reports and corrections to be entered into the database.

The reproductive performance indicators studied were herd-level averages or sums of: number of inseminations (NI), percentage of non-returns at 56 days (%NR56), number of days from calving to first and last insemination (CFI and CLI), percent pregnant per insemination (%PPI), percent pregnant per animal submitted for AI (%P), and fertility index (FI). The outcome variables ΔNI, Δ%NR56, ΔCFI, ΔCLI, Δ%PPI, Δ%P, and ΔFI were constructed by subtracting the measure of interest in the "updated" dataset from the measure in the "original" dataset. Deviations of more than ±5% were considered indicative of disagreement between the two datasets. The available herd characteristics were geographic region, herd breed composition, herd size, 365-d ECM yield, do-it-yourself (DIY) insemination, rate of inseminations (ROI), and percent pregnancy checks (%PC). ROI was calculated according to Heersche and Nebel (1994); it is a measure of oestrus detection efficiency at the herd level and is expressed as the percentage of possible oestruses, based on 21-day intervals, that were observed and subjected to AI.

The associations between herd characteristics and disagreement in reproductive performance indicators were analysed using logistic regression models.

4.4 Evaluation and comparisons of indicators, Paper III

In this paper, we studied reproductive performance indicators by means of simulation. We produced an initial herd and simulated it for 20 years to obtain a stable starting point for our simulated scenarios. This initial herd was constructed to mimic a future Swedish dairy herd with an average herd size of approximately 100 cows. We simulated 18 scenarios over ten years; 50 replicates were made for each scenario, which could also be seen as 50 different herds for each scenario, totalling 900 herds. The various scenarios were constructed by altering the reproductive physiology and management. The reproductive performance indicators studied were CFI, CLI, CI, fertility index (FI), 100-day in-calf rate (IC100), 200-day not-in-calf rate (NotIC200), PV30, and IV30.

Logistic regression models were used to examine to what extent the various reproductive performance indicators could discriminate between herds of different levels of reproductive management efficiency or reproductive physiology. The predictive ability of the model was evaluated using receiver operating characteristics (ROC) analysis assessed in a logistic regression model with reproductive performance indicator as the only explanatory effect.

4.5 Associations at cow level, Paper IV

All cows that calved between 1 July 2008 and 30 June 2009 and originated from herds that had more than 50 milking cows on average were available for inclusion in the study. Cows also needed to come from herds comprising cows of at least two breeds (of Swedish Red, Swedish Holstein, or other/cross breed), the presence of at least 10% of one breed being sufficient for inclusion. After data editing, 132,721 cows from 1421 herds remained. The reproductive performance indicator studied was whether or not the cow was pregnant within the VWP plus 30 days. The characteristics studied were breed, status at claw trimming, disease related to reproduction, disease other than reproductive, dystocia, HDE (herd level), insemination type (herd level), length of VWP (herd level), milking system (herd level), milk fat/protein ratio, milk yield, organic production (herd level), parity, season, somatic cell count, TMR (herd level), twin birth, and milk urea.

Associations between the outcome variable (i.e., pregnant at VWP plus 30 days) and the predictor variables were analysed using generalized estimation equations adjusting for the clustering of the data at the herd level.

5 Results

5.1 Associations at herd level, Paper I

The overall distribution of the studied reproductive performance indicators is shown in Table 3.

Table 3. *Overall median, 25th percentile, and 75th percentile of reproductive and production measures in the 2728 Swedish dairy herds studied.*

Measure	Median	25th	75th
Calving interval, d	400	386	417
Calving to first AI[1] interval, d	89	79	102
Calving to last AI interval, d	125	112	141
AI per animal submitted for AI, n	1.76	1.57	1.97
Cows culled because of reproductive problems, %	8.6	4.8	13

[1]AI = artificial insemination

5.1.1 Calving interval

The calving interval was shorter in herds comprising mainly SRB cows than in herds comprising mainly SH cows. The calving interval was also shorter in organically than in conventionally managed herds. The calving interval was longer in herds that fed TMR than in herds that did not. The calving interval was also longer in tie-stall than in free-stall herds. The calving interval was shorter in herds using automatic rather than ordinary pipeline milking; comparison indicated the same results for automatic milking and for milking parlours/rotaries. The calving interval was longer in herds that used DIY AI than in herds that did not. The calving interval was shorter in high-yielding than low-yielding herds.

5.1.2 Calving to first AI interval

The calving to first AI interval was shorter in herds comprising mainly SRB cows than in herds comprising mainly SH cows. Calving to first AI was also shorter in organically than in conventionally managed herds. In herds that used an advanced feed advisory service, calving to first AI was shorter than in herds that did not use such a service. Calving to first AI was longer in tie-stall than in free-stall herds. Calving to first AI was shorter in herds using automatic rather than ordinary pipeline milking systems; comparison indicated the same results for automatic milking and for milking parlours/rotaries. Herds using DIY AI had longer calving to first AI than did herds using professional inseminators. High-yielding herds had shorter calving to first AI than did low-yielding herds. Larger herds had shorter calving to first AI than did smaller herds.

5.1.3 Calving to last AI interval

Herds comprising mainly SRB cows had a shorter calving to last AI interval than did herds comprising mainly SH cows. Calving to last AI was shorter in organically than in conventionally managed herds. Calving to last AI was longer in herds that fed TMR than in herds that did not, and in tie-stall than in free-stall herds. Calving to last AI was shorter in herds using automatic rather than ordinary pipeline milking systems; comparison indicated the same results for automatic milking and for milking parlours/rotaries. Calving to last AI was also shorter in high-yielding than low-yielding herds.

5.1.4 Number of AIs per animal submitted for AI

The number of AIs was greater in herds that used an advanced feed advisory service than in herds that did not. Larger herds had more AIs than did small herds. The interaction between herd breed composition and DIY AI indicated that herds comprising mainly SRB cows that used DIY AI had more AIs when than did herds comprising mainly SH cows that used DIY AI. The interaction between herd breed composition and stall type indicated an overall difference between the two stall types, with more AIs for all breeds in tie-stall than free-stall herds. Herds comprising mainly SRB cows had more AIs when held in tie stalls than did mainly SH herds in tie stalls; the two breeds did not differ in performance when held in free stalls. The interaction between 365-day milk yield and stall type indicated an overall difference between the two stall types, with more AIs occurring in tie-stall than free-stall herds. If the herd was high yielding and had free stalls, the number of AIs was greater than in low-yielding herds in free stalls. The same was seen for tie-stall herds, high-yielding herds having more AIs than did low-yielding herds.

5.1.5 Culling due to reproductive problems

The odds of culling due to reproductive problems were greater in small-sized herds than in both medium- and large-sized herds. Low-yielding herds had greater odds of culling due to reproductive problems than did high-yielding herds; the same difference was evident between medium- and high-yielding herds. There was no significant difference between low- and medium-yielding herds. Herds using automatic milking systems had lower odds of culling due to reproductive problems than did herds using pipeline milking, and herds using parlours/rotaries also had lower odds of culling due to reproductive problems than did herds using pipeline milking. The odds of culling due to reproductive problems were lower in organic than nonorganic herds. Herds using an advanced feed advisory service had greater odds of culling due to reproductive problems than did herds that did not. The interaction between herd breed composition and DIY AI indicated that the odds of culling due to reproductive problems were greater in Swedish Red and White-dominated herds than in herds comprising mainly Swedish Holstein cows if DIY AI was used, whereas the odds did not differ if DIY AI was not used. In herds comprising mainly Swedish Holstein cows, the odds of culling due to reproductive problems were greater for herds not using DIY AI than in herds using DIY AI, but no differences were found for herds comprising mainly SRB cows.

5.2 Comparisons of disagreements between datasets, Paper II

The distribution of disagreements between the “original” and “updated” datasets for the various reproductive indicators is shown in Table 4.

5.2.1 Number of inseminations, ΔNI

Herds comprising mainly SH cows had higher odds of having a disagreement than did herds comprising mixed/other breeds. Herds comprising mainly SRB cows had lower odds of disagreement than did herds comprising mainly SH cows. Herds with poor, moderate, and good ROI had higher odds of disagreement than did herds with an ROI over 1.

Table 4. *Distribution of herds according to disagreements between reproductive measures in the artificial insemination (AI) recording system computed in September ("original") and May ("updated"). The disagreements were calculated by subtracting "updated" from "original" data. The total number of herds for each variable may vary due to missing information*.

	Percentage disagreement[2]				
Reproductive measure[1]	< –10%	–5% to –10%	–5% to +5%	5% to 10%	>10%
NI	0	0	60	389	21
%NR56	0	0	470	0	0
CFI	0	0	399	37	36
CLI	0	0	87	267	118
%PPI	7	10	382	50	22
%P	15	31	405	1	2
FI	96	99	196	2	1

[1]NI = number of inseminations per animal submitted for AI; %NR56 = the percentage of non-returns at 56 days; FI = fertility index; CFI = days from calving to first insemination; CLI = days from calving to last insemination; %PPI = percentage pregnant per insemination; and %P = percentage pregnant of animals submitted to AI.
[2]Negative values indicate that the measure increased between September and May, while positive values indicate that the measure decreased between September and May.

5.2.2 Percentage of non-returns at 56 days, Δ%NR56

The %NR56 did not change by more than 5% for any of the herds, so statistical analysis of this measure was not performed.

5.2.3 Days from calving to first insemination, ΔCFI

In this model, geographic region was found to be a confounder and was included in the model. Herds that used DIY AI had higher odds of disagreement than did herds that did not use DIY AI. Herds with poor ROI had higher odds of disagreement than did herds with moderate, good, and over 1 ROI. Medium-sized herds had higher odds of disagreement than did large-sized herds. Medium-yielding herds had higher odds of disagreement than did high-yielding herds.

5.2.4 Days from calving to last insemination, ΔCLI

Herds that used DIY AI had higher odds of disagreement than did herds that did not. Herds comprising mainly SRB cows had lower odds of disagreement than did herds comprising mainly SH cows or mixed/other cows. Herds comprising mainly SH cows had higher odds of disagreement than did herds comprising mixed/other cows. If herds had a %PC of 94.4–112.8%, the odds of disagreement were lower than in herds with a %PC over 112.8%.

5.2.5 Percentage pregnant per insemination, Δ%PPI

Small- and medium-sized herds had higher odds of indicator disagreement than did large-sized herds. If the herds had a %PC below 94.4%, the odds of disagreement were higher than in herds with a %PC over 112.8%. Herds that had a %PC of 94.4–112.8% did not differ from those with a %PC over 112.8%.

5.2.6 Percentage pregnant of started: Δ%P

None of the available predictor variables was found to explain the disagreement for this outcome.

5.2.7 Fertility index, ΔFI

Herds comprising mainly SRB cows had lower odds of disagreement for FI than did herds comprising mixed/other breeds. Herds comprising mainly SRB cows also had lower odds of disagreement for FI than did herds comprising mainly SH cows. Herds comprising mainly SH cows did not differ from those comprising mainly mixed/other breeds. The interaction between DIY AI and ROI indicated that herds with moderate ROI and that used DIY AI had higher odds of disagreement than did herds with moderate ROI but not using DIY AI. Herds with poor ROI and that did not use DIY AI had higher odds of disagreement than did herds with moderate, good, and over 1 ROI.

5.3 Evaluation and comparison of indicators, Paper III

The results of the ROC analysis are shown in Table 5, which also shows the ranking of the reproductive indicators.

When predicting the level of management efficiency, IV30 was the indicator that best discriminated between the various levels. The second best indicator for this purpose was PV30. However, IV30 could not be used to predict the levels of reproductive physiology at all; for this purpose, FI was the best indicator, though it was the least useful for predicting the management efficiency. Finally, for assessing a combination of reproductive management efficiency and reproductive physiology, the best reproductive performance indicator was PV30.

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Table 5. *Results of the receiver operational characteristics curve from the logistic regression model showing the area under the curve and ranking of the various reproductive performance indicators divided according to management efficiency and reproductive physiology.*

	Reproductive performance indicator	Area under curve	95% Wald confidence limits	Rank
Management efficiency	CI[a]	0.877	0.794–0.849	5
	FI[b]	0.743	0.777–0.833	6
	IC100[c]	0.897	0.851–0.896	3
	NotIC200[d]	0.886	0.885–0.925	4
	PV30[e]	0.902	0.895–0.931	2
	IV30[f]	0.999	0.990–0.996	1
Reproductive physiology	CI[a]	0.663	0.627–0.699	5
	FI[b]	0.823	0.794–0.852	1
	IC100[c]	0.707	0.673–0.742	4
	NotIC200[d]	0.744	0.711–0.777	2
	PV30[e]	0.727	0.694–0.760	3
	IV30[f]	0.511	0.471–0.551	6

[a] CI = calving interval, days
[b] FI = fertility index
[c] C100 = proportion of pregnant cows 100 days after calving
[d] NotIC200 = proportion of non-pregnant cows 200 days after calving
[e] PV30 = proportion of pregnant cows 30 days after the herd VWP
[f] IV30 = proportion of inseminated cows 30 days after the herd VWP

5.4 Associations at cow level, Paper IV

Overall results of the GEE models are summarized in Table 6.

Table 6. *Associations between risk factors and chance of pregnancy at VWP plus 30 days; odds ratios are given for comparisons between pairs of risk factors.*

Factor	OR	Factor	OR
SRB vs. SH	1.15	High vs. low MY [2]	0.71
Reproductive disease vs. no reproductive disease	0.81	Autumn vs. spring	1.19
Disease vs. no disease	0.71	High vs. low SCC [2]	0.87
High vs. low FPR [1]	0.79	Twin vs. non-twin birth	0.69
Free vs. tie stalls	1.44		

[1] Milk fat/protein ratio

[2] Milk yield, kg

[3] Somatic cell count

The chance of pregnancy at VWP plus 30 days was higher for SRB and other/cross breed cows than for SH cows. The difference between SRB and SH cows was greater for older than first-parity cows. Claw trimming was not significant in the model for first-parity cows, so the results for claw trimming are only reported for cows of second and higher parities. The chance of pregnancy was lower for cows with severe remarks at trimming than for cows with no remarks at trimming. In addition, cows not included in the claw trimming database had a lower chance of pregnancy than did cows that had no remarks at trimming. Cows with mild remarks at trimming were not significantly different from cows with no remarks at trimming.

Cows that had a record of disease related to reproduction had a lower chance of pregnancy than did cows without such a record. Cows that had a record of non-reproductive disease also had a lower chance of pregnancy than did cows without such a record. The higher the somatic cell count in the milk, the lower the chance of pregnancy. Second- and higher-parity cows with records of dystocia had a significantly lower chance of pregnancy than did cows with no record of dystocia. Cows giving birth to twins had a lower chance of pregnancy than did cows with single births.

As the milk fat/protein ratio became greater, the chance of pregnancy declined, and this seemed to be the case for all parities. First-parity cows in the group with the highest milk yield had a lower chance of pregnancy than did first-parity cows in the group with the lowest milk yield. Second-parity cows in the two middle yielding groups had a greater chance of pregnancy than did those in the lowest yielding group. Third- and higher-parity cows in all groups had a greater chance of pregnancy than did the group with the lowest milk yield.

Cows from herds with a long VWP (i.e., over 51 days) had a higher chance of pregnancy than did cows from herds with a short VWP (i.e., under 51 days). Cows held in free stalls had a greater chance of pregnancy than did cows in tie stalls.

The chance of pregnancy was lower in summer than in winter–spring (not significant for first-parity cows) and higher in autumn–winter than in winter–spring (not significant for second-parity cows).

6 Discussion

6.1 General

In this section of the thesis I will discuss the findings of Papers I–IV; more detailed discussions can of course be found in the individual papers. I will first review issues concerning the ecological fallacy (section 6.2). Then I will discuss reproductive performance indicators adjusted for the herd VWP (section 6.3), continuing with a discussion of what the findings mean to herd advisors and herd managers (section 6.4). Finally, I will discuss the quality of the data used (section 6.5).

In Papers I–IV, we examined reproductive performance indicators used, or that presumably could be used, by herd advisory services. The end-users of these indicators are herd advisors together with herdsmen or herd managers. They are the ones who ultimately decide whether something should or could be done with respect to reproduction. We have seen that reproductive performance differs between systems (Paper I), that the system used affects the reproductive performance indicators (Paper II), and that there are usable reproductive indicators that take the management regime into account (Papers III and IV). We conducted our studies using data aggregated at both the herd and cow levels, which highlights the importance of taking account of the possibility that the ecological fallacy may be in play.

6.2 Ecological fallacy

In Paper I, we examined the associations between herd characteristics and reproductive performance. It must be kept in mind that the results are to be interpreted at the herd level and that associations found may not necessarily hold at the individual animal level. This refers to the ecological fallacy, which would entail ascribing the group mean to individuals. Robinson demonstrated in the 1950s (2009, reprint) that ecological correlations cannot validly be used as substitutes for individual correlations. An individual correlation is a correlation in which the statistical object described is indivisible and the variables are descriptive properties of the individual. In the context of animal science, such variables could be the height, breed, or age of the animal and in the specific context of animal reproduction, whether or not the animal is pregnant, CFI for the animal, and number of inseminations used. In an ecological correlation, the statistical object is the group and the variables describe the properties of the group, often expressed as mean values.

In Papers I and II, the classification of herds as being low, medium, or high yielding based on the average 365-day milk yield for all cows in the herd is a good example of a group property. When discussing the results, it is important not to conclude that *high-yielding cows* have a certain outcome, when we only can rightfully speak of *high-yielding herds* in those situations in which we have detected associations between herd attributes and reproductive performance (Papers I and II). However, providing the variables are measured at the group level, any inferences directed towards this level pose no particular problems (Dohoo *et al.*, 2009). The ecological fallacy is especially important to bear in mind when comparing the results of Papers I and II, where the studies were conducted at the herd level, with the results of Paper IV, where we examined reproductive performance at the cow level. It is of course possible to observe the same relationships at the herd level as can be found at the cow level. It is crucial to remember at which level the data are aggregated so as not to draw the wrong inference.

6.3 Reproductive performance indicators adjusted for the herd VWP

Differences in reproductive performance between herds are likely largely caused by differences in management at the herd level and not by systematic differences in the reproductive physiology of the individual cows. That is, herd-level factors can potentially have greater effects on reproductive performance, measured at the herd level, than can factors acting on individual cows (Morton & McGowan, 2002). One way to reduce the variation caused by herd management and to better capture the biological reproductive performance is to use an indicator that controls for management strategy at the herd level. However, most traditionally used indicators do not take account of the various management strategies applied at the farm level. This was something we wanted to explore further, so we sought a reproductive performance indicator that would adjust for management strategy. One management factor that can be found to differ between herds is the VWP. In an survey study, we observed that the VWP, as reported by herdsmen, varied between herds, having a mean of 66.5 days with a range of 50–80 days (Löf *et al.*, 2007). Herd managers may have various reasons for choosing a certain VWP duration, and even though most studies find that a CI of 12–12.5 months is economically optimal (Huirne *et al.*, 2002; Esslemont, 2003; Sørensen & Østergaard, 2003), there is ongoing discussion of the benefits of voluntarily extending the CI by increasing the VWP. Increasing the VWP by 60 days in high-yielding cows has been found to have economic advantages (Arbel *et al.*, 2001). Österman and Bertilsson (2003) concluded that a prolonged CI (VWP = 280 days), combined with milking three times a day, gave a more tenable production system than did a conventional one (VWP = 50 days). A prolonged VWP is something that some herd managers may approve of and may try to implement at the herd level. The VWP may also vary within a herd according to the cow's parity and milk yield. The variation in VWPs between and within herds will influence the commonly used reproductive indicators. As these indicators will be greatly influenced by strategic or managerial decisions as well as biological variation, it can be difficult to compare reproductive efficiency between herds managed according to different strategies. We therefore argue that the VWP is a key management strategy factor that should be taken into account and controlled for when developing reproductive performance indicators.

As noted in section 2.3.3, one way to overcome problems of data incompleteness is to use failure-time models such as survival analysis in which incomplete records contribute to the indicator as censored variables. This is also a way to reduce the bias that could be introduced when not considering all eligible cows. By controlling for different management strategies and by using failure-time models, we explored the indicators *proportion of pregnant cows after the herd VWP plus 30 days* (PV30) and *proportion of inseminated cows after the herd VWP plus 30 days* (IV30). The rationale for choosing 30 days after the herd VWP as the point at which to evaluate whether or not the cows are pregnant was based on a normal oestrus cycle length of 21 days. When half of this time (10 days) has passed, at least half of the cows should have been seen in heat; to this we then add another cycle length, ending up with 30 days. This allows for the fact that the VWP is not a definite length of time and that the cycle length might also vary between cows. We could have chosen a different number of days after the voluntary waiting period, but this would then have had other consequences. For example, the closer one is to the end of the VWP, the fewer cows would be pregnant or even served by this time, limiting the usefulness of the indicators. On the other hand, the further away in time one is from the end of the VWP, the more cows would be pregnant or served, but the longer the time becomes for when the indicators can be calculated, influencing the rapidity of the indicators.

In Paper III we evaluated the herd-level reproductive performance indicators PV30 and IV30, and in Paper IV we verified the cow-level reproductive performance indicator, *pregnant or not at the VWP plus 30 days*. In Paper III, after assessing reproductive management efficiency, reproductive physiology, ease of use, and robustness to differences in management and future changes in management, we found the single best reproductive performance indicator at the herd level to be PV30. In addition, PV30 was also demonstrated to be the best correlated to net return (Emanuelson *et al.*, 2010). In Paper III, IV30 was not found to be able to distinguish between herds with different reproductive physiologies, so it was not evaluated in Paper IV. However, IV30 was good at revealing the reproductive management level of the herds, so it could be used by herd advisory services to distinguish herds that are late in initiating insemination. In Paper IV, we wanted to verify whether known factors affected the chance of cows being pregnant at VWP plus 30 days, which is the cow-level equivalent of PV30. Our results indicate that well-known associations also apply to this reproductive performance indicator that adjusts for VWP and that the indicator could be a suitable tool for use in preventive herd health work.

Some bias in reproductive performance indicators is avoided by considering VWP and applying survival analysis in calculating PV30. Nevertheless, animals not intended to be inseminated will be included in the calculation; this proportion may vary between herds and introduce some bias. Another central aspect is to perform pregnancy checks early and regularly to be able to calculate PV30 as early and correctly as possible. It is of course possible to use the calving date to retrospectively calculate the pregnancy date, but then the ability of the indicator to describe current reproductive efficiency would be lost, meaning the indicator would instead describe past reproductive performance. We used the VWP to account for management differences, but other managerial factors also could or should be accounted for. One example is the herd HDE, which varies between herds. In Paper IV we added herd HDE to the statistical model to account for differences between cows from herds with different HDEs. The results, not surprisingly, indicated that cows from low-HDE herds had a lower chance of pregnancy at VWP plus 30 days. If a reproductive performance indicator could be adjusted for both VWP and HDE, it would be easier to establish benchmarks between herds and, perhaps, to uncover more of the underlying physiological reproductive performance. This is also something that could be important when using the reproductive indicator in genetic evaluation to select for the next generation of cows.

If using PV30 and IV30 to obtain information on how the herd is performing and for benchmarking against other herds, it is important to know the optimal value or target value for the indicators. To obtain this knowledge, researchers must consider actual herds to establish the range of variation in these indicators. This must also be done to determine where to establish when the indicators should be considered too low and when action is needed.

Comparing PV30 and IV30 to the indicators presented in section 2.3.2, the advantages of the former indicators are that they control for management and take account of all cows in the herd because the indicators are based on survival analysis. This is not the case for indicators such as the calving to first service interval, in which the VWP could influence the length of the interval. PV30 and IV30 describe the current reproductive efficiency, while, for example, the calving interval better describes past reproductive performance. The disadvantages of PV30 are that pregnancy checks need to be performed in a timely fashion and that it is only calculated for first-parity and older cows. The latter disadvantage could be taken care of by having separate heifer indicators calculated according to the desired age at calving.

6.4 What do the findings mean to herd advisors and herd managers?

6.4.1 Factors that can be influenced independently of the management system used

First, we can conclude that the various studied reproductive indicators display variation between herds. In Paper I, we saw that the length of the CI differed by 31 days (or one month) from the 25th to the 75th percentile of the herds. PV30, as well, display variation, i.e., the difference being 12% between the 25th and the 75th percentile of the herds (Löf *et al.*, 2008). The range of the indicators, indicating that some herds have poorer reproductive performance than others, demonstrates that there is scope for improvement.

Some factors found to significantly affect reproductive performance can be influenced at the herd level, such as the use of TMR and DIY AI (Paper I) and the level of heat detection (Paper IV). In addition, health-related factors such as energy balance and disease play an important role in reproductive performance at the cow level (Paper IV) and also can be improved to some extent.

DIY inseminations

The results of Paper I indicate that herds with DIY inseminators had poorer reproductive performance than did herds using AI technicians; this is in agreement with the findings of McCoy *et al*. (2006), who suggested that poor DIY technique contributes to lower fertility performance on Northern Ireland dairy farms. In contrast, Buckley *et al*. (2003a) recorded no difference between AI technicians and DIY AI by farmers in terms of pregnancy rates with first inseminations in well-managed herds. In Paper IV, we investigated whether belonging to a DIY AI herd affected the chance of a cow being pregnant or not at VWP plus 30 days. DIY AI was not significantly associated with pregnancy, indicating that, at the cow level, DIY and technician-administered AI do not differ in performance. However, in the statistical model DIY AI was defined at the herd level and should actually not be regarded as a cow-level factor. In the model, we controlled for many factors, some of which might have co-varied with herds using DIY AI, even though we found no indications of colinearity between predictor variables. In light of the results of Paper IV, DIY AI seems to be a herd-level factor and our results indicate that being a DIY AI herd must be regarded as a risk factor for poor reproductive efficiency. DIY AI herds should thus be closely monitored and herdsmen could be offered refresher courses to eliminate negative factors causing suboptimal conception rates.

Nutritional status

The nutritional status of the cows is also something that the herd management can control. In Paper I, herds using TMR had longer calving intervals and calving to last AI intervals than did herds without TMR. It has been observed by feed advisers in Sweden that some cows in TMR systems are obese at calving if the system is not properly managed. It is known that overconditioned cows eat less and have a lower dry matter intake after calving than do lean cows (Garnsworthy & Topps, 1982). These cows will experience a greater loss in body condition and be in NEB, which leads to a higher risk of delayed ovarian resumption. This can also be applied to the results we found in Paper IV, in which cows with a higher milk fat/protein ratio (used as an indicator of NEB) displayed poorer reproductive performance. If cows in NEB have delayed ovarian resumption, they will also take longer to become pregnant and display poorer results in terms of certain reproductive performance indicators. In Paper I, the associations between TMR and reproductive performance were made at the herd level, and in Paper IV we analysed the associations between TMR and the chance of a cow being pregnant at VWP plus 30 days at the cow level. In Paper IV, we did not find any significant association between the use of TMR and chance of pregnancy. The use of TMR may mean that more cows enter NEB in such systems. In Paper IV, cows in NEB are captured by the factor milk fat/protein ratio instead of the factor TMR, which would explain why TMR was not found to have significant effects at the cow level. Our results indicate that the fat/protein ratio could be a good candidate for identifying cows at risk of poor fertility, indicating where preventive measures should be taken.

Heat detection efficiency

In Paper IV we added herd-level HDE to the statistical model to correct for herd differences. The results indicated that the reproductive performance is, as expected, higher for cows in herds with high HDE. Therefore, one way to improve reproductive performance is to attain high HDE (Roelofs *et al.*, 2010). This could be achieved by making the correct observations, using sufficient time for heat detection, and using various heat-detection aids. In automatic milking systems, the use of pedometers and other online tools is likely to improve HDE. This may also partly explain the higher reproductive performance in herds using automatic milking systems that was observed in Paper I. Fricke *et al.* (2005) found that HDE had the largest potential impact on reproductive performance since it is more easily improved than is conception risk, i.e., a factor largely determined by physiology rather than management. This also stresses the importance of heat detection, indicating that HDE should be addressed by herd advisory services and that resources should be allocated to herds with low HDE.

Health deviations

Paper IV found that cows that had severe remarks at claw trimming had poorer reproductive performance and that cows that had been diseased had poorer reproductive performance. The results further showed that the higher the somatic cell count in the milk, the lower the chance of pregnancy. This is in agreement with the findings of several authors who found impaired reproductive performance in cows with: claw disorders (Sprecher *et al.*, 1997; Garbarino *et al.*, 2004; Hultgren *et al.*, 2004), reproduction-related diseases (Oltenacu *et al.*, 1990; LeBlanc *et al.*, 2002; Dubuc *et al.*, 2011), and other diseases (Barker *et al.*, 1998; Walsh *et al.*, 2007). This demonstrates that healthy cows perform better and that one should strive to prevent disease to maintain high reproductive performance.

6.4.2 Other factors that should be considered

Housing and management

The fear that the ongoing structural change could impair reproductive performance might be exaggerated, at least considering how cows are held. In both Papers I and IV, we found that being a free-stall herd or free-stall cow results in better reproductive performance than does being a tie-stall herd or cow. In addition, the use of automatic milking systems seems advantageous for reproductive performance. However, we have no information as to what would happen to reproductive performance if a tie-stall herd were converted into a free-stall herd or a conventional milking herd into an automatic milking herd.

Others have found similar results. Petersson *et al.* (2006a) demonstrated that the interval between calving and first ovulation and oestrus is shorter in free-stall than tie-stall herds, enabling earlier insemination in free-stall herds. Valde *et al.* (1997) demonstrated that tie-stall herds had a lower fertility status index than did free-stall herds, implying that cows in free stalls have better reproductive efficiency. These findings emphasize that for tie-stall herds, greater attention to reproductive performance would be worthwhile.

In paper I we found better reproductive performance in organically managed herds, but in paper IV we did not find any association between chance of pregnancy and organically managed cows. Reksen *et al.* (1999) found lower reproductive performance in organically managed herds when adjusting for yield, season and parity, while Fall and Emanuelson (2009) did not reveal any differences between conventionally and organically managed herds. In paper IV we studied many factors and the effect of being organic might have co-varied with some factor, which might have captured this effect. The relationship between organic management and reproductive performance should perhaps be studied further.

Breed

As mentioned in the previous section, the fear that the ongoing structural change could impair the reproductive performance might be exaggerated in light of some of the results we have described from Papers I, II, and IV. However, this is not the case when considering the structural change in the breeds being used in Sweden. As described in section 2.2.1, the distribution between breeds has come to favour SH cows over SRB cows. The proportion of SH cows has increased by 12.1 percentage points, compared with a decrease of 13.3 percentage points in the proportion of SRB cows. In Paper I, we discovered breed differences at the herd level, herds comprising primarily SRB cows displaying better reproductive performance than did herds comprising primarily SH cows. However, these breed comparisons were made across herds, so the differences could have been due to between-herd differences in reproductive management. In Paper IV, we included only herds containing at least two breeds, so the comparisons were within herd. The statistical model also took into account both herd management (i.e., different HDEs) and milk yield at the individual-cow level. In addition, the outcome variable in Paper IV, pregnant after the herd VWP plus 30 days, eliminates some of the herd differences that could increase the breed effect. Despite these factors, we found that cows of the SRB breed had a greater chance of pregnancy than did cows of the SH breed. We also found that the difference between SRB and SH cows increased when comparing second- and higher-parity cows to first-parity cows, i.e., the breed effect was more prominent in second- and higher-parity cows. Differences in reproductive efficiency between breeds have been reported by Dillon *et al*. (2003), who compared four breeds, of which Holstein-Friesian cows had a lower pregnancy rate and longer calving to conception interval than did the other breeds. These and our findings disagree, however, with those of Friggens and Labouriau (2010), who did not find any differences in the probability of pregnancy between three different Danish breeds, though they did find differences in the rate of occurrence of first oestrus, which was 30% higher for Danish Red than Danish Holstein cows. Fertility has been taken into account in the Swedish national breeding programme for both SH and SRB breeds, but the programme has been less effective in SH cows because of the constant influx of foreign genetic material (Berglund, 2008).

Breed is a factor that should be considered when analysing impaired reproductive performance. Herds comprising mainly SH cows, as well as individual SH cows, risk poorer reproductive performance and should therefore be closely monitored to obtain higher reproductive performance. It is also important to bear reproductive performance in mind when choosing bulls to sire the next generation of cows.

Milk yield

In Paper I, we observed that low-yielding herds had longer CI, CFI, and CLI and higher culling due to reproductive problems than did high-yielding herds, suggesting that reproductive performance is better in high-yielding herds. Windig *et al*. (2005) found that herds with high average yields had shorter calving to first AI intervals, but that within herds, high-producing cows had longer calving to first AI intervals. Our results in Paper I are based on 2005 data and are essentially the same as those reported by Emanuelson and Oltenacu (1998) based on Swedish data from 1983–1989, implying better general fertility in high- than in low-producing herds.

An important consideration is that the relationship might actually be the inverse: high reproductive efficiency may be necessary to achieve a high herd average for the 365-day milk yield, i.e., short CIs are required to produce high average milk yields. As previously noted in section 6.2, it is important to remember that these results are at the herd level and that such associations may not necessarily hold at the individual animal level. However, this being said, in Paper IV we examined associations at the cow level and found that cows of second and higher parity in the group with low milk yield at first-test milking had a lower chance of pregnancy than did cows in groups with higher milk yields. Third- and higher-parity cows had an approximately 50% lower chance of pregnancy if their milk yield was in the lowest group than did cows in the group with high milk yields. In contrast to our studies, other studies describe a negative genetic correlation between milk yield and reproductive efficiency (Dematawewa & Berger, 1998; Roxstrom *et al.*, 2001), and still others find associations between high milk yields and poorer reproductive performance (Heuer *et al.*, 1999). This was also something that we observed in Paper IV, which found that first-parity cows in the group with the highest milk yield had lower chances of pregnancy than did first-parity cows in the group with the lowest milk yield. A factor contributing to this relationship is that first-parity cows are less likely to belong to the highest milk yield group, but tend to belong to the lower yielding groups in which most first-parity cows can also be found. Although the association was statistically significant for differences between the highest and lowest yielding groups for first-parity cows, it is of little relevance to this relationship in the population as a whole, since few animals are affected. Conversely, Eicker *et al.* (1996) found that the 60-day cumulative milk yield only minimally affected pregnancy and that the highest yielding cows had a slightly lower conception rate.

The difference found in Paper IV between high-yielding first-parity cows and low-yielding first-parity cows might be because the farmer actively chooses to allow high-yielding first-parity cows a longer VWP, which would give them a lower chance of pregnancy after the herd VWP plus 30 days compared with low-yielding first-parity cows, which might be inseminated earlier. The same reasoning, that farmers make active choices, can be applied to the third- and higher-parity cows, where a high-yielding cow would be at lower risk of replacement than a low-yielding cow of third or higher parities. This would be manifested in the farmer being more eager to get high-yielding than low-yielding cows pregnant, resulting in a higher chance of pregnancy in high-yielding older cows. That is, it is more important for the farmer to get a high-producing than a low-producing older cow to calve again. Eicker *et al.*

(1996) demonstrated that high-yielding cows were more likely to be inseminated then were low-yielding cows.

If herd management differentiates between groups of cows, it might be beneficial to analyse and describe the reproductive performance of these groups separately. The reproductive indicator PV30 can be modified to apply a different length of VWP to different groups of cows and is thus suitable to use for different groups.

6.5 Data quality

6.5.1 Registration in the databases

General on validation

Data used in observational studies are either collected for research purposes as primary data or retrieved from secondary data sources (Jansson Mörk., 2009). The records in the databases from which we retrieved the data used in Papers I, II, and IV were not primarily compiled for research purposes but were intended for monitoring disease, production levels, and reproduction and also for genetic evaluation. The records were routinely compiled and we were unable to control the generated data in the first place, since we had nothing to do with the registrations per se. The quality of such secondary data can be assessed by means of validation. This can be measured as the data accuracy, which may be defined in terms of completeness and correctness. *Completeness* measures the proportion of observations that are recorded in the database, while *correctness* is the proportion of recorded observations that are correct. NADRS was previously subject to validation (Jansson Mörk., 2009; Wolff., 2012), which found underreporting (i.e., completeness of 71–75%) for various diseases, the extent of which differed between groups of herds and cows. Completeness of the AI recording system could be measured as the proportion of inseminations performed that are recorded in the database. Correctness, in the sense of AI recording systems, could include the proportion of correct records of positive pregnancy checks. Substantial completeness and correctness problems could then lead to bias when investigating associations between risk factors and diseases or between risk factors and reproductive performance. Neither SOMRS nor the AI recording scheme has been scrutinized in this way. One may suspect flaws in the records, but there could instead be less underreporting in these systems than in the NADRS due to a shorter reporting chain. However, there could be differential data loss that co-varies with herd characteristics, and this is an issue that should be investigated further.

Validating some of the reproductive performance indicators currently used by herd advisory services

In Paper II we wanted to investigate how data management affected reproductive performance indicators. We found disagreements between some of the reproductive indicators, while others displayed little or no disagreement when recalculated after six months. This implies that some measures tend to be more robust than others and do not shift over time to the same extent. Here we mean robust in the sense that the indicator is unaffected by data management. There were no disagreements between the two datasets for the indicator %NR56, which can therefore be seen as a robust indicator; there were disagreements for as many as 80% of the studied farms for NI, over 70% for CLI, and approximately 25% for FI. These levels of disagreement affect how those indicators can be used and interpreted. However, various factors could account for the poor agreement. Data handling and computer systems could be such factors, but herd characteristics can also affect the agreement. Differences may be a consequence of how the individual measures are calculated and of the extent to which late-arriving information is allowed to affect the measure when it is recalculated. These policies are established in the programming formula for the measure and may vary between the AI recording systems of different countries. A second reason for differences after recalculation is that a sufficient amount of new information continuously enters the database, leading to changes in the values of the measures. This is probably linked to the level of herd management and care. We selected some herd factors or characteristics that may be linked to the willingness and care to report reproductive events to the central database. Factors such as breed composition, milk yield, and herd size may reflect the attitude or level of professionalism with which a dairy herd is managed. Factors such as DIY AI, ROI, and %PC may reflect the attitudes of herd management towards fertility management. We have used ROI as a factor for two reasons. First, we see ROI as a marker of general herd fertility management. Second, ROI affects specific measures per se; for example, low ROI due to missed oestruses will lead to fewer performed inseminations, in turn affecting the NI. The %PC may also be seen as a sign of interest and care, on the one hand, but will also obviously influence %PPI.

Studies such as Paper II can help identify system shortcomings or farmers not reporting AI activities promptly, and help identify what reproductive performance indicators can be trusted and used by advisory services and for benchmarking between farms. The amount of disagreement for reproductive performance indicators varies greatly, which means that some measures are more reliable than others. We also identified that some herd characteristics may be used to predict the risk of disagreement. The results of Paper II indicate the need to be careful when interpreting reproductive performance indicators, because they may indicate much better conditions than exist or even worse than the actual conditions. These findings may also have implications for benchmarking between farms.

A reproductive performance indicator adjusted for the herd VWP

We have not considered how data management might affect PV30 or IV30. The data quality issue discussed above will of course affect any new reproductive performance indicator as well. Putatively, the situation would be the same for these indicators, i.e., the quality would depend on what records are recorded. If the records sent to the system are rubbish, the system will in turn produce rubbish indicators. If records of insemination dates or pregnancy checks are more easily lost than are calving dates, this would mean that indicators based on insemination dates or pregnancy checks will be less accurate than indicators based on calving dates. However, this matter has not yet been evaluated. Future research could aim to properly validate the AI recording scheme.

6.5.2 The simulation study, Paper III

In Paper III we used SIMHERD (www.simherd.com) to simulate data to evaluate the indicator PV30 in different types of herds and to compare PV30 with indicators currently used by herd advisory services. Evaluating reproductive performance indicators using data from actual herds may be problematic because the "true" status is never known: it is difficult to know to what extent a given component has influenced the reproductive status of a herd. The inherent natural variation of the components that influence the reproductive status makes it necessary to acquire a large quantity of data to evaluate differences between herds. To control the setting, one could perform large-scale experiments, but these are both expensive and time consuming. Stochastic simulations have therefore been used to exemplify herds of various reproductive statuses (Dijkhuizen *et al.*, 1986; Plaizier *et al.*, 1997). The greatest advantage of simulated data is that they are inexpensive. Another advantage is that one can easily change parameters that would be impossible to control in the real world. In Paper III, we changed the reproductive physiology of various herds by altering the abortion and conception rates of the cows – something that could not be done in the real world. Results based on simulated data are confined by the simulation environment and by the parameters that can be modified. Just changing a limited number of factors, such as the abortion and conception rates, does not tell the whole truth about impaired reproductive physiology. Simulation studies reflect an ideal world where all information on the events under study is complete and correct. This is seldom the case in the real world, where, for example, not all animals are pregnancy checked after every insemination and data can be lost or misread. The alternative, to work on real, observed data, is clearly affected by the underlying mechanisms, which cannot be observed or controlled experimentally. One approach would be to have experienced herd advisors subjectively select herds as exemplifying either good or bad reproductive management, and then to evaluate these herds. However, this would not have been a better alternative for objectively assessing the relative merits of different reproductive performance indicators than using simulated data.

6.5.3 Calculation of VWP

The actual VWP at the farm level may not be readily available without asking the herdsman, which is not practically possible when using the indicator at the national level. An alternative is to calculate when 5% or 10% (Miller *et al.*, 2007) of the animals in a herd have had their first insemination. We have previously investigated the correlation between the VWP, as reported by herdsmen, and the calculated time to when 5% of the cows were inseminated. We found an overall correlation of 0.51 (Löf *et al.*, 2008), which is fairly low and suggests either that herdsmen do not have a defined strategy or that the VWP is not strictly implemented, perhaps because of the use of individual VWPs. A calculated VWP may therefore be more reasonable to use than the VWP given by the farmer when calculating reproductive performance indicators that take account of VWP. Another issue to ponder is the word "voluntary" in voluntary waiting period, as it is unclear to what degree this waiting period actually is indeed voluntary. This could explain the low correlation between reported and observed VWP. It might actually be more accurate to refer to this period simply as the waiting period (WP) or, when it is calculated, as the calculated waiting period (CWP).

6.5.4 Bias and inference

Papers I and IV are based on data retrieved from SOMRS and in Paper II the data were retrieved from the AI recording system. We also required that herds had to have had at least 45 milking cows (50 in Paper IV) for one year to be included in the studies. As described earlier, 85% of herds in Sweden are enrolled in SOMRS, and 95% of these are enrolled in the AI recording system. In Paper I we included all herds that had more than 45 milking cows on average, and in Paper II we took a random sample of these herds to avoid selection bias. To draw inferences applicable to all herds in Sweden based on our results, we need information on herds not enrolled in the various recording systems, to evaluate whether these herds differ from enrolled herds. If unenrolled herds differ in characteristics from enrolled herds, it might be difficult to extrapolate our results. However, it is probably not useful or even necessary to make any extrapolations to unenrolled herds because these herds are few.

Drawing inferences and extrapolating our results to herds elsewhere in the world might be difficult. Milk production in Sweden differs from that in most other countries, and the milk yield per cow and year in Sweden is among the highest in the world. In addition, how the cows are held and managed differs in Sweden; for example, herds are relatively small sized and the cows are by law required to have access to pasture in the summer months. Other production differences exist, for example, hormonal regimes are only allowed in Sweden for curing disease. Our results can be used to draw inferences applying to countries with similar production settings and similar herd structures as those in Sweden, probably most of the Nordic countries.

7 Conclusions and recommendations

7.1 Factors associated with reproductive performance

- Breed is a factor that should be considered when analysing impaired reproductive performance. Herds of predominantly SH cows, but also individual SH cows, risk poorer reproductive performance and should therefore be closely monitored to obtain higher reproductive performance.
- Herds with managers who are DIY inseminators may risk poor reproductive efficiency; consequently, DIY AI herds should be closely monitored and herdsmen could be offered refresher courses to eliminate negative factors causing suboptimal conception rates.
- HDE should be addressed by herd advisory services and resources should be allocated to herds with low heat detection efficiency.
- Healthy cows have better reproductive performance, which emphasizes that one should strive to prevent diseases to maintain high reproductive performance.
- Tie-stall herds should pay greater attention to the reproductive performance to improve the reproductive efficiency.
- The milk fat/protein ratio could be a good candidate indicator to use in identifying cows at risk of poor fertility, and to determine where preventive measures should be taken.

7.2 Data management

- Care is needed when interpreting reproductive performance indicators, because they may indicate a much better reproductive situation than actually exists. The opposite could of course also be expected. Benchmarking between farms can be affected because of differential loss of information for different types of herds.

7.3 Reproductive performance indicators adjusted for management strategy

- PV30 was found to be the best reproductive performance indicator with which to assess both reproductive management and reproductive physiology. Both PV30 and IV30 could be used by herd advisory services. These indicators would be useful in providing information on herd performance and in establishing more efficient benchmarking between herds.

7.4 General

- Trying to extend our results to a broader perspective, one could argue that current negative trends in reproductive efficiency cannot be explained solely by the ongoing structural change in herd management. This is because of the findings of better reproductive performance in some of the systems that will be predominant in the future. It is conceivable that the negative trends in overall reproductive efficiency experienced in most industrialized countries in recent decades are indeed due to changes in animal factors and not only to changes in management and herd structure.

8 Further research

- When using PV30 and IV30 to obtain information on how a herd performs and for benchmarking against other herds, it is important to know the optimal or target value of the indicators. To obtain this knowledge, research into actual herds must be conducted to establish the range of variation of these indicators. This must also be done to determine where to establish when indicators should be considered too low and when and where action is needed.
- To better describe the reproductive performance of groups within the herd, these groups could be analysed separately and the reproductive indicators PV30 and IV30 can be modified to have different VWP lengths for different groups of cows. To determine whether this approach would be meaningful, research must be performed examining different groups of cows.
- To evaluate reproductive performance in heifers, reproductive performance indicators similar to PV30 and IV30, for example, could be developed. This could be done by calculating indicators according to the desired age at calving, using survival analysis to do this. Further research would then be needed to explore these indicators.
- Future research should validate SOMRS and the AI recording scheme to explore whether there is differential data loss that co-varies with herd characteristics and to find herds that do not comply with the data recording of AI events.
- More research is needed to determine why SH and SRB herds and cows differ in reproductive performance. It would be interesting to learn whether these performance differences should be ascribed to different management strategies or to possible physiological differences.
- In addition, the milk yield should be scrutinized further to explain our findings of better reproductive efficiency in high-yielding herds and cows.

- Lastly, and perhaps most importantly, the association between economic net return and reproductive performance must be evaluated and explored. This should also be done in relation to cow longevity, internal herd growth, and the replacement of older cows.

9 Populärvetenskaplig sammanfattning

9.1 Bakgrund

Fruktsamheten eller reproduktionsförmågan hos mjölkkorna är en av de viktigaste faktorerna för mjölkproducenter. En mjölkkos produktiva liv börjar först när hon har fött en kalv. För att fortsätta att producera mjölk måste kon fortsätta att kalva med jämna mellanrum. Fertiliteten hos mjölkkor, det vill säga deras förmåga att bli dräktiga, behålla en dräktighet och föda en kalv, är därför en nödvändig förutsättning för en naturlig mjölkproduktion (utan användning av hormoner för konstgjord reglering av mjölkproduktionscykeln).

Många studier har identifierat nedsatt reproduktionsförmåga som en viktig orsak till minskad produktionseffektivitet inom mjölkproduktionen. Denna minskning orsakas av högre kostnader för att ersätta äldre kor och för att behålla storleken på besättningen men också av ökande kostnader för veterinär och framförallt en reducerad årlig mjölkavkastning. Besättningsrådgivningen har ofta reproduktiv effektivitet som mål och för att mäta effektiviteten använder man många olika mått, dvs. nyckeltal eller indikatorer. Dessa mått används för att övervaka och jämföra den reproduktiva effektiviteten hos mjölkkor och mjölkkobesättningar. De baseras på uppgifter som lämnas genom seminpersonal eller djurägaren själv och de sammanställs i ett centralt seminbokföringssystem.

Det svenska lantbruket genomgår en strukturell förändring i hur mjölkkor hålls och hanteras. Samtidigt som antalet producenter minskar så ökar antalet kor per gård. Ett ökande antal mjölkproducenter blir djurägarseminörer istället för att anlita professionella husdjurstekniker, allt fler kor hålls i lösdriftssystem och användningen av automatiska mjölkningssystem ökar. Dessa förändringar kan påverka fruktsamheten hos mjölkkor.

Det övergripande syftet med denna avhandling var att få kunskap om faktorer som påverkar de reproduktiva nyckeltalen eller indikatorerna som används i besättningsrådgivningen men också att hitta andra, eventuellt mer effektiva sätt att mäta reproduktionsförmågan hos mjölkkor. Specifika syften var:

- Att studera besättningsfaktorers samband med fruktsamhetsnyckeltalen.
- Att undersöka om datahantering av inrapporterade händelser påverkar de fruktsamhetsnyckeltalen och även att studera om det fanns några systematiska effekter på tillförlitligheten hos indikatorerna.
- Att utvärdera alternativa fruktsamhetsnyckeltal som är justerade för besättningens reproduktiva strategi.
- Att på konivå studera riskfaktorers samband med fruktsamhetsnyckeltal som är justerade för besättningens reproduktiva strategi.

9.2 Sammanfattning av studier och resultat

I studie I undersöktes samband mellan fruktsamhetsnyckeltal och besättningsfaktorer. Data hämtades från den svenska ko-kontrollen och 2 728 besättningar, med en genomsnittlig storlek på 45 eller mer kor, ingick i studien. Sambanden undersöktes med linjära och logistiska regressionsmodeller. Studien visade många statistiskt signifikanta samband mellan besättningsfaktorer och reproduktions effektivitet. Det som framkom var att fokus vid rådgivning bör ligga på besättningsfaktorer som är lätta att påverka, till exempel utfodring. Det framkom också att djurägarseminörer kan behöva mer stöd för att uppnå god fruktsamhet hos korna.

I studie II studerades om datahantering av inrapporterade händelser påverkade fruktsamhetsnyckeltalen och även om det fanns några systematiska effekter på tillförlitligheten hos nyckeltalen. Vi använda data från 483 mjölkobesättningar som var medlemmar i den svenska seminbokföringen. Samstämmighet mellan de rutinberäknade nyckeltalen och uppdaterade nyckeltal, där vi lät systemet vänta in information i ytterligare 6 månader, beräknades. Vi tittade alltså på samma period men lät eventuell ytterligare information bidra, t.ex. sent inkomna rapporteringar om inseminationer. Om det nya värdet skiljde sig mer än 5 % från det första värdet så noterades detta som att måttet hade förändrats. Därefter undersökte vi om det fanns något samband mellan förändring i måtten och olika besättningstyper. Andelen av förändrade mått varierade. Måttet %NR56 visade ingen förändring alls, medans antalet inseminationer per djur visade störst förändring. Vissa besättningsegenskaper, t ex djurägarseminör, andel dräktighetsundersökta djur, ras och andelen av brunstiga djur som blev inseminerade påverkade om måtten förändrades.

I studie III utvärderades två fruktsamhetsnyckeltal som var justerade för besättningens frivilliga väntetid (FVT). Måtten var den procentuella andelen dräktiga kor i besättningen efter FVT plus 30 dagar (PV30) och andelen inseminerade kor i besättningen efter FVT plus 30 dagar (IV30). Genom att använda oss av en simuleringsmetod (www.simherd.com) så utvärderade vi PV30 och IV30 i jämförelse med traditionella fruktsamhetsnyckeltal. De simulerade mjölkkobesättningar (n = 900) hade olika nivåer av reproduktiv management och olika nivåer av reproduktiv fysiologi. Logistiska regressionsmodeller tillsammans med ROC-analys användes för att undersöka hur väl de olika fruktsamhetsnyckeltalen kunde skilja mellan besättningar av olika reproduktiv management och reproduktiv fysiologi. Vi drog slutsatsen att PV30 var det enskilt bästa måttet för att uppskatta graden av såväl besättningens managment och reproduktiv fysiologi. Måttet följdes NotInCalf-200-dagar och InCalf-100 dagar. IV30 kunde bara användas för att utvärdera besättningens nivå av reproduktiv management. PV30, och eventuellt också IV30, skulle kunna vara en potentiell kandidat för att ingå som ett nyckeltal i besättningsrådgivningen.

I studie IV studerade vi om faktorer som är kända för att påverka reproduktiv effektivitet också påverkade fruktsamhetsnyckeltalet PV30 (som vi studerade i papper III), men detta gjordes då på konivå dvs. om kon var dräktig eller inte vid besättningens FVT plus 30 dagar. Detta gjordes med hjälp av generalised estimation equations som var justerat för klustring av data på besättningsnivå. För att kunna vara med i studien var korna tvungna att komma från en besättning med minst 50 mjölkkor och besättningen var tvungen att ha minst två raser. De kor som hade kalvat mellan den 1 juli 2008 och 30 juni 2009 var sedan med i studien. Efter dataredigering fanns det 132 721 kor från 1 421 besättningar kvar. Våra resultat visar att väl kända samband gäller även för detta fruktsamhetsmått som är justerat för besättningens FVT.

9.3 Slutsatser och rekommendationer

9.3.1 Faktorer

Ras

Rasen hos mjölkkon påverkar hur fruktsam kon är. Besättningar med SH kor, men också enskilda kor av SH ras kan riskera lägre fruktsamhetseffektivitet och bör därför särskilt övervakas i fruktsamhetshänseende.

Djurägarseminörer

Besättningar med djurägarseminörer verkar ha sämre fruktssamhet. Djurägarseminörer bör därför erbjudas kurser och fortbildning för att förhindra att fruktsamheten i besättningen påverkas. Det är även viktigt att påpeka att rapportering av händelser till ko-kontrollen och seminbokföringen måste göras snabbt och korrekt för att kunna få pålitliga nyckeltal.

Brunstpassningseffektivitet

Att upptäcka brunst är något av det viktigaste i fruktsamhetsarbetet och är något som besättningsrådgivningen bör fokusera på. De finns många hjälpmedel att tillgå och i de nya systemen finns många möjligheter till automatiserade hjälpmedel för att hitta brunstiga djur.

Sjuklighet och hälsa

Friska djur har bättre fertilitet och det är viktigt att hålla djuren friska i alla avseenden för att behålla en hög fruktsamhetseffektivitet.

Stalltyp

Besättningar med uppbundna djur måste aktivt jobba med fruktsamheten för att uppnå bättre fruktsamhet

Mjölk-fett/protein kvoten

Mjölk-fett/protein kvoten verkar vara ett bra mått för att kunna upptäcka kor som löper risk för nedsatt fruktsamhet.

9.3.2 Datahantering och beräkning av nyckeltal

Det är viktigt att vara medveten om att man bör vara försiktig när man tolkar fruktsamhetsnyckeltal då de är beroende av att händelser (som påverkar måtten) rapporteras in till de olika systemen korrekt och i god tid. Måtten kan visa på en betydligt bättre situation än det egentligen är. Det omvända kan förstås också förekomma. Det finns risk att jämförelser mellan mjölkkogårdar kan påverkas av att det är olika bortfall av data i olika typer av besättningar.

9.3.3 Nya nyckeltal som är justerade för besättningens reproduktiva strategi

PV30 var den enskilt bästa måttet för att uppskatta graden av såväl besättningens managment och reproduktiv fysiologi. IV30 kunde bara användas för att utvärdera besättningens nivå av reproduktiv management. PV30, och eventuellt också IV30, skulle kunna vara potentiella kandidater för att ingå som nyckeltal i besättningsrådgivningen.

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