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GENETIC AND PHENOTYPIC STUDIES ON CULLING IN QUEBEC HOLSTEIN COWS

by

João Walter Dürr

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Department of Animal Science McGill University Montreal, Canada

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To my princess, Thais, and to the greatest happiness of my life, Nicolas.

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Preface

This thesis consists of a collection of two manuscripts already submitted to the Canadian Journal of Animal Science (Chapter 3 and Chapter 4) plus four related studies which are presented in separate chapters (chapters 5, 6, 7 and 8). The Faculty of Graduate Studies and Research of McGill University requires the full reproduction of the five intended paragraphs below in order to inform the readers of this dissertation.

"Candidates have the option of including, as part of the thesis, the text of one or more papers submitted or to be submitted for publication, or the clearly duplicated text of one or more published papers. These texts must be bound as an integral part of the thesis.

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In the case of manuscripts co-authored by the candidate and others, the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent. Supervisors must attest to the accuracy of such statements at the doctoral oral defense. Since the task of the examiners is made more difficult in these cases, it is in the candidate's interest to make perfectly clear the responsibilities of all the authors of the co-authored papers."

The contribution of each of the authors of the included manuscripts are presented at the beginning of the corresponding chapters.

João Walter Dürr Ste-Anne-de-Bellevue, Canada Ph.D.

João Walter Dürr

Animal Science

Genetic and phenotypic studies on culling in Quebec Holstein cows

A series of studies were conducted to evaluate genetic and phenotypic aspects of culling, herd life and survival in Quebec Holstein herds. Data consisted of lactation records obtained from the Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ) files, which included 2.2 million records before the editing procedures. The average productive herd life in Quebec herds was approximately 33 months, corresponding to an average replacement rate of 36%, for both milk recording options. Herds enrolled in the PATLQ official option had cows with longer calving intervals and culled their heifers earlier than herds in the owner sampler option. The probability of being culled for each major reason for disposal was assessed by logistic regression models, and it was shown that culling for low production (voluntary) had a clearly descending trend from 1981 to 1994, while involuntary culling (assumed to include all the reasons other than production) increased in importance mainly because of the ascending trends observed for culling due to reproductive problems, mastitis and feet and legs problems. Proportion of cows culled for involuntary reasons increased with parity number, but the opposite occurred for culling due to low production. Herds in the official option culled less for mastitis and sold more cows for dairy purposes than owner sampler herds. After these preliminary studies, a sequence of Weibull models were fitted to analyze different aspects of the data. The genetic study of herd life traits focused on differences between sires regarding true and functional herd life, but also described the effect of different explanatory variables on the failure time variable. Heritability for true and functional herd life was, respectively, 0.09 and 0.08 in the log scale and 0.19 and 0.15 in the original scale. The difference in the median survival time of daughters of bulls with extreme proofs for functional herd life was 1.7 lactations. Quebec dairymen use classification for Final Score and for Fore Udder as culling criteria in registered herds. Competing risks analysis was used successfully to study

cause-specific hazard functions relative to cows culled for different reasons. Differences in survival of first-crop daughters of Holstein bulls in first lactation were significant.

Résumé

Ph.D.

João Walter Dürr

Zootechnie

Études génétiques et phenotypiques des politiques de réforme des vaches Holstein de la province de Québec

Une série d'études ont été conduits afin d'évaluer les aspects génétiques et phenotypiques des politiques de réforme, de la longueur de la vie productive et de la survivance des vaches chez les troupeaux Holstein de la province de Québec. Les données initiales étaient 2.2 million des records de lactation obtenus de la banque de données du Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ). La longueur de la vie productive, en partant du premier vêlage, fut de 33 mois en moyenne, ce qui corresponds à un taux de remplacement de 36%, tant pour les troupeaux en option de contrôle officiel comme pour les non-officiels. Les troupeaux officiels montrèrent plus longues intervalles de vélage et éliminèrent les vaches plus tôt durant la première lactation que les troupeaux non-officiels. La probabilité d'être éliminée pour différentes raisons fut évaluée par des modèles de regression logistique. L'élimination volontaire (par basse production) montra alors une tendance descendante de 1981 à 1994, tandis que l'élimination involontaire (toutes les autres raisons) augmenta principalement à cause des problèmes reproductives, des pieds et membres, et de la mammite. La proportion des vaches éliminées par des raisons involontaires augmenta avec les parités, à l'envers de la raison volontaire. Les troupeaux officiels éliminèrent moins à cause de la mammite que les non-officiels. Ensuite, plusieurs modèles Weibull servirent à faire une étude des effets génétiques et non-génétiques de la vie productive réelle et fonctionnelle des vaches. L'héritabilité de la v.p. réelle et v.p. fonctionnelle fut 0,9 et 0.08 dans l'échelle logarithmique, et 0.19 et 0.15 dans l'échelle originale. La plus grande différence dans le temps de survivance des filles des taureaux évalués pour la v.p. fonctionnelle fut de 1.7 lactations. Les résultats montrent que les éleveurs des troupeaux enregistrés utilisent la Classification Finale et

l'Avant-Pis comme un critère important dans ces décisions de réforme. Un analyse des risques concurrentiels fut aussi incorporé dans cet étude. Finalement, une différence significative dans le taux de survivance fut trouvée entre les filles des taureaux en voie d'épreuve.

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I am also thankful to Dr. Robert Moore, the last member of my advisory committee. Robert was always our last resource in problems related to milk recording data and the dairy industry in general. "If Bob does not know it, nobody knows!", I was told several times.

I would never be able to express properly my appreciation to Dr. Vincent Ducrocq, who taught me everything I know about survival models. Not only his contribution to the field of survival analysis has opened a new chapter in the analysis of herd life data, but he is also engaged in the popularization of the new techniques among animal breeders. His endless patience to promptly answer my "e-mail" questions saved me from trouble innumerous times. I would like to acknowledge especially the use of the "SURVIVAL KIT", a set of FORTRAN programs written by Dr. Ducrocq and Dr. Sölkner, which made possible the use of survival analysis in this thesis. My gratitude to Dr. Kevin Wade and Dr. Flan Hayes for letting me use their computer facilities, which greatly accelerated my analyses.

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CHAPTER 1

Introduction

After many decades of selection based mostly on production traits in dairy cattle, more attention has been paid to the so-called auxiliary or secondary traits in recent years. Particularly longevity has been recognized as one of the attributes with the highest impact on the herd profitability. The longer a cow stays healthy and productive in the herd, the more profitable she is. There are many concurrent factors, however, that prevent dairy cows from having long productive lives: diseases, accidents, fertility problems, physical limitations to endure intensive milk production in different housing systems, anatomical characteristics that prevent mechanization, behavioral problems and, at the top of the "perils list", the eventual inability to meet dairymen's expectation in terms of milk production. Many studies have been published on methods and strategies to improve cows' ability to survive in modern dairy herds genetically. However, direct selection to increase the herd life of dairy cows has to overcome two serious problems: 1) waiting until cows have completed their herd lives to estimate breeding values would be useless and increase tremendously the generation interval, and 2) disregarding information about animals that are still alive at the time genetic parameters are estimated would seriously bias the results. Similar problems are found in follow-up studies in medicine, epidemiology, economics, engineering and sociology, for which proper statistical methodologies have been developed. Such methods are referred to as survival analysis and have also been shown to be appropriate for studies of herd life in dairy cattle (Wolynetz and Binns, 1983; Smith, 1983; Ducrocq, 1987).

The present dissertation combines different studies on culling of dairy cows in Holstein herds located in the Canadian province of Quebec. The initial goal of this project was to examine the issue using the codes for reasons for disposal of individual cows recorded by the producers enrolled in the Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ). Disposal codes have been recorded for many years at PATLQ without being utilized in any major study. Producers, who are ultimately in charge of reporting the causes of disposal, have expressed their interest in studies which make use of the information that has been collected. What is referred to as "cull rates" for proven sires seems to be of particular concern to a lot of breeders in Canada. Some dairymen are suspicious that daughters of particular bulls may be more prone to be culled due to specific reasons compared to daughters of other bulls, and no recent publication has addressed these concerns.

The first question to be answered in the present project was: how should culling codes be analyzed in order to provide meaningful results for producers and to establish a standard procedure which could be used to evaluate such data on a regular basis. Reasons for disposal are categorical traits by definition: cows are either culled due to a given reason or not. The appropriate treatment of discrete data requires the use of generalized linear models, which were introduced by Nelder and Wedderburn (1972) as a natural extension of linear models to consider the exponential-family distributions. For example, the incidence of each reason for disposal can be modeled using logistic regression models, in which the dependant variable is the log odds of being culled for a given reason, and the explanatory variables are the effects of year, herd, age, etc. With animal breeding situations in mind, threshold models have been proposed by Gianola and Foulley (1983) to estimate variance components for the random (additive) effects for categorical data. However, analyzing reasons for disposal as independent binary responses, in which 1 = culled for a given reason and 0 = not culled for the same given reason, ignores the fact that the occurrence of one type of disposal prevents the occurrence of all other disposal types. Hence, culling of dairy cows could be viewed as a multinomial (non-ordered) response, in which the disposal reasons are the possible outcomes. Although multivariate extensions of generalized linear models to the case of multinomial responses are

well established in the literature, availability of software that handle this class of models for large data sets is quite limited. The implementation difficulties become prohibitive when estimation of variance components for the random effects is required. Fortunately, there are more options to consider. If, instead of trying to model the incidence of the various reasons for disposal, one considers modeling the time from a given origin point (e.g., birth) to the occurrence of the event (e.g., death due to disease), then survival analysis becomes the "natural" choice for estimation. In the survival analysis framework, reasons for disposal can be treated as competing risks, which is what actually happens if one assumes that each cow is culled due to a single reason. The other advantage of this approach is that it relates culling reasons directly to length of productive life, which is a measure of herd life. Thus, the use of competing risks models not only provides a description of the factors affecting the risk of being culled due to a given reason, but also allows a straightforward interpretation of the results in terms of changes in herd life (which is the trait of interest, regardless the cause of disposal). The use of survival models for the analysis of herd life traits has been described (Smith, 1983; Ducrocq, 1987), and a software program that runs survival analysis for typical animal breeding applications has been developed (The SURVIVAL KIT, Ducrocq and Sölkner, 1994). Utilizing competing risks analysis to describe reasons for disposal in dairy cattle is not only the most appealing methodology available, but it is also possible to implement.

At this point, it is important to present the evolution of the project or the "learning process" that occurred in the course of this study, whose results are presented in the following chapters. Since the beginning of the work, there was a concern with obtaining not only a valuable contribution to the scientific knowledge, but also results which could be readily translated into practical recommendations for the dairy producers at PATLQ and in the other Canadian provinces. This is evident from the interpretation of the results of all chapters. Although the competing risks alternative was found attractive from the initial stages

of the investigation, the existence of the "SURVIVAL KIT" was ignored until the candidate took a course in survival analysis with Dr. Vincent Ducrocq in May 1996. Before that, other approaches had been tried, more specifically to describe general phenotypic trends for both herd life and reasons for disposal (Chapters 3 and 4). The methodologies used in that initial work are comparable to other studies in different populations, and besides providing interesting results from a practical point of view, revealed several unknown aspects of the data that were of great value in the subsequent phases of the project. After the decision to use survival analysis techniques was made, the first study implemented looked at survival in first lactation of first-crop daughters of Holstein bulls (Chapter 8). The choice of running this analysis first was based on the fact that data preparation was much simpler and the total number of records much smaller than for the analysis of the completed herd life data (Chapters 5, 6 and 7). The 'first-crop' study served as a training period, in which the candidate improved his understanding of both the methodology and the use of the SURVIVAL KIT, and it is presented after all other studies to facilitate the discussion of the results. Finally, lifetime records of Holstein cows calving in PATLQ herds from 1981 to 1994 were analyzed in three closely related studies, the genetic analysis of herd life traits (Chapter 5), the impact of conformation on culling decisions (Chapter 6) and a competing risks analysis of reasons for disposal (Chapter 7). The last chapter of this thesis (Chapter 9) is an attempt to summarize the main conclusions from the various studies and to put together a set of recommendations for producers and the Canadian dairy industry as a whole.

Therefore, the objectives of the present investigation were: a) to describe phenotypic trends in herd life of Quebec Holstein cows from 1981 to 1994, in order to verify assumptions and better prepare the models for the genetic analyses; b) to describe phenotypic trends in reasons for disposal in Quebec dairy herds, providing valuable general statistics for extension specialists and also improving the models for the genetic analyses; c) to apply survival analysis techniques to evaluate Canadian Holstein bulls regarding the survival of their daughters, in

an attempt to demonstrate that Canadian official evaluation for herd life could be carried out using state-of-the-art methodologies instead of linear models; d) to investigate the impact of type classifications on the culling decision-making process in Quebec; e) to demonstrate the feasibility of using competing risks analysis to study culling reasons, setting up a framework for future investigations in this area; f) to analyze differences among sires regarding their daughters reason-specific risks, evaluating the potential contribution of disposal codes to studies of herd life; g) to combine results from the different studies and prepare a set of recommendations for the Canadian dairy industry on culling policies and herd life.

CHAPTER 2

Literature Review

CULLING DAIRY COWS

The Culling Process

Culling milking cows in a dairy herd is a dynamic process that requires an integrated view of all the factors affecting herd profitability. Every day the dairyman has to evaluate whether or not each of his cows is still more profitable than her potential replacement (Renkema and Stelwagen, 1979), and then decide which cows should be culled and when should these animals be discarded. The main factors that would be considered during this decision-making process are: cows' production relative to the herd average; the cow's genetic merit and reproductive performance as indicators of her ability of producing replacement calves; the cow's general health; secondary traits such as conformation traits, which would vary in importance depending on the breeding goals established by the producer (type characteristics may be an important culling criteria for registered herds, but they may be completely disregarded by some commercial producers); the ratio between milk revenues and salvage values; costs and availability of replacement heifers; price of feedstuffs, as it is the most important component of the variable costs in a dairy farm; commitments related to the quota system where it exists (a producer that expects to be short of milk to fulfill his quota would likely wait longer to cull his cows which are still in milk); the cow's temperament and social behavior, in as much as it can affect other cows' production and annoy dairy managers; the dairyman's personal beliefs and managerial style. However, many cows, regardless their

relative economic value, will have their herd life discontinued as a consequence of diseases or accidents. The proportion of cows leaving the herd under these circumstances will greatly affect herd profitability, because it takes the control over which animals have to be replaced out of the dairyman's hands.

Researchers and practitioners have adopted a simple classification to indicate the type of culling associated with dairy cows disposals: involuntary culling, which occurs when a cow is culled regardless of the dairyman's intention to cull her or not, and voluntary culling, which takes place when a cow is considered to be less profitable than her potential replacement. Although these concepts are well accepted and routinely used to describe culling reasons, a careful observer would note that in many cases it is unclear whether a cow was culled voluntarily or not. For instance, when an average producing cow is culled due to bad temperament, one could argue that although there was nothing wrong with that cow regarding her producing ability, the producer still thought that the most appropriate decision was to cull her, and this should be considered as a voluntary removal. On the other hand, the producer certainly did not choose to have a "troublemaker" in his herd and he was practically obliged to cull a profitable cow in order to avoid further losses, which would make the point for a case of involuntary culling. In order to overcome the uncertainty of classifying culling reasons into voluntary or involuntary based on the producer's intentions, many studies have assumed that culling for low milk production is the only truly voluntary culling. This is justified by the fact that production traits are the most important factors in any economic index utilized by the dairy industry, and that increasing production of milk and of milk components is the ultimate goal of dairy farmers. Involuntary culling is then assumed to occur when a cow is sufficiently poor for a trait that she is culled regardless of the performance of her herdmates, and it includes culling for reproductive failure, temperament, milking speed, feet and leg problems, udder problems, health problems and accidents. Although this is an oversimplification of the farmer's rationale having to discard cows in his herd, it provides a

reasonable starting point to analyze and interpret disposal reasons across herds.

Major Reasons for Disposal

Dairy producers enrolled in the Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ) are expected to report every month which cows have left the herd since the last milk recording test and to provide one major culling reason for each cow culled. This information provides a means of quantifying proportions of cows being culled for low production, mastitis, reproductive problems, and other reasons. Table 2.1 shows the disposal codes used by PATLQ herds to describe culling reasons.

Sale Codes	Culling Codes	Death Codes
Export	Low Milk Production	Sickness
Dairy Purposes	Low Fat	Bloat
Rented to	Bad Temperament	Injury
	Slow Milker	Poison
	Mastitis/High SCC	Old Age
	Udder Breakdown	Electrocution
	Feet and Leg problems	Milk Fever
	Reproductive Problems	Displaced Abomasum
	Sickness	Other
	Injury	
	Old Age	
	Milk Fever	
	Displaced Abomasum	
	Other	

Table 2.1 -	PATLQ	disposal	codes.
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Considering that one of the main objectives of the present investigation was to describe trends in culling reasons and to study the genetics of being culled for different reasons, it is important to discuss the type of information provided by the disposal codes listed in Table 2.1. Producers have a limited number of "reasons" to choose from, and often they cannot find a code that would correspond to the true motive why a given cow had to be discarded. Particularly in cases of cows being culled due to undesirable conformation, no codes are available. Culling for feet and leg problems and for udder breakdown are certainly related to type, but these codes are meant to report extreme cases of lameness and pendulous udders, as opposed to those cows that simply do not meet the criteria established by the breeder for conformation traits. Culling for low protein production should also have a code of its own, considering the weight that protein production has in the contemporaneous selection indices and milk payment formulae. Another deficiency of the current system is that only one culling code is allowed, even though in most of the cases there is not a single cause as to why a cow had to be culled, but a combination of reasons. For example, a cow that has lost a quarter due to a severe case of mastitis might end up being reported as culled for low production because the producer has to pick a single disposal code. Perhaps the use of secondary culling codes would help to increase the accuracy of the reports. Cows leaving their herds with sale codes are difficult cases to classify as voluntary or involuntary culling. A given cow may be sold because the producer wants to get rid of her and finds a buyer for her (voluntary culling), whereas another cow might be a superior cow and the breeder decides to sell her only because he gets a good offer (involuntary culling, in a sense that this cow is not considered to be less profitable then her potential replacement). Furthermore, cows sold for dairy purposes will continue their productive life in another herd, where they would have to be compared with a different group of contemporaries and perform under a distinct environment. Culling due to reproductive problems is also difficult to interpret. In most situations, this code is associated with failure to conceive, which is a combination of the

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cow's physiological status and the breeder's ability to conduct an efficient insemination program. In addition, a poorly producing cow would probably be treated as unable to conceive after two or three unsuccessful inseminations, whereas a top producing cow would undergo many services before being culled for reproductive problems. Finally, it is important to keep in mind that these codes are voluntarily recorded by producers, and that the accuracy of this data depends on the producers will to keep good records and on their understanding of the usefulness of the information collected. Hopefully the present study will help to clarify the potential uses for culling codes as well as to bring suggestions on how to improve the current system of data collection and handling.

Table 2.2 shows the distribution of the major culling reasons reported by different authors in Canada and in the United States. Reproductive problems and low milk production are the most important causes for culling cows in dairy herds, followed by problems in the mammary system and mastitis. Sale codes explain a high portion of the cow removals in herds that have a significant part of their revenue coming from selling livestock. This is evident in the comparison of the proportions of registered and grade cows being sold for dairy purposes in Dentine et al. (1987a) and in the comparison of the proportions of cows from official and owner-sampler herds in Monardes (1992). In addition, sales were the most important reason for disposal in Burnside et al. (1971) and Westell et al. (1982) who used Canadian Record of Performance (ROP)¹ data.

Dentine et al. (1987a) found that culling policies in grade and registered herds were markedly different and should not be treated alike in studies of herd life. Registered cows were kept longer and were culled for different reasons than grade cows. Monardes (1992)

¹The ROP was a federal program of milk recording in Canada for official herds only, that is to say, producers who commercialize breeding stock and are interested in improving both production and conformation characteristics (Van Doormaal et al., 1986).

Study	Sample	Cows Disposed	SAL [*]	DEA	LOW	REP	UDD	MAS	ТҮР	ACC	DIS	LEG	WOR	Other
			(%)											
Burnside et al. (1971) - Canadian ROP		19336	25.8	9.4	15.5	22.6	10.2	4.0	0.4	*	2.9	2.8	2,1	4.0
Van Vleck and Norman (1972) ^b - New York		3475	-	0.9	32.5	26.6	13.0	10.4	1.1	2.4	7.7	2.0	2.7	0.7
Allaire et al. (1977) ^b - Ohio	Primary°		-	-	17.9	38.8	-	16.3	8,4	5.6	7.2	-	1.8	4.1 ^d
	Secondary	8722	-	-	20.7	24.2	. •	7.6	17.2	1.3	2,8	-	2.8	23.3
	Tertiary		-	-	14.2	16.8	-	4,3	20,8	0,6	0.9	-	2.3	40.2
Westell et al. (1982) - Canadian ROP	Group I°	11580	43,8	-	14.0	21.7	4.1	1.3	-	2.2	6.9	1.0	1,3	3.6
	Group II	16631	30,6	-	17.5	26.1	5.7	2.0	-	2.5	8.4	1.9	1.3	4.1
	Group III	14480	24.7	-	17.7	27.7	7.3	2.6	-	2.9	9,3	2.3	1.3	4.3
Dentine et al. (1987a) - U.S.	Registered	238150	22.9	4,9	39.2	9.2	6.7	-	-	-	17.0	-	-	0.6
	Grade	231584	14.0	5.0	41.4	11.0	9.3	-	-	-	19,3	-	-	0.4
Monardes (1992) - Quebec	Official		16.2	2.7	33.9	16.3	8.1	5,3	-	1,8	4.6	4.5	2.0	4.6
	Owner- Sampler	263000	5,5	2.5	36.1	19.1	8.7	7.4	-	1.9	5,1	4.5	2.4	6,7
Falk and Fiez (1996) ^b - U.S.	2542 herds	-	-	-	22.4	26.7	26,5 ¹	-	-	15,1 ⁸	4.3	•	1.0	4.1

Table 2.2 - Proportion of Holstein cows being culled for different reasons in North American studies.

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^a SAL = sale codes; DEA = death codes; LOW = low milk production; REP = reproductive problems; UDD = udder problems; MAS = mastitis; TYP = undesirable type; ACC = accidents and injury; DIS = diseases; LEG = feet and leg problems; WOR = "workability" (slow milkers, bad temperament).

^b Sale and/or death codes not included.

° Each cow in this study had up to three reasons identified in order of importance for the decision to remove the animal.

^d In this study, other reasons refer to a category defined as "general health," which was considered very important as secondary and tertiary reason for disposal.

^e Group I: cows with opportunity to complete one lactation; group II: cows with opportunity to complete two lactations; group III: cows with opportunity to complete three lactations.

^f Includes cows culled for mastitis.

^B Includes cows culled for lameness.

showed that the same type of variation in culling policies exists among herds enrolled on the official and the owner-sampler milk recording options. The distinction here is based on having supervised tests (official) or not (owner-sampler), and even though official herds have most of their cows registered, there is nothing that prevents owner sampler herds from doing the same. However, only supervised herds would receive official lactation certificates for their cows, which is a valuable marketing tool for those interested in selling breeding stock. Therefore, most herds for which marketing cows is an important source of revenue are enrolled on the official option, while owner-sampler herds are chiefly interested in milk sales. Monardes (1990, unpublished) compared official and owner-sampler herds regarding the proportions of sale codes, voluntary culling (low production) and involuntary culling (remaining codes) over a 10-year period, and found evidence that involuntary culling is increasing in both groups, especially in owner-sampler herds.

The usefulness of secondary and tertiary disposal codes was shown by Allaire et al. (1977), who used data collected in 12 Ohio institutional herds from 1933 to 1972. For instance, type characteristics were considered to be the major reason for disposal only in 8.4% of the cases, but were included as secondary and tertiary reasons in about 20% of the cow removals (Table 2.2). The same authors found that the distribution of reasons for disposal varies with age at culling. Culling for low production, the major voluntary reason for disposal, was high in the beginning of cows' productive life (between 36 and 48 months of age) and then decreased as the animals aged. Culling for reproductive problems was higher right after first calving (from 24 to 36 months of age) than in any other period of cows' herd life. Harris (1989), using data from New Zealand, also reported different frequencies of removal reasons associated with distinct age groups, especially for mastitis, and poor fertility (both increased with age). Westell et al. (1982) divided their data into three groups, according to the opportunity to complete one, two or three lactations, and also found changes in the distribution of reasons for disposal in different parities (Table 2.2).
The reviewed reports indicate, therefore, that the most important reasons for disposal in dairy herds are sales for dairy purposes, low production, reproductive problems, udder problems and mastitis. Periodical studies of culling reasons are important to observe the trends and evaluate current management practices and selection programs (Burnside et al., 1971). One major difficulty with milk recording data is to classify the existent disposal codes into voluntary or involuntary culling, since this distinction is important to judge whether the relative frequency of each disposal reason is acceptable or calls for changes in the breeding programs. In the present dissertation, sale codes are not classified into voluntary or involuntary, culling for low milk production and culling for low fat test are considered to be voluntary culling and all the other codes are assumed to be involuntary culling.

Culling as a Selection Tool

A within-herd selection program is often based on breeders' intention to promote phenotypic improvement by keeping the best cows for further lactations and to promote genotypic improvement by breeding replacements only from the best cows. In other words, phenotypic and genetic progress are intuitively sought by means of voluntary culling, mostly based on production traits. Intensive voluntary culling, however, is prevented by three main factors (Hill, 1980): (a) the low reproductive rate of dairy cattle (with less than one progeny per cow per year, the number of replacement heifers available to choose from is small); (b) the occurrence of involuntary culling) (Allaire and Cunningham, 1980); and (c) the fact that milk yield rises with parity number (since intensive culling rates increase the proportion of young cows in the herd, overall production tends to decrease). Furthermore, many authors have shown that the mean performance of the herd and the rate of genetic progress in a herd are hardly affected by the intensity of culling for production (Rendel and Robertson, 1950; Korver and Renkema, 1979; Allaire and Cunningham, 1980; Hill, 1980; Allaire, 1981). Allaire

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(1981) used a deterministic model of a dairy herd to investigate optimal cow replacement rates with variable genetic trends in milk per year associated with different selection methods. The general conclusions regarding genetic progress within a herd were: no genetic gain would occur when there was no voluntary culling or when replacements were purchased; expected genetic gains from raising replacements from a random sample of dams or from the best cows in the herd, after 20 years of selection, were quite small; the higher the cow replacement rate, the fewer heifers were available for selection, which lead to a decline in the genetic superiority of the replacements and cancelled the positive effect of a reduced generation interval; and the use of superior sires was the only selection method that promoted actual genetic gain within a herd.

In conclusion, increasing voluntary culling in a dairy herd is not an effective strategy to accelerate genetic progress. The exceptions would be herds that are upgrading or buying genetically superior cows as replacements, but in this case the progress does not happen through selection, it happens through migration. The decision to replace a dairy cow should therefore be mainly an economic decision, and the factors affecting optimum culling rates will be discussed in the next topic.

Economics of Culling

Many studies have focused on the factors affecting optimum culling decisions in dairy cattle. Renkema and Stelwagen (1979) studied the economic impact of improved health as a means of increasing herd life and found that the involuntary replacement rate was of major importance on the farm level. Increasing average herd life from 3.3 lactations to 5.3 lactations resulted in 20% more earned income each year. Using an extended version of the same model, Korver and Renkema (1979) looked at the economic optimal rate of culling for production (voluntary) and concluded that moderate voluntary culling was the most profitable

scenario, followed closely by the policy with no culling for milk yield, and that heavy culling policies were not economically attractive. The same authors estimated that cows producing less than 86% of the herd level at the end of lactation (about 20% of first lactation cows) could be culled for low production. The economic consequences of culling on milk yield were also studied by Allaire and Cunningham (1980), who found that the greatest benefits from voluntary culling occur when involuntary replacement rates and net cost per replacement are minimum. Allaire (1981) concluded that, at most, 1 to 3 cows in 100 should be culled to maximize the net present value of the herd, and that benefits from maintaining a relatively high proportion of mature cows with a low replacement rate exceed those from a higher rate of replacement with genetically improved heifers. Van Arendonk (1985) estimated an optimum herd life of 42.9 months for dairy herds in The Netherlands, and voluntary culling corresponded to 26% of all replacements. This author found that changes in replacement costs and in carcass prices significantly affected optimum replacement policy, as opposed to changes in milk prices, calf prices, feed prices, herd production level and rate of genetic improvement, which did not greatly affect the optimum replacement policy. Rogers et al. (1988a) estimated an optimum culling rate of 25% for the Holstein population in the United States, as well as an optimum average herd life of 47.8 months. In the same study, milk yield, milk prices and feed prices had major effects on annualized net revenue, but only changes in replacement heifer prices significantly affected optimum culling decisions. Results from Rogers et al. (1988b) indicated that lowering involuntary culling by one cow per year in a 100-cow herd would improve net revenue by about US\$750 to US\$900 per year. They pointed out that the benefits of decreasing involuntary culling rates are the reduction in the probability of having to replace high yielding cows, the increase in the opportunity for voluntary culling for all age groups, and the reduction of rearing costs. Working with economic parameters practiced in Ontario dairy farms, Dekkers (1991) estimated an optimum annual culling rate of 30.1%, of which 50.1% was voluntary culling (this author considered cows left open earlier in lactation as voluntary culling). Decreasing the level of involuntary

culling, while optimizing management, resulted in an almost linear increase in annual profit per cow. Finally, McCullough and DeLorenzo (1996) used a stochastic dynamic model to evaluate the effects of price and management changes on optimal decisions for replacement and insemination and concluded that optimal policies change across different price structures and management levels, and that general recommendations rarely apply. In this study, pregnancy rate was the most dominant input influencing optimal replacement and insemination decisions, and improvements in conception rate and estrus detection were considered worthwhile.

In summary, lowering involuntary culling in dairy herds is always economically beneficial, and management and breeding programs should be directed towards improving health and husbandry characteristics of dairy cows. Economic returns to the herd are significantly affected by the replacement costs and voluntary culling on milk yield is justified only at the lowest replacement costs. Replacement policies should be specific to each given situation.

HERD LIFE AS A TRAIT TO SELECT FOR

The Economic Value of Herd Life

Rendel and Robertson (1950) visualized that a longer milking life may increase profitability in a dairy farm (a) by reducing the annual cost of replacements per cow in the herd; (b) by increasing the average herd-yield through an increase in the proportion of cows in the higher producing age groups; (c) by reducing the number of replacements which need to be reared, liberating resources that may be used to increase the milking herd; and (d) by

increasing the voluntary culling possible. Several studies indicated that herd profitability increased if herd life was extended (Renkema and Stelwagen, 1979; Allaire and Cunningham, 1980; Hill, 1980; Congleton and King, 1984; Stott, 1994). Bakker et al. (1980), in an attempt to develop a profitability index for sires, concluded that the stayability of a bull's daughters has a potentially large impact on profitability. Dentine et al. (1987b) pointed out that the potential economic effect of increasing herd life could be as great as that of increasing producing ability for milk yield, because costs of raising a heifer must be amortized over several lactations for maximum profit. Allaire and Keller (1990) found that the importance of herd life in merit for genetic improvement ranged from 0 to 12% and was highest when mean herd life was low, mean milk per cow was high and fixed cost was low relative to depreciation cost. Allaire and Gibson (1992) found that an increase of 100 kg of milk was equivalent to an increase of 2.2 months of herd life adjusted for milk production. Finally, Table 2.3 shows several estimates of the relative economic values of milk yield and herd life found in the literature. Although considerable variation exists between the relative weight given to herd life by different authors, all of them acknowledge the economic importance of the trait.

Herd life has an important impact on dairy herds profitability, and any effort to improve the general understanding about this trait would be justified. Different approaches have been tried to include herd life as part of the selection indices used by the dairy industry. An overview of the difficulties, advantages and disadvantages of the diverse strategies is given next.

Study	Yield Relative Value	Herd Life Relative Value
Burnside et al. (1984)	2.0	I
Congleton and King (1984)	3.9	I
Rogers and McDaniel (1989) ^b	0.8	1
Van Arendonk (1991)	1.4	1
Allaire and Gibson (1992) ^c	2.5	1
Dekkers (1993) ^d	2.7	1
Harris and Freeman (1993)	8.0	1

Table 2.3 - Relative economic values^a of milk yield and herd life (adapted from VanRaden and Wiggans, 1995).

Value of 1 genetic standard deviation of yield divided by 1 genetic standard deviation of herd life.

^bOriginal relative value was 1.4:1 for yield:involuntary culling.

^cOriginal relative value was 3.2:1 for yield:herd life adjusted for milk yield.

^d Original relative value was 3.4:1 for yield:herd life adjusted for milk yield and was standardized using phenotypic rather than genetic standard deviation.

Defining a Trait

Several ways of measuring herd life have been proposed and used in the literature, each one establishing a new operational definition to the trait. Everett et al. (1976) created the term "stayability" to refer to the ability of a cow to survive (0=survived; 1=culled) up to predetermined ages, namely 36, 48, 60, 72, and 84 months of age. The cow population had to be divided into opportunity groups, which included only those cows that had a chance to reach the predetermined ages. A slightly different definition of stayability was used by Van Doormaal et al.(1985), who looked at survival from first calving up to 17, 30, 43 and 55 months after first calving. Survival after first calving was thought to represent productive herd life, instead of total herd life, and to be free of the variation in age at first calving. Measuring herd life from first calving is more suitable to milk recording data, because females that die or are culled prior to first calving do not have a record, and ignoring this information inflates the estimates of total herd life. The major drawbacks of survival up to a given age (stayability)

are the need to arbitrarily define cutoff points at which cows will be compared, and the loss of information due to the use of an all-or-none trait. Cows culled right after the cutoff point and cows culled one year later are treated alike.

Herd life of dairy cows has also been quantified in terms of survival within each consecutive lactation (Nieuwhof et al., 1989). Although parities are more related to the cows' biological ability to survive than predetermined ages, there is still a need to define thresholds when creating opportunity groups and the trait is still a binary trait. Madgwick and Goddard (1989) proposed measuring herd life in terms of a series of survival scores (Si) defined as Si=1 if the cow survives from i years to i+1 year after first calving and Si=0 if the cow does not survive; Si is undefined or missing if the cow was culled or died before i year post first calving. They used a single trait repeatability model to analyze genetic and phenotypic parameters in Australian dairy cattle, assuming that survival in each lactation was the same trait. One interesting feature of this method is that it accommodates left censored records (animals entering data after first calving), but the problems related to the use of cutoff points and binary responses remain.

More accurate measures of the herd life of a cow are those referring to the actual time that she managed to stay in the herd, such as age at culling, number of lactations performed or length of productive life. The major problem associated with these "actual" measures of herd life is the presence of incomplete records, in which herd life is unknown, either because cows are still alive or because data collection was discontinued (cows exported to a different country, for instance). This has been the main justification for defining opportunity groups and considering survival up to predetermined cutoff points, since the uncertainty about the length of herd life is avoided for cows that are still alive. However, the problem persists for records of cows sold for dairy purposes, and those might represent a significant portion of the population in registered herds (Table 2.2). VanRaden and Klaaskate

(1993) have proposed to project incomplete herd life records in a similar way as lactation yields are projected to 305 days in lactation. The authors looked at total months in milk by 84 months of age as a measure of length of "useful" life, and cows with incomplete records received projections for months in milk at 84 months of age. Once again, even if the distribution of herd life data currently supports an arbitrarily chosen threshold or set of thresholds, there is no guarantee that changes in culling policies and in breeding goals will not create a situation in which new cutoffs are needed. A more elegant and appropriate manner to deal with incomplete lifetime records is the use of censoring (Famula, 1981; Wolynetz and Binns, 1983). If T is the time from calving to culling, T of a given cow is right censored if all that is known about T is that it is greater than some value c. If data collection stopped when a cow had c = 200 days of productive herd life and was still alive, all that is known is that she survived more than 200 days after first calving, certainly not less. Methodology that deals with censoring in the analyses of response times has been well established and is referred to as survival analysis in epidemiological studies, event history analysis in sociological studies, reliability analysis and failure time analysis in engineering, duration analysis and transition analysis in economics (Allison, 1995, p.1). Since the nature of herd life studies is more closely related to the type of problems encountered in epidemiology, this kind of analysis will be referred to as survival analysis herein. Some good examples of the use of survival analysis in studies of herd life in dairy cattle are given by Hocking et al. (1988b), Pollari et al. (1993) and Beaudeau et al. (1995). A more detailed discussion on the advantages and limitations of survival analysis will be given later.

Reviewing the multiple definitions of herd life presented above, Dekkers and Jairath (1994) grouped them into three main categories: **I.** traits related to length of total or productive life (e.g., age at last calving or disposal; time from first calving to last calving or disposal; number of lactations or calvings); **II.** survival up to a certain age, lactation, or length of productive life (stayability); and **III.** survival within each consecutive lactation (survival

scores). Ideally, length of productive life (first category) should be the response variable of choice in studies of herd life as long as censoring is adequately handled (Ducrocq, 1987). Length of productive life makes optimum use of the information on survival because neither cutoffs need to be specified nor opportunity groups have to be defined.

True Herd Life and Functional Herd Life

Ducrocq (1987) defined true herd life as a cow's aptitude to stay as long as possible in the herd, regardless of the reasons why she may have to leave the herd, and functional herd life² as the ability to remain a sound and healthy cow, regardless of her milk production level. Functional herd life can also be defined as the ability to delay involuntary culling (Ducrocq et al., 1988a) if culling for low production is assumed to be the only reason for voluntary disposal. Since culling for low production is actually the most important reason of voluntary culling, adjusting length of productive life for a cow's phenotypic production has been thought to approximate very well functional herd life. Van Arendonk (1986) showed that the increase of the production level of a cow within a herd increases the optimum average herd life, but this does not apply to an increase in the production level of the herd. Therefore, adjustments for a cow's production in length of productive life should be carried out as a deviation from herd mates, not as a raw yield. The question of whether using herd life adjusted for phenotypic production to estimate genetic parameters is desirable or not was discussed in detail by Dekkers (1993). The author demonstrated that estimates of heritability for survival obtained from half-sib correlations are biased as a result of culling based on production, and that although the adjustment of herd life for production does not remove all biases in estimates of genetic parameters, measures of herd life should be adjusted for

² The author used in fact the terms **true stayability** and **functional stayability**, but since the word stayability has been usually associated to survival up to predetermined ages, true herd life and functional herd life are preferred in the present dissertation.

production when included in selection strategies (given current levels of culling on production).

Heritability of Herd Life Measures

Table 2.4 shows heritability estimates for various herd life traits found in the literature. As noted by Dekkers and Jairath (1994), heritability of herd life depends on the trait definition. The highest heritability estimates are for traits in category I, which range from 0.02 to 0.10, but most of them are above 0.06. Herd life traits in category II have a wider range of estimates, 0.01 to 0.15, however most estimates are around 0.03. Finally, traits in category III have very low heritabilities when defined as survival scores (Madwick and Goddard, 1989), 0.01 to 0.03, and higher estimates when defined as survival in different lactations (Jairath and Dekkers, 1994), 0.03 to 0.12. These higher heritabilities of traits in category I reflect a better use of the information available, since they are a measure of completed herd life and they are usually defined as continuous variables (e.g., days from first calving to disposal). Categories II and III, on the other hand, are measures of partial herd life and are defined as all-or-none traits. Table 2.4 also shows that animal breeders prefer using linear models to analyze binary responses, when non-linear models, such as threshold models (Gianola, 1982) and logistic regression (DeLorenzo and Everett, 1986), are theoretically more appropriate. This is partially justified by the complexity of non-linear models compared with linear models and by the lack of software that can accommodate random effects and estimate variance components using non-linear models in large applications. The advantages of using logistic regression to analyze herd life traits in categories II and III (binary responses) were discussed by DeLorenzo and Everett (1986). They are illustrated by the obtained heritability estimates of 0.12 and 0.15 for stayability up to 41 and 54 months of age, respectively, which are considerably higher than the estimates obtained from linear models (Table 2.4). The same authors acknowledged the fact that computations are more difficult using logistic regression

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Study	Cows	Trait	h²	Category*	Methodology
Hoque and Hodges (1980)	30738	Length of productive life (days)	0,10	I	Linear model / least
		Number of lactations completed	0,09	Ι	squares / sire model.
Van Doormaal et al. (1985)	118362	Stayability up to 17 months of productive life	0,01	II	Linear model /
		Stayability up to 30 months of productive life	0.02	II	Herderson's Method III
		Stayability up to 43 months of productive life	0.02	II	/ sire model.
		Stayability up to 55 months of productive life	0,03	II	
DeLorenzo and Everett (1986)	18941	Stayability up to 41 months of age	0.12	II	Logistic linear model /
	16427	Stayability up to 54 months of age	0,15	II	maximum likelihood / sire model,
Dentine et al. (1987b) 1145616	1145616	Percentage of Cows Culled	0.01	II	Linear model /
		Stayability up to 48 months of age	0.01	II	Herderson - BLUP / sire
		Stayability up to 54 months of age	0,02	II	model.
		Stayability up to 84 months of age	0.04	II	
		Age at last record	0.04	Ι	
Ducrocq et al. (1988b)	87338	True herd life (days)	0.09 ^b	I	Proportional hazards
		Functional herd life (days)	0,09	I	model / empirical Bayes approach / sire model,
Madwick and Goddard (1989)	253000	Survival scores ^c :			Linear model ^d /
		Sa	0,03	III	univariate REML / sire
		S ₁	0.01	III	model.
		S ₂	0.01	HI	
		S ₃	0.01	III	
		S_4	0.01	III	
Harris (1989)	30594	Survival rate of 2 yr old cows in 1985-86 season	0.04 (0.18)°	П	Linear model
· ·		Survival rate of 3 yr old cows in 1985-86 season	0.03 (0.14)	II	/univariate REML / sire
		Survival rate of all cows in 1985-86 season	0.01 (0.08)	II	model.

Table 2.4 - Heritability estimates for different measures of herd life in dairy cattle.

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Study	Cows	Trait	h²	Category*	Methodology
Brotherstone and Hill (1991a) ^f	19294	Survival in 2 nd lactation	0.05	11	Linear model / multiple-
		Survival in 3 rd lactation	0.07	П	trait REML / sire model
		Survival in 4 th lactation	0.07	II	
Harris et al. (1992)	39910	True herd life in days up to 48 months of age	0,06	I	Linear model / multiple-
		True herd life in days up to 72 months of age	0.07	I	trait REML / sire model.
		Functional herd life in days up to 48 months of age	0,02	I	
		Functional herd life in days up to 72 months of age	0.05	I	
Strandberg (1992b)	12027	Length of productive life (days)	0.05	I	Linear model / multiple- trait REML / sire model.
Short and Lawlor (1992)	125887	Stayability up to 2 nd calving	0.02	II	Linear model / multiple-
		Stayability up to 54 months of age	0,05	П	trait REML / sire model.
		Stayability up to 84 months of age	0,04	Ш	
		True herd life (months)	0.07	I	
		Functional herd life (months)	0,06	I	
Boldman et al. (1992)	53830	True herd life in days up to 72 months of age	0.03	I	Linear model / multiple-
		Functional herd life in days up to 72 months of age	0.03	I	trait REML / sire model.
VanRaden and Klaaskate	1984038	Total months in milk by 84 months of age	0.09	Ι	Linear model / multiple-
(1993)					trait REML / sire model.
Jairath et al. (1994)	383097	Lifetime days in milk	0.09	Ι	Linear model / multiple-
		Length of productive life (days)	0.08	Ι	trait REML / sire model.
		Number of lactations	0.07	I	
Jairath and Dekkers (1994)	43594	True survival in 1 st lactation	0.09	III	Linear model / multiple-
		True survival in 2 nd lactation	0.03	III	trait REML / sire model.
		Functional survival in 1 st lactation	0.04	III	
		Functional survival in 2 nd lactation	0,12	III	
		Functional survival in 3 rd lactation	0.04	III	

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Study	Cows	Trait	h²	Category*	Methodology
Visscher and Goddard (1995)	143250	Stayability up to 2 nd calving	0.05	II	Linear model / multiple-
		Stayability up to 3 rd calving	0.07	II	trait REML / sire model.
•		Stayability up to 4 th calving	0.07	II	
		Stayability up to 5 th calving	0.07	II	
		Stayability up to 6 th calving	0.03	II	
		Survival scores:			
		S,	0.03	III	
		S,	0,03	III	
		S,	0.02	III	
		S,	0.02	III	
		S ₅	0.03	III	
				_	
Weigel et al. (1995)	433116	Length of productive life (days)	0.06	I	Linear model / multiple-
		Total months in milk by 84 months of age	0.06	I	trait REML / sire model.
		Months in milk by 84 mo, in milk with projected records	0.02	I	
Vollema and Groen (1996)	38957	Number of lactations initiated	0.04	I	Linear model / multiple-
		Functional [®] number of lactations initiated	0.04	Ι	trait REML / animal
		Lifetime days in milk	0.04	Ι	model.
		Functional lifetime days in milk	0.04	Ι	
		Total herd life	0.04	Ĩ	
		Functional total herd life	0.04	Ī	
		Length of productive life	0.04	Ī	
		Functional length of productive life	0.04	Ī	
		Stavability up to 72 months of age	0.03	II	
		Functional stayability up to 72 months of age	0.03	II	
		Stayability up to 48 months of productive life	0.03	II	
		Functional stayability up to 48 mo, of productive life	0.03	II	

* Categories as proposed by Dekkers and Jairath (1994): I = traits related to length of life; II = survival up to a predetermined threshold; III = survival within each consecutive lactation.

^bBecause of the inclusion of time-dependent covariables in the model and due to the presence of censored records, these are pseudo-heritability estimates defined on the log scale, which are difficult to interpret.

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^cSurvival scores (S_i) were defined as $S_i = 1$ if the cow survived from i years to i+1 years after first calving and $S_i = 0$ if the cow did not survive; S_i was undefined or missing if the cow was culled or died before i years post first calving.

^dAuthors also used a non-linear model (Gianola and Foulley, 1983), which is more theoretically sound to analyze binomial responses such as survival scores. When comparing the solutions for the sire effect from linear and non-linear models, they found a correlation of 0.99.

* Estimates of heritability on underlying normal scale.

^fOnly cows that had completed a first lactation were included in the study.

⁸Functional lifetime traits were pre-corrected for milk production during first lactation.

than linear models, especially for variance component estimation. Smith (1983) and Ducrocq (1987) have also shown that linear models are not the state-of-the-art methodology to analyze herd life traits in category I. Survival analysis is the field of statistics that deals specifically with the modeling of response times such as length of productive life. The problem of software availability was also true for this type of models until recently, when Ducrocq and Sölkner (1994) released the "Survival Kit", a set of FORTRAN programs specially designed for animal breeding situations, including the estimation of variance components. For a review on the estimation of genetic parameters using non-linear models see Ducrocq (1990). Table 2.4 also shows that heritability estimates of functional herd life traits are slightly lower than estimates of true herd life traits. Dekkers (1993) have demonstrated that the difference between the two depends on the amount of voluntary culling (culling for low production).

Heritability of herd life traits is low, generally below 0.10. If traits in category I have the advantage of making a better use of the information available and consequently having higher heritability, this is somehow compensated by the fact that traits in categories II and III can be measured earlier in life and, therefore, are more suitable for genetic improvement programs. Two options have been proposed to circumvent this impasse: the use of survival analysis, which accommodates censored records without the need to wait until herd life is completed for all animals (Ducrocq et al. 1988a), and the use of indirect selection for herd life, based on correlated traits such as conformation characteristics (Rogers and McDaniel, 1989). The relationships between herd life and production and conformation traits as well as the use of survival analysis in studies of herd life are discussed in subsequent sections.

Herd Life and Milk Production

Many dairy producers fear that the intensive selection for milk yield and milk components might have a negative effect on cows' ability to stay healthy for a long period in

the herd. Shook (1989), in a review about genetics of disease resistance, concluded that the evidence is fairly consistent in indicating that selection for milk yield is accompanied by increased susceptibility to disease, and when genetic trends are projected over a long term, considerably increased health problems can be forecast. Although disease incidence is an important determinant of involuntary culling, other factors play a role in determining the relationship between production and herd life. Estimates of genetic correlation between true herd life traits and first parity production traits are mostly moderate to high and positive (Madgwick and Goddard, 1989; Harris et al., 1992; Short and Lawlor, 1992; Strandberg, 1992b; VanRaden and Klaaskate, 1993; Visscher and Goddard, 1995). Dekkers et al. (1994), working with data from Quebec Holsteins, reported that cows that produced one standard deviation below (above) the herd average during first lactation had a herd life that was 330 days shorter (280 longer) than the herd life of an average producing cow. Given the positive association between production and herd life, one could expect that selection for milk production would indirectly improve herd life. However, because of the presence of culling for low production, milk, fat and protein yields in first lactation have a direct influence on the environment of the herd life trait (Strandberg, 1992b). In other words, high-yielding first-calf heifers will likely receive a preferential treatment and will surely be selected to stay in the herd longer. Strandberg and Håkansson (1994) found that voluntary culling (based on production) had a substantial effect on the estimates of genetic correlation between milk yield in first lactation and productive life: there was a favorable genetic correlation between the two traits as long as there was any voluntary culling at all in the first lactation. Finally, both Ducrocq et al. (1988b) and Short and Lawlor (1992) encountered slightly negative genetic correlations between herd life and production after adjusting for yield deviation from herd average (functional herd life), which could be interpreted as a slight antagonism between milk production and fitness.

Herd Life and Conformation

One of the main objectives of classifying dairy cows using linear scores is to identify and to emphasize traits associated with herd life (Short and Lawlor, 1992). Most selection indices used to rank Artificial Insemination (AI) bulls, such as the Canadian Lifetime Profitability Index (LPI) and the American Type-Production Index (TPI), include those conformation traits which are considered to be closely related to longevity and profitability. However, estimates of phenotypic and genetic correlations between herd life and conformation traits are not as high as envisioned by producers, and are quite variable from one study to another. The degree to which conformation traits influence herd life varies with milk recording program (Van Doormaal et al., 1986), herd registry status (Short and Lawlor, 1992; Dekkers et al., 1994), breed (Rogers et al., 1991; Harris et al., 1992; Visscher and Goddard, 1995) and the presence (absence) of an adjustment for production (true vs. functional herd life) (Rogers et al., 1989a; Burke and Funk, 1993; Jairath and Dekkers, 1994). Across different studies that estimated genetic correlations between herd life and type traits, udder characteristics were found to be more closely related to survival in dairy herds than other traits, especially udder depth and fore udder attachment (Rogers and McDaniel, 1989; Rogers et al., 1989a; Brotherstone and Hill, 1991b; Boldman et al., 1992; Short and Lawlor, 1992; Weigel et al., 1995). The other traits that have been reported as being positively correlated to herd life are final score, dairy form and angularity (Brotherstone and Hill, 1991a; Short and Lawlor, 1992; Klassen et al., 1992; Jairath and Dekkers, 1994; Visscher and Goddard, 1995; Weigel et al., 1995). Traits often found to be negatively related to herd life are teat length, stature, body depth, strength and thurl width (Brotherstone and Hill, 1991b; Boldman et al., 1992; Short and Lawlor, 1992; Harris et al., 1992; Klassen et al., 1992). The negative correlations of body traits with herd life were observed for grade herds, whereas the estimates were small and sometimes positive for registered herds (Short and Lawlor, 1992). This indicates the existence of different perceptions by breeders in the two subpopulations regarding the importance of traits such as stature. Traits related to feet and legs are usually considered by the producers to be highly related to the fitness of dairy cows, specially in tie stalls. Most studies, however, did not find feet and legs characteristics to be clearly related to herd life, with the exception of Jairath and Dekkers (1994) and Dekkers et al. 1994, who found moderate to high genetic correlations between functional herd life and feet and legs (a composite trait). Burke and Funk (1993) examined the matter in detail and concluded that even if herd life is shorter for cows with extremely straight or extremely curved legs (phenotype), there is limited opportunity for dairy producers to improve curvature of the rear legs genetically by selection in an effort to extend herd life. Short and Lawlor (1992) found that feet and legs traits also have merit for herd life, but low heritability will make improvement from selection slow.

Indirect selection for herd life based on indices that include conformation traits has been proposed (Rogers and McDaniel, 1989). Boldman et al. (1992) pointed out that the main advantage of estimating herd life from type traits is that genetic evaluations would be available early enough to allow selection among sires based on their sample of daughters, and that reliability of these proofs would be higher than from direct selection, considering the low heritability of herd life. As practically every previously mentioned author agreed upon, udder traits should receive the most emphasis of all type traits in indices to improve herd life. Dekkers et al. (1994) found that indices based on combinations of type traits explained less than 50% of the genetic variation in functional herd life, indicating that indirect selection for functional herd life based on conformation would be only moderately efficient.

Canadian Genetic Evaluations for Herd Life

Since January 1996, Canadian dairy sires have received a genetic evaluation for functional herd life which is a combination (blend) of proofs based on daughter survival (direct herd life) and predictions of functional herd life based on type traits (indirect herd life):

$$HL = b1 \times HL_{IND} + b2 \times HL_{DIR}$$
 (1)

where HL = (functional) herd life, $HL_{IND} = indirect$ herd life, $HL_{DIR} = direct$ herd life, b1 and b2 = the weights which depend on the repeatability of HL_{IND} and HL_{DIR} of each sire, as well as the number of a sire's daughters that contribute to both HL_{IND} and HL_{DIR} (Dekkers et al., 1995). With few daughters early in a sire's "career", HL is largely dependent upon mammary system and feet and leg ratings, while with many daughters it becomes almost exclusively a measure of the ability to survive involuntary culling (SEMEX Canada, 1995). Direct herd life is estimated as:

$$HL_{DIR} = 2.27 \times (Average ETA for survival in the first three lactations)$$
 (2)

and indirect herd life is computed as:

$$HL_{IND} = 0.00243 \times (1 \times CAP + 1 \times RUMP + 4 \times F\&L + 8 \times MS)$$
(3)

where CAP = sire ETA for the composite trait capacity, RUMP = sire ETA for the composite trait rump, F&L = sire ETA for the composite trait feet and legs, and MS = sire ETA for the composite trait mammary system. The decision of which type traits to be included in the indirect herd life evaluation, as well as of the weights for the different traits was mostly based on the results obtained by Jairath and Dekkers (1994) and Dekkers et al. (1994). Heritability of herd life traits (functional survival in the first three lactations) is assumed to be 0.03 and genetic correlations between survival in lactations 1 and 2, 1 and 3, and 2 and 3 are assumed to be 0.62, 0.57 and 0.75, respectively (Jairath and Dekkers, 1994). These parameters imply that a large number of daughters with data on lactational survival is needed for the reliability

of direct herd life to increase and overcome the weight given to indirect herd life in the calculation of HL. A faster increase on the reliability of direct herd life would be desirable because indirect herd life is only a moderate predictor of functional herd life (Jairath et al., 1996). This may be achievable if a different herd life trait with higher heritability estimates are used as the measure of direct herd life.

Alternative Approaches

Functional herd life seems to be the preferred trait to be included in selection programs due to the nature of culling for production (Strandberg, 1992b; Dekkers, 1993). Although correcting herd life for milk production traits reduces the dependancy among herd life and first lactation milk production, estimating functional herd life in this manner may still be a crude estimate of the "true" functional herd life (Harris et al., 1992). In addition, direct selection based on functional herd life would have slow response because of low heritability and because the trait is not observed early enough to become part of the selection criteria to select young sires. Indirect selection based on conformation characteristics is a viable option, but the reliability of such an index is also low, leading to moderate responses in herd life (Dekkers et al., 1994). Rogers et al. (1988b), after quantifying the economic value of involuntary culling, concluded that direct and indirect selection for improved health and husbandry characteristics may be warranted to reduce involuntary culling. Hence, alternative approaches to decrease involuntary culling (or to improve herd life), such as selection for disease resistance and selection to decrease major reasons for disposals, should also be considered.

Several studies have shown that disease incidence is directly related to culling in dairy herds (Cobo-Abreu et al., 1979; Martin et al., 1982; Milian-Suazo et al., 1989; Beaudeau et al., 1994). However, occurrence of health problems is a poor predictor of culling of dairy

cows (Martin et al., 1982; Hocking et al., 1988a), and individual production has always the greatest impact on length of productive life (Hocking et al., 1988b). The use of appropriate methods of analysis would probably help to describe more adequately the effect of diseases on herd life. This was demonstrated by Beaudeau et al. (1995), who used proportional hazards models (Cox's regression) to study the effect of disease on length of productive life in French Holstein cows. The authors showed that expected survivor curves can be powerful tools for examining the impact of health disorders on herd life. Uribe et al. (1995) estimated genetic parameters for the most common diseases of dairy cows assuming an underlying threshold model, and heritability estimates ranged from 0 to 0.15, with the exception of abomasal displacement, which had an heritability of 0.28. Their overall conclusion was that the long term cumulative effect of genetic selection against diseases might be useful to diminish their incidence. Because of its economic importance, mastitis is by far the most studied disease affecting dairy cows. Estimates of heritability for clinical mastitis are low, and because the subclinical form of the disease is believed to cause more losses than the clinical cases, many countries are adopting indirect selection based on somatic cell scores to slow the increase in susceptibility to udder infections (Dürr, 1995). However, the effect of selection to decrease somatic cell scores on herd life is still to be determined. Even if selection to decrease diseases that are directly related to involuntary culling is found to be advantageous, there is no regular data collection on health events being performed in North America, and it is unlikely that producers would be willing to assume the extra costs associated with recording of new information until researchers are able to show that significant genetic gains can be expected from selection for disease resistance.

Another approach for selecting against involuntary culling could be based on the reasons for disposal reported by producers through the milk recording service. The main advantages of this source of information is that data has been routinely collected for a long period of time and that cows can be grouped according to the primary reason they left the

herd. For each reason for disposal, a different set of factors would be of major importance in determining a cow's removal from the herd (Milian-Suazo et al., 1989). If a selection program is able to decrease individually the major forms of involuntary culling by choosing the best possible model for each reason, then the genetic progress could be higher than just selecting for functional herd life. Only two attempts to produce genetic evaluations for reasons for disposal in dairy cattle were found in the literature. Uribe et al. (1995) included "culling due to reproductive failure" and "culling due to leg problems" among the list of most common diseases in dairy cattle for which genetic parameters were obtained, and found heritability estimates of 0 for culling on reproduction and 0.15 for culling on feet and leg problems. Westell et al. (1982), using data from the Canadian ROP milk recording program, estimated variance components for all major disposal reasons reported by producers. They found that most disposal reasons had very low heritability and concluded that culling codes from milk recording data would not provide accurate sire proofs for disposal reasons. The methodology used by the authors (Henderson's Method I) is not appropriate for the nature of herd life data, and new efforts to produce genetic evaluations for different reasons for disposal may open novel possibilities of improvement in herd life.

A BRIEF REVIEW ON SURVIVAL ANALYSIS

Survival Analysis of Herd Life Data

Famula (1981) was perhaps the first author to propose the use of survival analysis to analyze length of productive life in dairy cattle. He assumed an exponential survival distribution for dairy cows in a model with covariates, and showed the possibility of accommodating censored observations (cows still alive at the time of data collection). Using Famula's simulated data set, Wolynetz and Binns (1983) demonstrated that assuming a Weibull distribution or a lognormal distribution would be more appropriate for dairy cattle survival data than trying to fit an exponential distribution (basic differences between survival distributions are discussed later). Smith and Quaas (1984) used proportional hazards models as proposed by Cox (1972) to estimate genetic parameters of length of productive life. Cox regression is a semi-parametric procedure that does not require any assumption regarding the distribution of the survival times, but it is very computationally demanding for large models. As an alternative, Ducrocq et al. (1988a) showed that Weibull models (which are a special case of proportional hazards models) are well-suited for an efficient analysis of length of productive life data, especially in large applications. The same authors (Ducrocq et al., 1988b) estimated genetic components for true and functional herd life using a Weibull (sire) model, but only a pseudo-heritability was computed because the presence of time-dependent covariates prevented the computation of the phenotypic variance. A more complete model was used by Ducrocq (1994) to analyze length of productive life in a larger data set, using the "Survival Kit" (Ducrocq and Sölkner, 1994), which clearly demonstrates the applicability of these methodologies in typical animal breeding situations. Recently, Ducrocq and Casella (1996) proposed a Bayesian analysis to estimate the distribution parameters of random effects in mixed survival models, and presented a definition of the heritability of the survival trait on the logarithmic scale.

Because survival analysis is an important part of the present dissertation and most animal breeders are not completely familiar with these methodologies, some basic concepts are presented here. For a complete presentation on survival analysis, Kalbfleisch and Prentice (1980) has been regarded as the reference textbook. For a specific discussion on the use of survival analysis to analyze dairy cattle herd life data, Ducrocq (1987) and Ducrocq (1997) are the recommended readings. The books on survival analysis by Lee (1992) and Allison (1995) were also used extensively during the preparation of this review.

Defining Survival Time

Survival time can be broadly defined as the time to the occurrence of a given event. This event can be the development of a disease, response to a treatment, relapse, or death. Essentially, survival time is a positive random variable that measures the "distance" or the size of the interval between the origin (point in which data start being collected) and the event of interest. Therefore, survival time does not have to be an actual measure of time (days, months), but it could well be the number of kilometers covered by a car before the tires have to be replaced, the number of rotations performed by an engine before it crashes or the cumulative milk production of a cow during her herd life. In studies of herd life, the survival trait is defined as length of productive life and the survival time is a continuous positive random variable measured as days from first calving to removal from the herd.

Censoring

Two basic types of censoring exist, **left censoring** and **right censoring**. Left censoring happens when the event cannot be observed because it occurred before the observation period. An example often used to illustrate left censoring refers to studies of menarche (the onset of menstruation) in women. If the follow up starts when girls are 12 years old, some of them may have already begun menstruating, and all we know about those girls is that menarche occurred before the age 12. Right censoring takes place when the event cannot be observed because data collection was discontinued, and it is by far the most common type of censoring. Right censoring may arise as a consequence of the end of the study period (patients that are still alive when data on survival after heart transplant are analyzed), because of loss of follow up (patients that moved before the end of the study) or due to loss to a competing risk (patients that die in car accidents before the end of the study). Studies on length of productive life in dairy cattle are mostly concerned with right censoring

(cows still alive at the time of analysis, cows sold for dairy purposes, cows from herds going out of milk recording), and therefore no attention will be given to left censoring hereafter.

Censoring times are further classified into Type I. Type II and random censoring. Type I censoring occurs when the censoring time is fixed by the design of the study, and all observations have the same censoring time. All subjects start the study at the same time, and the observation period is fixed in a given period of time (e.g., one year after the experiment started). Records can be divided then into individuals that failed and individuals that did not fail. Type II censoring refers to those cases in which observation is terminated after a number of events have occurred. If in a study with 500 individuals, observation ends whenever 250 of them have failed, all individuals that are still alive at that time would be censored. Both Type I and Type II are particularly useful in pre-designed experiments, which is not the case in herd life studies. A third type of censoring is referred to as random censoring, and happens when observations are terminated for reasons that are not under the control of the investigator. For example, random censoring can be produced when there is a single termination time (end of the study), but entry times vary randomly across individuals. This is clearly the case of cows of different ages that are still alive when herd life data is analyzed. Standard methods of survival analysis require that random censoring be **non-informative**, which means that the knowledge of the distribution of the censoring times does not supply any information about the distribution of failure times. In other words, an individual that is censored at time c should be representative of all those subjects with the same values of the explanatory variables who survive to time t = c. If this assumption does not hold, results might be biased due to informative censoring. A good example of a situation in which random censoring could be informative is the case of dairy cows which are sold from their original herds. Because no information on their survival times is available after they are sold, these cows have to be treated as censored in studies of herd life. Suppose only the best cows in each herd were commercialized, then their survival expectation would be consistently higher

than for cows being culled at the time sales occur. In this case, the consequence of informative censoring would be to underestimate the median survival time.

Functions of Survival Time

The survival time of some particular individual is a random variable T, which has a probability distribution. The probability distribution of T is what distinguishes one survival model from another, and these probability distributions are usually described by three mathematically equivalent functions: the **survivor function**, the **probability density** function, and the hazard function. If one of them is given, the other two can be derived, and each of them is used to illustrate different aspects of the data. Although discrete survival times can be handled by survival models, T is assumed to be a continuous random variable herein.

The survivor function S(t) is defined as the probability that an individual survives longer than t:

$$S(t) = Prob(T \ge t) = Prob(T \le t) = 1 - F(t)$$
(4)

where F(t) is the **cumulative distribution function**, which is the probability that an individual fails before t. Because T cannot be negative, S(t) = 1, for t = 0; and S(t) = 0, for $t = +\infty$. Another intuitive interpretation of S(t) is the fraction of individuals still alive at t.

Like any other continuous variable, the survival time has a probability density function f(t) defined as the limit of the probability that an individual fails in the short interval t to $t + \Delta t$ per unit width Δt , or simply the probability of failure in a small interval per unit of time.

$$f(t) = \lim_{\Delta t \to 0} \frac{Prob[t \le T \le t + \Delta t]}{\Delta t} = \frac{dF(t)}{dt} = -\frac{dS(t)}{dt}$$
(5)

Therefore, f(t) is the derivative or the slope of the F(t). The proportion of individuals that fail in any time interval and the peaks of high frequency of failure can be estimated from the density function.

Finally, the hazard function $\lambda(t)$ is defined as the probability of failure during a very small time interval, given that the individual has survived to the beginning of the interval (conditional failure rate):

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{\operatorname{Prob}[t \le T < t + \Delta t \mid T \ge t]}{\Delta t} = \frac{f(t)}{S(t)} = \frac{d \log S(t)}{dt}$$
(6)

Hence, $\lambda(t)$ is the limiting ratio of a probability over an interval length, and this ratio is always positive and can be greater than 1. The hazard function of survival time T gives the risk of failure per unit time during the aging process. The hazard at any point t corresponds directly to intuitive notions of the risk of event occurrence at time t. Because $\lambda(t)$ is a dimensional quantity that has the form number of events per interval of time, it must be interpreted according to the units in which time is measured. For instance, if a given cow has a hazard for getting an udder infection of 0.15 at a particular point in time, with time measured in months, then one should expect that she would have 0.15 cases of mastitis in a 30 days period (assuming that her hazard stays the same over a period of one month). In this example, the event is repeatable over time (cows can have mastitis more than once). When the event of interest is a nonrepeatable one (e.g., death), taking the reciprocal of the hazard, $1/\lambda(t)$, gives the expected length of time until the event occurs, assuming that $\lambda(t)$ remains constant. If someone's hazard for death is 0.02 per year at this moment, then one can expect to live another 1/0.02 = 50 years, given that the hazard remains the same. Obviously assuming constant hazards is far from what happens in real situations. That's why the analysis of the hazard function is more informative than the analysis of the hazard at a given point in time.

Although f(t) and F(t) are common representations of the distribution of a random variable, the hazard function plays a central role in survival analysis, especially in the modeling of survival curves. Often some information is available on how the failure rate (or the risk of failure) will change with time, and this information can be used to model $\lambda(t)$ and easily translated into implications for S(t) and f(t). For example, even without knowing the exact survival times of individuals in a given population one can expect that smokers have, on average, a higher hazard for heart disease than nonsmokers.

Survival Distributions

There are multiple causes that lead to the occurrence of a time event such as a disease or death. It is extremely difficult to isolate all these factors and mathematically account for them. Therefore, choosing a theoretical distribution to approximate survival data is as much an art as a scientific task (Lee, 1992). Some distributions, however, have been successfully used in survival analysis due to their convenient properties. The most commonly utilized distributions are the exponential, the Weibull, the lognormal, the Gamma, the generalized Gamma, the Gompertz and the loglogistic. It is out of the scope of this dissertation to discuss the particularities of all these distributions, but a brief review about two of them seems necessary.

The exponential distribution.

The simplest and most widely used of all survival distributions is the exponential distribution, which is obtained by assuming that the hazard function is constant over time. Chances of failure are always the same, regardless of how long the subject has been on test. Because age does not affect future survival, the exponential distribution is considered to have a "lack of memory". The exponential distribution is characterized by a hazard function

$$\lambda(t) = \lambda = constant, \tag{7}$$

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a survivor function

$$S(t) = \exp(-\lambda t), \tag{8}$$

and a probability density function

$$f(t) = \lambda(t)S(t) = \lambda \exp(-\lambda t).$$
(9)

The mean and variance of the exponential distribution are $1/\lambda$ and $1/\lambda^2$, respectively. For modeling purposes, it is important to consider also the logarithm of the survival time $y = \log T$. The density function of y is

$$f(y) = \lambda e^{y} \exp(-\lambda e^{y}) = \exp[(y + \log \lambda) - e^{(y + \log \lambda)}].$$
(10)

From this result, y can be written as $y = \alpha + \omega$, where

$$\alpha = -\log \lambda$$
 (11)

and

$$f(\omega) = \exp(\omega - e^{\omega}) \tag{12}$$

with $-\infty < \omega < +\infty$. This type of distribution for ω is known as extreme value distribution, with mean $E(\omega) = -\gamma$ ($\gamma=0.5772...$ is the Euler's constant) and variance $Var(\omega) = \pi^2/6 =$ 1.6449.... Therefore,

$$E(y) = E(\log T) = \alpha - \gamma \tag{13}$$

and

$$Var(y) = Var(\log T) = \frac{\pi^2}{6}.$$
 (14)

The popularity of the exponential distribution is explained by its extreme simplicity,

however assuming a constant hazard over time rarely provides a good description of the actual distribution of the survival times.

The Weibull distribution.

The Weibull distribution is a generalization of the exponential distribution, which does not assume a constant hazard rate and therefore has broader application. The Weibull distribution is characterized by two parameters, ρ and λ . The value of ρ determines the shape of the distribution curve and the value of λ determines its scaling. Consequently, ρ and λ are called the shape and scale parameters, respectively. The Weibull survivor function is a simple modification of the exponential one:

$$S(t) = \exp(-(\lambda t)^{\rho})$$
(15)

with $\lambda > 0$ and $\rho > 0$. The hazard function is

$$\lambda(t) = \lambda \rho(\lambda t)^{\rho-1}, \tag{16}$$

and the probability density function is

$$f(t) = \lambda \rho(\lambda t)^{\rho - 1} \exp(-(\lambda t)^{\rho}).$$
(17)

If $\rho = 1$, S(t) reduces to the exponential survivor function; if $\rho > 1$, the hazard is monotone increasing, and when $\rho < 1$, the hazard is monotone decreasing. Examples of increasing hazard rates are patients with lung cancer, and of decreasing hazard rates are patients who undergo successful major surgery.

The density of the logarithm of the survival time $y = \log T$ is

$$f(y) = \lambda \exp(\rho(y + \log \lambda) - e^{\rho(y + \log \lambda)}).$$
(18)

Again, y can be written as

$$y=\alpha+\sigma\omega$$
 (19)

where $\alpha = -\log \lambda$, $\sigma = \rho^{-1}$ and ω follows an extreme value distribution.

Regression Models

In the previous section, the exponential and the Weibull survival distributions were described for modeling the survival experience of a homogeneous population. In most situations, however, there are explanatory variables upon which failure time may depend, and the survival models have to be able to account for concomitant information on the individuals sampled.

Let $\mathbf{x} = (x_1,...,x_n)$ be a vector of explanatory variables (covariates) and $\beta' = (\beta_1,...,\beta_n)$ a vector of regression parameters. The exponential distribution can be generalized to obtain a regression model by allowing the failure time to be a function of the covariates \mathbf{x} . The hazard at time *t* for an individual with covariates \mathbf{x} is

$$\lambda(t;\mathbf{x}) = \lambda(\mathbf{x}). \tag{20}$$

Thus the hazard for a given x is a constant, characterizing an exponential failure time distribution, but the failure rate depends on x. The usual parametrization for $\lambda(\mathbf{x})$ is

$$\lambda(t;\mathbf{x}) = \lambda e^{\mathbf{x}\boldsymbol{\beta}} \tag{21}$$

which corresponds to a conditional density function of T given **x**:

$$f(t;\mathbf{x}) = \lambda e^{\mathbf{x}\beta} \exp(-\lambda t \ e^{\mathbf{x}\beta}).$$
(22)

This model specifies that the log failure rate is a linear function of the covariates x. Translating this for the log survival time y,

$$y=\alpha-x\beta+\omega$$
 (23)

where $\alpha = -\log \lambda$ and ω has the extreme value distribution. The model for $\lambda(t, \mathbf{x})$ is a log-linear

model, and the model for y is a linear model with the error variable ω having a specified distribution.

The Weibull distribution can also be generalized to the regression situation in the same way:

$$\lambda(t;\mathbf{x}) = \lambda \rho(\lambda t)^{\rho-1} e^{\mathbf{x}\beta}$$
(24)

and

$$f(t;\mathbf{x}) = \lambda \rho(\lambda t)^{\rho-1} e^{\mathbf{x}\beta} \exp[-(\lambda t)^{\rho} e^{\mathbf{x}\beta}].$$
(25)

Covariates have also a multiplicative effect on the Weibull hazard, but a linear effect on y:

$$y = \alpha + x \beta^* + \sigma \omega \tag{26}$$

where $\alpha = -\log \lambda$, $\sigma = \rho^{-1}$, and $\beta^* = -\sigma \beta$.

The form of the exponential and Weibull regression models in which the effect of covariates act multiplicatively on the hazard function suggests a general model called **proportional hazards model**, but the fact that the above models have a log-linear form, in which the covariates act additively on the logarithm of the survival time and multiplicatively on the survival time itself, suggests a general class of models known as **accelerated failure time model**. A quick description of both general models follows.

The Proportional Hazards Model

The proportional hazards model, as proposed by Cox (1972), specifies that

$$\lambda(t;\mathbf{x}) = \lambda_0(t)e^{\mathbf{x}\beta}$$
(27)

where $\lambda_0(t)$ is an arbitrary unspecified baseline hazard function for continuous *T*. This baseline hazard function represents the aging process of the whole population, and the second part of the conditional hazard, $e^{x\beta}$, represents a stress-dependent term specific to individuals with covariates **x**. The expression "proportional hazards" refers to the fact that the ratio between the hazards for two individuals is a constant over time due to the presence of a common baseline hazard function. In this model, the covariates act multiplicatively on the hazard function. When $\lambda_0(t) = \lambda$, (27) reduces to the exponential regression model (21). The Weibull model (24) is also a special case of (27), in which $\lambda_0(t) = \lambda \rho(\lambda t)^{\rho-1}$. When the baseline hazard function is left completely arbitrary, the proportional hazards model is called a **Cox regression** or Cox model.

The conditional density function of T given **x** is

$$f(t;\mathbf{x}) = \lambda_0(t)e^{\mathbf{x}\beta} \exp\left[-e^{\mathbf{x}\beta} \int_0^t \lambda_0(u) du\right]$$
(28)

and the conditional survivor function for T given **x** is

$$S(t;\mathbf{x}) = \exp\left[-e^{\mathbf{x}\beta} \int_0^t \lambda_0(u) du\right] = \exp\left[-e^{\mathbf{x}\beta} \int_0^t \lambda_0(u) du\right]^{\exp(\mathbf{x}\beta)}$$
(29)

The equation (29) can be written as

$$S(t;\mathbf{x}) = S_0(t)^{\exp[\mathbf{x}\beta]}$$
(30)

where it can be easily seen that the survivor function of t for a covariate value x is obtained simply by raising the common baseline survivor function $S_0(t)$ to a power.

The Accelerated Failure Time Model

In this class of models, the conditional hazard function has the form

$$\lambda(t;\mathbf{x}) = \lambda_0(t \ e^{-\mathbf{x}\beta})e^{-\mathbf{x}\beta}$$
(31)

and the corresponding survivor function is

$$S(t;\mathbf{x}) = \exp\left[-\int_0^{t \exp(-\mathbf{x}\beta)} \lambda_0(u) du\right].$$
(32)

It can be readily seen that, differently than in the proportional hazards model, the covariates act multiplicatively on *t* rather than on the hazard function. Allison (1995) writes:

"This model says, in effect, that what makes one individual different from another is the rate at which they age. A good example is the conventional wisdom that a year for a dog is equivalent to seven years for a human."

Therefore, a baseline hazard function is assumed to exist and the effect of the covariates is to modify the rate at which an individual proceeds along the time axis. In other words, x is responsible to accelerate or decelerate the time to failure.

Finally, it should be noted that the exponential and the Weibull regression models are the only proportional hazards models that are also accelerated failure time models.

Parametric Estimation (from Ducrocq, 1997)

Random censoring is assumed throughout this section. Let $C_1, C_2,...,C_n$ be the independently and identically distributed (*i.i.d.*) censoring times. The distribution characteristics of these censoring times are described by their density function h(c) or their survivor function $H(c) = \operatorname{Prob}[C > c]$. Let $T_1, T_2,...,T_n$ be the corresponding *i.i.d.* failure times

with density function f(t) and survivor function $S(t) = \operatorname{Prob}[T > t]$. What we actually observe is, for each individual *i*, a pair of random variables (Y_i, δ_i) where Y_i is the first event to occur (censoring or failure: $Y_i = \min(T_i, C_i)$) and δ_i is an indicator variable equal to 1 if the record is uncensored $(T_i \le C_i)$ and to 0 if the record is censored $(C_i \le T_i)$. This is represented as $\delta_i = \operatorname{Ind}(T_i \le C_i)$.

Likelihood construction.

Let $L_{i(j)}$ be the contribution to the likelihood of an uncensored observation y_i (j=1) or of a censored observation y_i (j=0):

$$L_{i(1)} = Prob[Y_i \in (y_i, y_i + dt); \delta_i = 1] \text{ assuming that } dt \rightarrow 0$$

= $Prob[T_i \in (y_i, y_i + dt); C_i > y_i]$
= $Prob[T_i \in (y_i, y_i + dt)] \times Prob[C_i > y_i]$
= $f(y_i) \times H(y_i)$ (33)

and

$$L_{i(0)} = Prob[Y_i \in (y_i, y_i + dt); \delta_i = 0] \text{ assuming that } dt \rightarrow 0$$

= $Prob[C_i \in (y_i, y_i + dt); T_i > y_i]$
= $Prob[C_i \in (y_i, y_i + dt)] \times Prob[T_i > y_i]$
= $h(y_i) \times S(y_i)$ (34)

If β^* is the set of parameters to estimate for the chosen parametric distribution, its likelihood $L(\beta^*)$ is:

$$L(\beta^{*}) = \prod_{i \in \{unc.\}} [f(y_{i})H(y_{i})] \prod_{i \in \{cens.\}} [h(y_{i})S(y_{i})]$$
(35)

where $\{unc.\}$ and $\{cens.\}$ represent the set of uncensored and censored observations, respectively. However, because of the random censoring assumption, h and H do not depend

on β^{\bullet} . Therefore,

$$L(\beta^*) \propto \prod_{i \in \{unc.\}} f(y_i) \prod_{i \in \{cen.\}} S(y_i)$$

$$\propto \prod_{i \in \{unc.\}} [f(y_i)]^{\delta_i} [S(y_i)]^{1-\delta_i}$$
(36)

and since $f(y_i) = \lambda(y_i) S(y_i)$,

$$L(\boldsymbol{\beta}^*) \propto \prod_i \left\{ \left[\lambda(\boldsymbol{y}_i) \right]^{\boldsymbol{\delta}_i} S(\boldsymbol{y}_i) \right\}$$
(37)

or, alternatively

$$\log L(\beta^*) = constant + \sum_{i \in \{unc.\}} \log \lambda(y_i) + \sum_i \log S(y_i)$$
(38)

Maximum likelihood estimates of β^* are obtained by maximizing (37) or its logarithm (38). The large sample properties of maximum likelihood estimates imply that β^* is asymptotically normal with mean β^* and variance-covariance matrix

$$V = \left[\nabla^2 \log L(\beta^*)\right]_{\beta^* = \beta^*}^{-1}$$
(39)

i.e., the inverse of the negative Hessian of the loglikelihood function.

Illustration: the Weibull regression model. In the case of the Weibull regression model:

$$\log S(y_i) = \log[\exp - \{y_i^{\rho} e^{x_i \beta}\}]$$

= -y_i^{\rho} e^{x_i \beta} (40)
and

$$\log\lambda(y_i) = \log[\rho y_i^{\rho-1} e^{x_i \beta}]$$
(41)

Therefore, omitting the constant term,

$$\log L(\rho,\beta) = N\log\rho + (\rho-1) \sum_{i \in \{unc.\}} \log y_i + \sum_{i \in \{unc.\}} x\beta - \sum_i y_i^{\rho} e^{x\beta}$$
(42)

where N is the total number of uncensored observations.

Estimation of the survivor function.

As both the parameters in $e^{x\beta}$ and in the baseline hazard function are estimated, the estimation of the survivor function is straightforward (e.g., in the Weibull model):

$$\hat{S}(t;\mathbf{x}) = \hat{S}_0(t)^{e^{i\theta}} = \exp\{t^{\hat{\rho}}\}^{e^{i\theta}}$$
(43)

Semi-parametric Estimation

In his famous paper "Regression models and life tables" (Journal of the Royal Statistical Society, Series B, 1972), Sir David Cox proposed not only a new general class of survival models known as proportional hazards model, but he also introduced a novel estimation method that was later named **partial likelihood**. What is considered to be remarkable about partial likelihood is that one can estimate the β coefficients without having to specify the baseline hazard function $\lambda_0(t)$. In equation (27), the hazard function of an individual with covariate vector **x** is the product of a totally arbitrary (non-parametric) baseline hazard function $\lambda_0(t)$ and a parametric function $e^{x\beta}$ of **x**. Consequently, Cox's estimation approach is considered to be **a semi-parametric** procedure. Since there is no

information about β coming from time intervals between two failures (arbitrary baseline hazard function), the partial likelihood considers only the "parametric" part of the likelihood function. Cox's partial likelihood has the form:

$$L_{C}(\boldsymbol{\beta}) = \prod_{k \in \{unc.\}} \left[\frac{e^{x_{[k]}\boldsymbol{\beta}}}{\sum_{j \in R(T_{[k]})}} e^{x_{j}\boldsymbol{\beta}} \right]$$
(44)

or, taking the logarithm,

$$LL_{C}(\boldsymbol{\beta}) = \sum_{k \in \{unc.\}} \left[\boldsymbol{x}_{[k]} \boldsymbol{\beta} - \log \sum_{j \in R(T_{[k]})} e^{\boldsymbol{x}_{j} \boldsymbol{\beta}} \right]$$
(45)

where R(t) is the list of individuals at risk at time t. The estimation of β is done by maximizing (44) or (45) as if they were true (log)likelihood functions.

Partial likelihood estimates have two of the three standard properties of Maximum Likelihood estimates: they are consistent and asymptotically normal (in large samples they are approximately unbiased and their sampling distribution is approximately normal). Another interesting property of partial likelihood estimates is that they depend only on ranks of the event times, not on their numerical values.

Generalizations of the Proportional Hazards Model

Sometimes it is clearly incorrect to assume that two individuals chosen at random have proportional hazards along the whole time axis. In order to add more flexibility to the proportional hazards model and somehow "relax" the proportionality assumption, some very powerful generalizations have been proposed.

Stratification.

Often the entire population can be subdivided into different strata for which the assumption of proportional hazards holds. For instance, the population can be stratified according to sex, breed, year of birth, etc. In this case, the hazard at time t of an individual of stratum s with covariate vector x can be written as

$$\lambda(t;\mathbf{x},s) = \lambda_{0,s}(t) \exp\{\mathbf{x}\mathbf{\beta}\}$$
(46)

The $\lambda_{0,s}(.)$ functions are baseline hazard functions which can be either parametric, such as Weibull hazard functions, or completely arbitrary and unrelated. The hazards of two individuals A and B with covariates \mathbf{x}_{A} and \mathbf{x}_{B} respectively are proportional if they belong to the same stratum:

$$\frac{\lambda(t; x_A, s)}{\lambda(t; x_B, s)} = \exp\{(x_A - x_B)\beta\}$$
(47)

If they are from two different strata s and s':

$$\frac{\lambda(t; \mathbf{x}_A, s)}{\lambda(t; \mathbf{x}_B, s')} = \frac{\lambda_{0,s}(t)}{\lambda_{0,s'}(t)} \exp\{(\mathbf{x}_A - \mathbf{x}_B)\mathbf{\beta}\}$$
(48)

which may vary with time.

Time-dependent covariates.

Stratification relaxes the proportionality assumption in those situations in which groups of individuals have completely different baseline hazard functions, but hazards remain proportional over time within strata. In many situations, however, variables affecting the hazard function in the vector \mathbf{x} change value over time. A classic example would be the effect of year on the failure time variable, which is included in the model to account for the variation in climatic, economic, and epidemiologic conditions occurring over time. If the subject survives 10 years, it is inappropriate to assume that its failure time was determined only by the conditions predominant in year 1. In addition, the inclusion in the model of all-or-none covariates representing events that have a strong impact on the hazard function (such as diseases) should only take place at the point in time in which the event occurs, since it



Figure 2.1 - Comparative hazard ratio for an individual with no disease reported (solid line), for an individual having a disease when effect has a fixed value over time (dashed line), and for an individual having a disease when effect is treated as a time-dependent covariate (dotted line).

obviously did not affect the failure time variable prior to that. Figure 2.1 illustrates what happens to the hazard ratio(sick/healthy) of an individual when disease status is treated as a 0/1 trait affecting the failure time variable during the entire lifetime or when disease status changes value only during the period in which the individual is sick. These variables are called **time-dependent covariates** and can be represented as $\mathbf{x}(t)$:

$$\lambda(t,x) = \lambda_0(t) e^{x(t)\beta}$$
(49)

In (49), the hazard ratio between individuals with different sets of (time-dependent) covariates is no longer constant over time, but can vary with t. Because the survivor function is difficult to compute when time-dependent covariates are present, it is normally assumed that the time axis can be partitioned into intervals and the proportional hazards assumption holds within intervals but may vary between intervals. In other words, $\mathbf{x}(t)$ is a piecewise constant function of time.

The computation of the log-likelihood function follows (38), and the only change from a model with "time-independent" covariates is in the estimation of the survivor function $S(y_i)$. Assuming that $\mathbf{x}(u)$ has jumps at $q_0 = 0 < q_1 < ... < q_J = y_m$ and is constant over the intervals $]q_{j-1}, q_j]$, the survivor function can be computed as:

$$S(y_{i}) = \exp\{-\sum_{j=1}^{J} \int_{q_{j-1}}^{q_{j}} \rho u^{\rho-1} e^{x(u)\beta} du\}$$

=
$$\exp\{-\sum_{j=1}^{J} \left[e^{x(q_{j}-1)\beta} (q_{j}^{\rho} - q_{j-1}^{\rho})\right]\}$$
(50)

Frailty Models

In the animal breeding context, estimation of variance components is of great interest.

As in regular mixed linear models used for genetic evaluations of animal populations, proportional hazards models can be extended to include random effects such as genetic effects. Survival mixed models are known as **frailty models** in the survival literature, because a **frailty term** v is defined as an unobserved random quantity which affects multiplicatively the hazard of individuals or groups of individuals. For example, if v_q is defined for all daughters of sire q, it describes the shared unobservable (genetic) characteristics which act on the hazard of each daughter. Using the classical mixed model notation, for individual m:

$$w' = (x'_m z'_m) \text{ and } \theta = \begin{pmatrix} \beta \\ s \end{pmatrix}$$
 (51)

where $\mathbf{x'_m}$ and $\mathbf{z'_m}$ are incidence matrices, $\boldsymbol{\beta}$ is the vector of fixed effects and \mathbf{s} is the vector of random effects (for simplicity, it is assumed here that all covariates are time-independent, there is only one baseline hazard function and the only random effect is sire). In the Weibull regression case, the hazard function for animal m is:

$$\lambda(t|\theta,\rho) = \lambda_0(t) \exp\{w'_m \theta\}$$

= $\lambda \rho(\lambda t)^{\rho-1} \exp\{w'_m \theta\}$
= $\rho t^{\rho-1} \exp\{\rho \log \lambda + w'_m \theta\}$ (52)

If the record comes from a daughter *m* of sire *q*, with observed failure at T_m :

$$\lambda(t|\theta) = \rho t^{\rho-1} v_a \exp\{x'_m \beta\} \qquad \text{for } t \le T_m$$
(53)

where $v_q = e^{\mathbf{r}_q}$ is the frailty term.

Ducrocq and Casella (1996) have recently proposed a general Bayesian approach to the analysis of mixed survival models for typical animal breeding situations (large applications, complex models and situations where a relationship matrix is used). They demonstrated the methodology using a simple Weibull model with two types of priors for the frailty term (gamma or log-normal), and straightforward generalization to other models were shown. To avoid redundance, their results are not going to be reproduced here. However, it seems appropriate to include their derivation of the heritability of the survival trait on the logarithmic scale.

From the usual relationship $f(t) = \lambda(t) S(t)$ the authors infer that (53) is a particular case of a log-linear model of the form

$$Y_{m} = \log(T_{m})$$

$$= \frac{1}{\rho} x'_{m} \beta + \frac{1}{\rho} s_{q} + \frac{1}{\rho} \omega_{m}$$

$$= w'_{m} \beta^{*} + \frac{1}{\rho} s_{q}^{*} + \frac{1}{\rho} \omega_{m}$$
(54)

where ω_m follows an extreme value distribution whose variance is equal to $\pi^{2/6}$. In (54) ω_m implicitly includes three quarters of the additive genetic variance, leading to a "natural" definition of the heritability of the survival trait on the logarithmic scale:

$$h^{2} = \frac{4 \ Var(s^{*})}{Var(\log T)} = \frac{4 \ Var(s)}{\frac{\pi^{2}}{6} + Var(s)}$$
(55)

Competing Risks

Different aspects of survival analysis have been discussed in this review, but in all cases it was assumed that the reason for failure was not important. In other words, $\lambda(t)$ has been used to model the risk of failure regardless the cause of failure. In many situations, however, it is important to distinguish between different types of events in survival data. For example, in a follow up study of heart transplants, records of patients that die due to accidents

or cancer should not be treated in the same fashion that records of those dying because of cardiovascular problems. When failure reasons are of interest and must be accounted for in the analysis, the method of **competing risks** offers an intuitive but powerful way of handling survival times. The general concept underlying competing risks analysis is that the occurrence of one type of event removes the individual from risk of all other types of events. Patients dying of cancer are no longer at risk of dying of heart attack.

A cause-specific hazard function can be defined as:

$$\lambda_{j}(t;\boldsymbol{x}) = \lim_{\Delta t \to 0} \frac{\operatorname{Prob}[t \le T < t + \Delta t, \ J = j | T \succeq t, \boldsymbol{x}]}{\Delta t}$$
(56)

for j = 1,...,m. Therefore, $\lambda_j(t;\mathbf{x})$ is the instantaneous rate of failure of type j at time t given \mathbf{x} and in the presence of the other failure types. Assuming that failure type j must be a unique element of $\{1,2,...,m\}$ gives

$$\lambda(t;\mathbf{x}) = \sum_{1}^{m} \lambda_{j}(t;\mathbf{x})$$
(57)

which states that the overall hazard function is just the sum of all the type-specific hazards. In practice, this means that $\lambda_j(t;\mathbf{x})$ can be obtained in the same way as $\lambda(t;\mathbf{x})$, just regarding all failures of types other than *j* as censored at the individual's failure time. It follows that any of the general methods discussed above can be used for inference on the $\lambda_i(t;\mathbf{x})$'s.

Competing risks is of particular interest in the study of reasons for disposal in dairy cattle. Cows being culled for different reasons were certainly affected by a distinct set of covariates or by the same covariates in different degrees, and modeling their hazards in a competing risks framework seems to be a very appropriate approach.

CHAPTER 3

Culling in Quebec Holstein Herds. 1. Study of Phenotypic Trends in Herd Life.

This chapter contains a manuscript accepted for publication in the Canadian Journal of Animal Science, which is co-authored by H. G. Monardes, R. I. Cue and J. C. Philpot. The work presented in the paper was carried out by the candidate, J. W. Dürr, including data edition, analysis and the preparation of the manuscript. Dr. Monardes and Dr. Cue are the thesis supervisor and a member of the advisory committee, respectively. They have actively participated in the discussions about the methodology and the interpretation of the results obtained. Jill Philpot is a graduate student at the Department of Animal Science of McGill University and has worked with the candidate in the preparation of lactation records from PATLQ files. The original manuscript was modified to conform to the format adopted in this thesis, Tables and Figures were renumbered, and the bibliography is presented at the end of the thesis with the references from the other chapters.

This is the first of a series of studies on culling in dairy cattle. Phenotypic trends in herd life are described from 1981 to 1994 in Quebec Holstein herds, and general statistics such as average productive herd life and average replacement rate per year are estimated. These results can be utilized to evaluate culling policies in Quebec and were used to refine the models for the survival analyses implemented in Chapter 5. The present chapter is particularly related to Chapter 4, where phenotypic trends in reasons for disposal are described.

Dürr, J. W., Monardes, H. G., Cue, R. I. and Philpot, J. C. 1997. Culling in Quebec Holstein herds. 1. Study of phenotypic trends in herd life. Can. J. Anim. Sci. Vol: pages. A total of 206,963 official lactation records and 128,182 owner sampler lactation records from the Programme d'Analyse des Troupeaux Laitiers du Québec herds were used to estimate survival rates of Holstein cows up to different parities by milk recording option and year of first calving. Survival up to a given parity was computed only for cows having the opportunity to reach that parity. Average productive herd life up to and including the eighth parity was computed for cows calving for the first time from 1981 to 1985. The overall productive herd life was 33.13 months for owner sampler herds and 32.97 months for official herds, and the respective replacement rates per year were 36.22% and 36.40%. Average herd composition in Quebec Holstein herds was: 33.4% of cows in parity 1, 24.2% in parity 2, 17.1% in parity 3, 11.4% in parity 4, 7.0% in parity 5, 3.9% in parity 6, 1.9% in parity 7, and 1.1% in parity 8. Cows in official herds had longer calving intervals than in owner sampler herds. First calf heifers have been culled by official producers earlier in lactation than by owner sampler producers. Survival rates decreased from 1981 to 1992, and trends for official and owner sampler herds were very similar.

Key words: Herd life, survival, Holstein, Quebec, culling

Dürr, J.W., Monardes, H.G., Cue, R.I., and Philpot, J.C. 1997. La réforme des vaches chez les troupeaux Holstein du Québec. 1. Étude des tendances phénotypiques de la vie productive. Can. J. Anim. Sci. Vol: pages. Un total de 206,963 lactations officielles et 128,182 lactations non-oficielles dans des troupeaux Holstein du Programme d'Analyse des Troupeaux Laitiers du Québec ont été utilisées afin d'estimer les taux de survivance des vaches jusqu'aux différentes vélages; ceci selon deux options de contrôle, officielle et nonofficielle, et selon l'année du premier vêlage. La survivance jusqu'à un certain vêlage fut calculé seulement pour les vaches ayant eu l'opportunité d'arriver au dit vêlage. La vie productive moyenne jusqu'au huitième vêlage fut calculée pour les vaches ayant vêlé pour la première fois entre 1981 et 1985, inclusives. La vie productive fut de 33.13 mois chez les troupeaux non-officiels et de 32.97 chez les troupeaux officiels; le taux de remplacement fut de 36.22% et 36.20%, respectivement. La composition moyenne des troupeaux Holstein du Québec fut: 33.4% des vaches primipares, 24.2% en deuxième vêlage, 17.1% en troisième, 11.4% en quatrième, 7.0% en cinquième, 3.9% en sixième, 1.9% en septième, et1.1% en huitième vélage. Les vaches dans les troupeaux officiels eurent intervalles de vélage plus longues que dans les troupeaux non-officiels. Il fut observé que l'élimination des vaches de premier vélage fut faite plus tôt durant la lactation chez les troupeaux officiels que chez les non-officiels. Les taux de survivance diminuerent dès 1981 à 1992; la même tendance fut observée chez les troupeaux officiels que chez les non-officiels.

Mots clés: Vie productive, survivance, Holstein, Quebec, réforme.

Herd life of dairy cows is considered to be a trait of major economic value, and herd profitability is affected every time the dairyman changes culling policy (Gill and Allaire 1976, Renkema and Stelwagen 1979, Congleton Jr. and King 1984, Stott 1994). Taking into consideration that survival of a dairy cow depends largely on its economic merit, Gill and Allaire (1976) concluded that "herd life probably contains sufficient a priori information on relative economic returns to serve as a measure to assess effectiveness of incomplete and approximate profit functions." Therefore, descriptive statistics on productive herd life in dairy cattle populations are valuable tools for evaluating culling strategies and the overall performance of dairy herds. Phenotypic trends in herd life have been described for different populations of dairy cows (Hoque and Hodges 1980, Dentine et al. 1987, Harris 1989, Madgwick and Goddard 1989, Nieuwhof et al. 1989a, Sattler and Dentine 1889, and Strandberg 1992a), but a detailed description of herd life trends in the province of Quebec is still lacking.

The Programme d'Analyse des Troupeaux Laitiers du Québec offers two types of milk recording for the producers: the official option, which is done by authorized field-supervisors, and the owner sampler option, in which the producer performs the milk recording. Producers enrolled in the official option are entitled to receive official production certificates for each lactation completed by their cows. These certificates have become important marketing tools where selling breeding stock is an important source of income. It has been implicitly accepted that official herds would generally be interested in selling breeding stock, and improving both production and conformation traits, while owner sampler herds would be primarily interested in improving production. Different goals would imply different selection criteria, and possibly distinct lengths of productive herd life for cows in the two milk recording options.

The objective of this investigation was to describe the phenotypic trends in herd life of Quebec Holsteins calving in 1981 or later, as well as to identify possible differences in survival and average herd life between cows from owner sampler and official herds.

Abbreviations: PATLQ, Programme d'Analyse des Troupeaux Laitiers du Québec; CMH, Cochran-Mantel-Haenszel.

MATERIALS AND METHODS

Data Editing and Computation of Herd Life Parameters

The computation of average survivals, average productive herd life, average replacement rates, and average herd composition follows exactly the methodology outlined by Nieuwhof et al., 1989a. Raw data were lactation records collected from January 1980 to March 1995 by the Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ). To be included in this study, records had to be of Holstein cows that first calved in 1981 or later and in Quebec herds that were at least one year on milk recording at PATLQ. These restrictions (not including records from 1980) were imposed because producers tend to cull more intensively their cows during the first year of milk recording and hence records from this first year are not really representative of actual trends (Nieuwhof et al., 1989a). Lactation records of 206,963 cows from official herds and 131,978 cows from owner sampler herds were used in this study. Because data from owner sampler herds are usually not edited as severely as data from official herds, historical files from PATLQ herds include all official herds and only those owner samplers with at least 90% of the cows identified and with consistent records for feeding information. This enhances the reliability of the information, but it surely creates a selected group of owner sampler herds which probably have a better management than the average owner sampler herds. Therefore, it should be noted that comparisons between milk recording options in the present study are biased due to selection

of owner sampler herds.

Data subsets were organized based on the opportunity of each cow to have calved for each parity. An opportunity of 450 days per calving interval was allowed. For instance, all cows calving for the first time at least 450 days prior to March 31, 1995, were included in the subset for parity 2; all cows calving for the first time at least 900 days prior to March 31, 1995, were included in the subset for parity 3; and so on. Because the present study was designed to analyse trends according to the calendar years, it was necessary to carry out a further edit to avoid biases due to truncation by excluding the last year of data of each opportunity group. In order to avoid an underestimation of the survival rates, cows from herds stopping milk recording and cows receiving sale codes (exported, sold for dairy purposes, and rented) were considered not to have had an opportunity to calve in the subsequent parity. Considering that all animals with partial records have survived to the next parity leads to an overestimation of the survival rates. The maximum use of the information occurs when partial records are censored, but the use of censoring was not possible with the methodology used in this paper. Data for parities after the eighth were not included. Only cows calving for the first time from 18 to 42 months of age were included. A minimum of 270 days and a maximum of 670 days for calving intervals (all parities) was imposed. Numbers of cows included in this study by milk recording option and year of first calving are shown in Figure 3.1.

Cows were considered to have survived to a given parity if they finished normally their previous lactation and a new calving date was reported. Survival rate up to parity 1 was assumed to be 100% (since no information prior to first calving was available) and for later parities survival rates were calculated as the ratio between the number of cows calving and the number of cows with opportunity to calve for each parity. Average number of calvings was estimated as the sum of average survival rates for parities 1 through 8. Average

productive herd life was defined as the period of time that an average cow stays in the herd, from her first calving to the day she is culled. It was calculated by the following expression:

$$H = \frac{\sum_{i=1}^{7} \left[(S_{i+1}) \times C_i + (S_i - S_{i+1}) \times D_i \right] + (S_8) \times 365.25}{30.4375}$$

where H is the average productive herd life in months, S_i is the survival rate up to parity i, C_i is the average calving interval in days started by parity i, and Di is the average number of days in milk for parity i for cows without a subsequent lactation (Nieuwhof et al., 1989a). A similar expression was also used by Harris (1992) in his dairy farm linear programming model to adjust the herd total metabolic live weight for the effect of herd life. Cows having an eighth parity were considered to have survived one year after calving. Since only a small proportion of cows are kept in their herds longer than that, this assumption should not cause any appreciable biases on the estimation of the average productive herd life. Average replacement rate per year was estimated by 100/(H/12). Average herd composition was calculated by:

$$P_{i} = \frac{[(S_{i+1}) \times C_{i} + (S_{i} - S_{i+1}) \times D_{i}]}{30.4375 \times H}$$

where P_i is the proportion of cows in a herd in parity i (i=1,...,7). Since all cows with an eighth parity were assumed to have survived 1 year after calving,

$$P_8 = \frac{12 \times S_8}{H}$$

Statistical Analysis

Data on individual cows were organized in three-way cross tabulation tables in which

columns represented the response variable y (y=1, if cow had a subsequent parity; and y=2, if cow failed to calve again), rows represented levels of the variable x (x=either years of first calving or milk recording option), and each level of the variable z (z=whatever variable not represented by x) formed a different stratum. The relationship between milk recording options and survival up to subsequent parity, and between years of first calving and survival up to subsequent parity as tested using a Cochran-Mantel-Haenszel (CMH) general association statistic (Landis et al. 1978) in the FREQ Procedure of SAS/STAT®. This general association statistic is a stratum-adjusted Pearson chi-square statistic in which the alternative hypothesis is that, for at least one stratum, there is some kind of association between the row variable and the column variable. For instance, this procedure gives a stratified statistical analysis of the relationship between survival (y) and years (x), after controlling for milk recording option (z), or between survival (y) and option (x), after controlling for year of first calving (z). The average survival rates up to different parities were estimated by this means.

Calving intervals starting at different parities were considered to be different traits and, therefore, analysed separately. The same reasoning applies to lactation lengths of cows without a subsequent parity. The following cell means model was used to test the hypothesis of equality of row (milk recording options) and column (years) calving interval means and length of lactation means of cows without a subsequent parity:

$$y_{ijk} = \mu_{ij} + e_{ijk}$$

where y_{ijk} is the kth observation (calving interval in days or days in milk for cows without a subsequent parity) for milk recording option i (i=1, for owner sampler; and i=2, for official) and for year j (i=1,...,m); μ_{ij} is the mean of a conceptual population corresponding to option i and year j; and e_{ijk} is a random error term with $e \sim N(0, I\sigma^2)$. The number of years with data (m) varied according to the parity in which the calving interval started or according to the last parity of culled cows (m=12, for parity 1; m=11, for parity 2; m=10, for parity 3; m=9, for

parity 4; m=7, for parity 5; m=6, for parity 7; and m=5, for parity 8). The equality between unweighted row means and unweighted column means was tested using appropriate F statistics, as described by Searle (1987).

RESULTS AND DISCUSSION

Average Survival Rates

The average survival rates up to different parities by milk recording option and year of first calving are shown in Figure 3.2. The CMH statistic detected significant association between milk recording option and survival up to parities 2 through 6 (P < 0.01), but no significant association between options and survival up to parities 7 and 8 was observed. Association between survival up to different parities and year of first calving was statistically significant for all opportunity groups (P < 0.01). Consistently over the years of study and across parity numbers, herds enrolled on the official milk recording option at PATLQ presented survival rates approximately 1% smaller than herds in the owner sampler option. Although this variation was statistically significant, it does not indicate any major differences among milk recording options regarding trends in herd life. Dürr et al. (1997 - Chapter 4 of this thesis) found that differences in culling rates between PATLQ official and owner sampler herds were mostly due to differences in the proportions of cows sold for dairy purposes, since trends for voluntary and involuntary reasons for disposal were similar for both milk recording options. These results suggest that culling policies in official and owner sampler herds are very comparable.

A decreasing trend in survival rates was observed in all opportunity groups from 1981 to 1984 (in owner sampler herds) and to 1985 (in official herds), followed by an increasing

trend until 1990. It should be noted that survival rates in this study always refer to the number of first calf heifers that had the opportunity to reach a given parity, not to the number of cows present in the previous parity. The primary consequence of this is that a high replacement rate during the first lactation of an opportunity group will reduce the survival rates not only up to second parity, but up to all parities. Having said that, one possible explanation for the low survival rates observed in cows calving for the first time between 1984 and 1985 would be a reduction in quotas on the Canadian milk supply system during the referred period, which probably induced producers to cull more intensively their heifers than at other times.

Despite the editing procedures, it seems that a truncation effect is still present, which would explain the fact that survival rates decreased more markedly in the last year of all opportunity groups.

Calving Intervals

Average calving intervals by parity, milk recording option and year of first calving are shown in Table 3.1. The F-statistics calculated to test the hypothesis of equality between row means (years of first calving) and among column means (milk recording options) were all statistically significant (P < 0.01), except for the comparison between years of first calving for the mean interval between the sixth and the seventh calvings. Average calving intervals were close to 13 months, which is in agreement with other estimates from large populations (Nieuwhof et al. 1989b, Short et al. 1990). Table 3.1 shows that, especially for official herds, mean calving intervals were quite constant from 1981 to 1985 and then increased in all opportunity groups. Official herds had longer mean calving intervals than owner sampler herds (Figure 3.3). This was probably due to the fact that official herds have a higher average production level than owner sampler herds (PATLQ 1996) and high milk yield per lactation has been associated with longer calving intervals (Short et al. 1990). Figure 3.3 also shows

 Year	Parity ^z													
	1		2		3		4		5		6		7	
	OS'	OF	OS	OF	OS	OF	OS	OF	OS	OF	OS	OF	OS	OF
1981	389.6	389,9	388.9	389.7	386.9	392,6	389,0	392.3	390,3	396,9	392.6	399.5	398,3	401.8
1982	387.7	388,6	387,4	390.2	385.9	390,1	389.5	395.8	391.4	400.9	394,3	406.8	400.8	405.7
1983	387,6	390,4	388,4	391.8	386,6	392,8	390.6	398.6	393,6	403.4	396.5	406.2	389.8	401,3
1984	386.7	390.4	388.4	392.8	388.3	395.3	391.4	401.0	395,2	405.9	394.5	406.6	395.5	407.0
1985	388,8	390.6	388.7	394,1	391.9	397,3	394.0	404.2	392.9	401,4	396.2	406.0	392,4	400.0
1986	389.4	392,9	389,9	396.9	394.9	400.7	391.4	403.4	393.9	405.1	394.0	403.1		
1987	391.6	395.7	392,5	400,8	391,7	402.0	392,4	404.7	394.1	403,9				
1988	393.2	397.2	393.7	399,9	392.3	400.7	390,3	402,3						
1989	394.3	398.5	393,5	398,6	393,3	399,3	384.8	390.6		e ^t an an an Bangar				
1990	394.3	396.2	393.6	398.7	383.0	392.9								
1991	393.2	398.9	387,0	393,8	el est The second se								· · ·	•
1992	387.1	393.2												
Overall	390,3	393,5	390.2	395,2	389,5	396,4	390,4	399.2	393.0	402,5	394.7	404,7	395,4	403.2
SD _{min} *	49.5	49.2	47.4	49.2	45.8	48.4	45.9	45.8	51.1	56,3	50.7	56,1	51.8	54.6
SD_	57.5	56.4	55.2	57.1	56.1	57.0	54.9	58.6	55.4	59.9	54.4	62.8	56.6	61.0

Table 3.1 - Average calving intervals in days by parity, milk recording option and year of first calving.

¹Parity in which calving interval started. ³OS = owner sampler herds; OF = official herds. ³SD_{min} = minimum standard deviation; SD_{max} = maximum standard deviation.

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that mean calving interval was longer in later lactations and this could also be related to the unfavourable relationship between milk yield and reproductive efficiency, as production increases with parity number. Nieuwhof et al. (1989b) also reported higher calving intervals for later parities in U. S. and found that registered herds presented slightly longer calving intervals than grade herds. Sattler and Dentine (1989), working with data from Wisconsin Dairy Herd Improvement Cooperative, reported that cows under DHI recording schemes had longer calving intervals than owner sampler herds. It is important to note that average calving interval is not only a function of when cows conceive, but also of how long the producer continues to inseminate a given cow. Therefore, average calving interval reflects reproductive management as much as conception rates. Those cows which the producer decides not to continue inseminating will be culled and do not contribute to the average calving interval. Finally, re-breeding management will likely vary with parity, e.g., it is possible that producers tend to continue breeding for a longer time in later parities (cows which have already proven their productive potential) than in first parity cows.

Average Days in Milk for Cows Without a Subsequent Lactation

Average days in milk for cows without a subsequent lactation are shown in Table 3.2. Although these descriptive statistics have high standard deviations and depend essentially on factors associated with the reasons for disposal, they are useful to indicate in which stage of lactation most cows have been culled. The F-statistics used to test the equality of mean days in milk for cows without a subsequent parity in different milk recording options and in different years of first calving showed that differences between years were statistically significant at P < 0.01 (except for cows culled during lactation 7), but no clear trends were observed. Differences between the two milk recording options were statistically significant (P < 0.01) only for cows disposed of during first and second lactation. Figure 3.4 shows that, on average, first calf heifers in official herds were culled earlier (19 days) than heifers in

							ينديد التكاويبي البراج							
							Terminal I	Lactation						
	1		2		3		4		5		6		7	
Year	OS [*]	OF	OS	OF	OS	OF	OS	OF	OS	OF	OS	OF	OS	OF
1981	231.6	221.4	223,6	216.9	235,4	228.4	221,3	223.9	221.6	227,6	218,5	235.7	242,7	224.2
1982	207.5	191.8	221.9	224.0	229.1	224.7	229.4	236.4	220,3	236.3	239.6	232.2	238.8	239.0
1983	209,8	195.9	219.6	215.8	227.4	232,5	235.4	232.3	245.3	242.2	235.3	232.2	231,3	240.0
1984	205.2	190.2	225.9	218.5	235.8	232.7	241.1	252.1	234.6	237.7	230,3	232,5	221.3	237.3
1985	204.6	181,6	221,5	223,2	233,2	248,6	240,3	240.9	241.5	236,5	220.8	230.8	216,4	225.7
1986	207.5	186.4	236,1	232.9	248.8	242,2	245,3	239.5	245.2	229.7	214.7	215.6		
1987	220,9	200,8	230.0	231,8	238,0	235,9	244.1	238.2	224.7	222.6	1 1 1	2000 M. A.	(
1988	222.1	204.2	236.0	228.5	237.1	234.0	215.1	217.9						
1989	226.4	202,5	236,3	230,0	227.0	219.0	235.1	237.6		i 				
1990	229.3	200.7	225.3	211.3	238.1	231.6								
1991	212.8	193.7	227.3	228,3	en an An an An airte An airte				ana ing pangangan Pagan ing pangangan Pagan ing pangangangan	• •				
1992	209,6	190.0												
Overall	215,6	196,6	227,6	223.7	235,0	233.0	234.1	235.4	233.3	233,2	226,5	229.8	230,1	233.2
SD _{min} ^y	118.4	116.9	113.0	112.4	115,5	117.9	116.6	113.3	114.0	123.8	115.2	120.8	119,7	120,4
SDmax	139,9	136,5	131,9	135,3	133,9	131,8	131.9	132.6	131.2	131,3	131,2	150.7	132,4	137,9

Table 3.2 - Average days in milk for cows without a subsequent parity, by lactation in which culling happened, milk recording option and year of first calving.

 10 OS = owner sampler herds; OF = official herds. 10 SD_{min} = minimum standard deviation; SD_{max} = maximum standard deviation.

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owner sampler herds, and that culling was conducted earlier in first lactation than in later lactations in herds from both options. Dissimilarities between average days in milk at culling in first and later lactations may occur because dairymen cull heavily for low production in first lactation, and the poor producing heifers are replaced as soon as production drops to a certain level. Differences between milk recording options are addressed in more detail in Figure 3.5. During the period of study, the proportion of cows being culled prior to 240 days in milk in official herds was 71.37% of the total number of cows disposed, compared to 62.29% in owner sampler herds. In Canada, only cows with more than 240 days in milk in official herd average only includes cows with more than 240 days in milk. Since both the certificates and the herd average are important marketing tools, official herds tend to practice voluntary culling prior to 240 days in milk.

Average Productive Herd Life

Table 3.3 shows average productive herd life in months up to and including parity 8. As a consequence of the editing criteria used, only cows calving for the first time in 1985 or earlier had the opportunity to have an eighth parity and, therefore, an estimate of productive herd life. Owner sampler and official herds had very similar estimates of productive herd life, and in both cases the trend was descending from 1981 to 1985 (mainly as a function of the trends in survival rates previously discussed). The overall average herd life for official herds was 32.97 months after first calving or 2.98 parities completed, and for owner sampler herds it was 33.13 months after first calving or 3.01 parities completed. These estimates of productive herd life correspond to average replacement rates of 36.40% and 36.22%, for official and owner sampler herds respectively. Although the present methodology is considered to be appropriate for estimating average productive herd life, it should be noted that by removing records of cows sold for dairy purposes from the data we may be

Table 3.3 - Average productive herd life up to and including parity 8, average number of										
parities (calvings) up to and including parity 8, and average replacement rate by milk										
recording program and year of first calving.										

Productive	e Herd Life	Number o	of Parities	Replacement Rate		
(m	10.)			(*	%)	
OS ^z	OF	OS	OF	OS	OF	
33.95	34.22	3.06	3.08	35.35	35.07	
33.95	34.04	3.08	3.07	35.34	35.25	
33.45	33.05	3.03	2.99	35.87	36.31	
31.64	31.91	2.89	2.89	37.93	37.60	
32.67	31.62	2.97	2.87	36.72	37.94	
33.13	32.97	3.01	2.98	36.22	36.40	
	Productive (m OS ^z 33.95 33.95 33.45 31.64 32.67 33.13	OS ^z OF 33.95 34.22 33.95 34.04 33.45 33.05 31.64 31.91 32.67 31.62 33.13 32.97	Productive Herd Life Number of (mo.) OS ^z OF OS 33.95 34.22 3.06 3.08 33.95 34.04 3.08 3.03 33.45 33.05 3.03 3.164 31.91 2.89 32.67 31.62 2.97 3.01 3.01	Productive Herd Life Number of Parities (mo.) OS ^z OF OS OF 33.95 34.22 3.06 3.08 33.95 34.04 3.08 3.07 33.45 33.05 3.03 2.99 31.64 31.91 2.89 2.89 32.67 31.62 2.97 2.87 33.13 32.97 3.01 2.98	Productive Herd Life Number of Parities Replaced (mo.) (* OS ^z OF OS OF OS 33.95 34.22 3.06 3.08 35.35 33.95 34.04 3.08 3.07 35.34 33.45 33.05 3.03 2.99 35.87 31.64 31.91 2.89 2.89 37.93 32.67 31.62 2.97 2.87 36.72 33.13 32.97 3.01 2.98 36.22	

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 $^{2}OS = owner sampler herds; OF = official herds.$

underestimating the actual "raw" replacement rates, especially for official herds.

Values for productive herd life in this study were smaller than most estimates from other populations. Hoque and Hodges (1980), using the Canadian Record of Performance (ROP) data on Holstein cows from 1957 to 1974, estimated an average herd life of 43 months; Sattler and Dentine (1989), working with data from Wisconsin Holsteins, reported an expected herd life of 3.4 years in owner sampler herds and 2.8 years in DHI herds; Nieuwhof et al. (1989), for U. S. Holsteins, estimated an average productive herd life of 39.6 months for registered herds and 37.2 months for grade herds; Harris (1989), studying data from New Zealand dairy herds, reported an average herd life of 4.77 lactations for the period 1985 to 1986; Madgwick and Goddard (1989), analysing longevity parameters in Australian dairy cattle, estimated average productive life per cow to be from 5.5 to 6.6 years; Strandberg (1992a) reported a mean productive life of 2.29 years for cows of the Swedish Red and White breed; Short and Lawlor (1992) published estimates of true herd life of 37.7 months for registered and 33.4 months for grade Holsteins in the U.S. Discrepancies between cow populations in the actual time from first calving to culling reflect the differences in production goals, replacement costs and milk prices existing between countries. Jairath et al. (1994), using a subset of the data included in the present study, estimated an average productive life per cow of 833.63 days, which is more than 5 months shorter than estimates in Table 3.3. These differences exist because different editing criteria were used, and in the present study only cows having the opportunity to reach the eighth parity were included in the computation of average productive herd life. Dekkers (1991) estimated an optimum average herd life of 39.9 months under Ontario conditions, as opposed to an optimum of 47.8 months calculated by Rogers et al. (1988a) in the U.S. Dekkers (1991) pointed out that the difference in optimum average herd life between Canada and the U.S. was largely due to a more than 50% higher milk price in Canada, while replacement costs were very similar in the two countries. Estimates of optimum herd life always refer to a given level of involuntary culling and to

certain economic circumstances. For instance, if the rate of involuntary culling in Quebec herds was higher than that assumed by Dekkers (1991), then the optimum average herd life would be less than 39.9 months.

Table 3.3 also shows the annual culling rates corresponding to the average productive herd life estimated for each year. Culling rates ranged from 35% in 1981 to almost 38% in 1984 (owner sampler herds) and 1985 (official herds). This ascending trend corresponds to the previously described descending trends in survival rates. As for herd life, average culling rates have to be interpreted with care, considering the proportion of involuntary culling and the economic scenario in which replacement decisions were made. The existence of the quota system in Canada tends to increase average culling rates because milk prices are higher than in a non-quota kind of situation (Dekkers 1991). In addition, herds that are not expanding (fixed amount of quota) tend to go repeatedly over quota and, therefore, cull more intensively due to the existing positive genetic trend for milk production. This would explain at least part of the discrepancy between the estimates on Table 3.3 and the optimum culling rate of 25% calculated by Rogers et al. (1988a) for the United States. On the other hand, Dürr et al. (1997 - Chapter 4 of this thesis) showed that involuntary culling increased in Quebec dairy herds in the period covered by the present study, while culling for low production (voluntary) decreased. In a situation in which most of the culling is involuntary, high culling rates are often associated with sub-optimal herd profitability (Renkema and Stelwagen 1979; Rogers et al. 1988b).

The average herd composition, as derived from the estimates of productive herd life was virtually the same for official and owner sampler herds. The fraction of cows in parities 1 through 8 were 33.38, 24.24, 17.14, 11.42, 6.98, 3.86, 1.93, and 1.05%. Almost 60% of all cows in the average Quebec herd were either in first or in second lactation, which means a very young population of dairy cows.

CONCLUSIONS

According to the findings of this study, average productive herd life in Quebec Holstein herds has been approximately 33 months after first calving, which corresponds to an annual replacement rate of 36% and is shorter than most of the estimates from other countries. Dairy cows in official herds had longer calving intervals than in owner sampler herds, and dairymen in official herds have been culling first calf heifers earlier in lactation than dairymen in the owner sampler option. Despite differences between the two milk recording options regarding survival rates, calving intervals and average days in milk for cows without a subsequent lactation, estimates of average productive herd life were very similar. Therefore, differences in breeding goals did not affect significantly average herd life. Actual differences among the two options may have been attenuated because data included in present study was from a selected group of owner sampler herds. Results presented here can be useful for economic studies on replacement policies in Canadian herds.

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Figure 3.1 - Number of cows included in this study by milk recording option and year of first calving (total of 131978 cows in owner sampler herds and 206963 cows in official herds).



Figure 3.2 - Survival rates (number of cows that calved/number of cows with opportunity to calve) to different parities by milk recording option (solid lines = owner sampler herds; dotted lines = official herds; \blacksquare = survival up to the second parity; \clubsuit = survival up to the third parity; \bigstar = survival up to the fourth parity; \bigstar = survival up to the fifth parity; \bigstar = survival up to the seventh parity; \clubsuit = survival up to the eighth parity).



Figure 3.3 - Average calving intervals for owner sampler and official herds by parity in which interval started.



Figure 3.4 - Average days in milk for cows without a subsequent lactation in owner sampler and official herds by their terminal lactation.



121 to 240 DIM

 \square 1 to 120 DIM

Figure 3.5 - Proportion of cows being culled in different stages of lactation relative to the total number of cows disposed, by milk recording option and year of first calving (DIM = days in milk).

CHAPTER 4

Culling in Quebec Holstein Herds. 2. Study of Phenotypic Trends in Reasons for Disposal

This chapter contains a manuscript accepted for publication in the Canadian Journal of Animal Science, which is co-authored by H. G. Monardes, R. I. Cue and J. C. Philpot. The work presented in the paper was carried out by the candidate, J. W. Dürr, including data edition, analysis and the preparation of the manuscript. Dr. Monardes and Dr. Cue are the thesis supervisor and a member of the advisory committee, respectively. They have actively participated in the discussions about the methodology and the interpretation of the results obtained. Jill Philpot is a graduate student at the Department of Animal Science of McGill University and has worked with the candidate in the preparation of lactation records from PATLQ files and to some extent in the analysis of the data. The original manuscript was modified to conform to the format adopted in this thesis, Tables and Figures were renumbered, and the bibliography is presented at the end of the thesis with the references from the other chapters.

This study presents a description of phenotypic trends on reasons for disposal in Quebec dairy herds and it complements the results from Chapter 3, which dealt with trends in herd life. Average replacement rates and average productive herd life (from Chapter 3) can be interpreted more appropriately if one knows why cows have left their herds. Results from this Chapter were also used to check the estimates obtained from the competing risks analyses in Chapter 7.

Dürr, J. W., Monardes, H. G., Cue, R. I. and Philpot, J. C. 1997. Culling in Quebec Holstein herds. 2. Study of phenotypic trends in reasons for disposal. Can. J. Anim. Sci. Vol: pages. A total of 1,558,080 lactation records from PATLQ Holstein cows were used to describe the annual trends in reasons for disposal in Quebec dairy herds from 1981 to 1994. Differences in culling trends between official and owner sampler herds, between parities, and between Quebec agricultural regions were compared. Statistical analysis was carried out by means of a logistic regression model, and the significance of trends was tested by linear contrasts. Involuntary culling had a clearly ascending trend during the period of study (from 23% in 1981 to 32% in 1994), as opposed to culling for low production (voluntary), which had a descending trend (from 16% in 1981 to 4.5% in 1994). This increase in involuntary culling was mainly due to increasing trends in culling for reproductive problems, mastitis and feet and leg problems. Official herds had a greater proportion of cows with sale codes and less cows culled for mastitis than owner sampler herds, and the trend for sale codes was ascending for official and stable for owner sampler herds. Culling for low production was more intensive in first parity, but all parities showed a descending trend over time. The proportion of cows with sale codes decreased with parity number. For all involuntary reasons, proportion of cows culled increased with parity number.

Key words: Reasons for disposal, Holstein, Quebec, culling

Dürr, J. W., Monardes, H. G., Cue, R. I., and Philpot, J. C. 1997. La réforme des vaches chez les troupeaux Holstein du Québec. 2. Étude des tendances phénotypiques des raisons de réforme. Can. J. Anim. Sci. Vol: pages. Un total de 1,558,080 records de lactation des vaches Holsteins dans les troupeaux du PATLO ont été utilisées pour étudier les tendances annuelles des raisons d'élimination de ces vaches. Les tendances, de 1981 à 1994, furent comparées entre les deux option de contrôle, officielle et non-officielle, entre différentes groupes de vêlage, et entre douze regions différentes de la province de Québec. L'analyse statistique fut par un modèle de regression logistique, et l'effet significatif des tendances fut testé par des contrastes linéaires. La réforme involontaire montra une claire tendance ascendante durant la période etudiée (de 23% en 1981 à 32% en 1994), à l'inverse de la réforme par basse production (volontaire) qui montra une tendance descendante (de 16% en 1981 à 4.5% en 1994. Cette augmentation dans la réforme involontaire fut causée principalement par une augmentation des problèmes reproductives, de la mammite, et des problèmes des pieds et membres. Les troupeaux officiels ont eu plus des vaches avec des codes de vente et moins des vaches eliminées à cause de la mammite que les troupeaux nonofficiels, mais les tendances furent ascendantes chez les officiels et stables chez les nonofficiels. La réforme par basse production fut plus intense en première lactation, mais toutes les groupes d'age montrèrent une tendance descendante à travers les années. La proportion de vaches avec des codes de vente diminua avec l'age productive. La proportion de vaches eliminées par des raisons involontaires augmenta avec l'age productive.

Mots clés: Raisons d'élimination, Holstein, Québec, réforme

Dairy cows can leave their herds for several reasons, either due to the producer's choice of eliminating animals with undesirable characteristics or as a consequence of diseases and accidents. Culling for low milk production is voluntary by definition, since the herd manager selects the best producing cows to stay in the herd and discards the poorest producing cows regardless of their health status. Involuntary culling occurs when a cow has to be culled irrespective of her performance relative to that of her herd mates, and involuntary reasons of disposal include reproductive failure, mastitis, udder breakdown, feet and leg problems, sickness, old age, injury, bad temperament, and others. Low production and reproductive problems have been reported as the most important causes of culling in North American dairy herds (Burnside et al. 1971; Allaire et al. 1977; Monardes 1992), although removals due to sales for dairy purposes may also be a primary reason in herds that have an important source of income from marketing of breeding stocks (Westell et al. 1982). The balance between voluntary and involuntary culling has a direct impact on the profitability of the herd (Allaire and Cunningham 1980). Lowering culling for involuntary reasons reduces the replacement of high producing cows, increases the opportunity for voluntary culling (selection) for all age groups and reduces rearing costs (Rogers et al. 1988). Monardes (1992) pointed out that involuntary culling increased in Ouebec dairy herds from 1980 to 1989. The objective of the present study was to describe the trends in reasons for disposal in the Quebec Holstein population from 1981 to 1994, according to different milk recording options, parities and agricultural regions.

Abbreviations: SALES, sales ; LOWP, culling for low production; INVOL, culling for involuntary reasons; MAST, culling for mastitis; UDBR, culling for udder breakdown; F&L, culling for feet and leg problems; REPRO, culling for reproductive problems; SICK, culling or death for sickness; INJUR, culling or death for injury; OLD, culling or death for old age; PATLQ, Programme d'Analyse des Troupeaux Laitiers du Québec; ROP, Record of Performance.

MATERIALS AND METHODS

Lactation records were obtained from the Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ) data files for Holstein cows in Quebec dairy herds calving from November 1979 to March 1995. Editing procedures were carried out to delete repeated records, records with no cumulative milk yield, records with incoherent dates (e.g., calving before birth date) and records in which neither a drying-off date nor an "out-of-herd" date were reported. Approximately 50,000 records were deleted in this first step. For the purposes of this study, a further editing (>240,000 records) was carried out to include only lactations ending from January 1, 1981, to December 31, 1994, as well as to delete partial lactations (lactations still in progress in herds stopping milk recording or at the truncation date, December 31, 1994). After editing, a total of 1,558,080 lactation records were included in the present study, 617,614 from owner sampler herds and 940,466 from official herds. Because data from owner sampler herds are usually not edited as severely as data from official herds, historical files from PATLQ herds include all official herds and only those owner samplers with at least 90% of the cows identified and with consistent records for feeding information. This enhances the reliability of the information, but it surely creates a selected group of owner sampler herds which probably have a better management than the average owner sampler herds. Therefore, it should be noted that comparisons between milk recording options in the present study are biassed due to selection of owner sampler herds.

Every cow leaving a PATLQ herd receives a disposal code that should correspond to the primary reason behind the decision of replacing that cow. No secondary reasons are reported. The list of disposal codes used by PATLQ producers, and the respective explanations are in Table 4.1. Cows that finish a lactation normally receive a code zero. Although every code assigned reflects a personal judgment of the herd manager instead of an objective measure, it is assumed here that the disposal reason recorded for a given cow was
Class	Code	Explanation	%²	Major Category ⁷
Sale Codes	40	Exported	0.11	SALES
817 	41	Sold for dairy purposes	4.82	SALES
	42	Rented to	0.16	SALES
Culling Codes	50	Low milk production	8.78	LOWP
	51	Low fat	0.20	LOWP
	52	Bad temperament	0.29	INVOL
	53	Slow milker	0.35	INVOL
	54	Mastitis and/or high cell count	2.28	MAST/INVOL
	55	Udder breakdown and milking problems	2.78	UDBR/INVOL
	56	Feet and leg problems	1.87	F&L/INVOL
	57	Reproductive problems	6.08	REPRO/INVOL
	58	Sickness	0.74	SICK/INVOL
	59	Injury	0.47	INJUR/INVOL
	60	Old age	0.82	OLD/INVOL
	61	Other	1.08	INVOL
	62	Milk fever	0.14	SICK/INVOL
	63	Displaced abomasum	0.21	SICK/INVOL
Death Codes	70	Sickness	0.45	SICK/INVOL
·	71	Bloat	0.04	SICK/INVOL
	72	Injury	0.15	INJUR/INVOL
	73	Poison	0.06	INVOL
	74	Old age	0.03	OLD/INVOL
	75	Electrocution	0.02	INVOL
	76	Other	0.49	INVOL
	71	Milk fever	0.25	SICK/INVOL
	78	Displaced abomasum	0.08	SICK/INVOL

Table 4.1 - PATLQ disposal codes grouped by major category.

Percentages across years.

³SALES = sales, LOWP = culling for low production; INVOL = culling for involuntary reasons; MAST = culling for mastitis; UDBR = culling for udder breakdown; F&L = culling for feet and leg problems; REPRO = culling for reproductive problems; SICK = culling or death for sickness; INJUR = culling or death for injury; OLD = culling or death for old age.

the primary cause of her removal from the herd. It is important to note that in many situations a cow is culled due to a combination of reasons, and only the last factor that played a role on making the culling decision is reported. For example, a cow with a severe case of clinical mastitis might lose a quarter and end up being culled for low milk production. However, a certain level of uncertainty is always associated with milk recording data, and this should not prevent researchers from analysing the information available and from drawing general conclusions based on the observed trends. Given that some codes have very low incidence in this population, reasons for disposal were grouped into major categories in the present study to enhance interpretation and facilitate statistical analysis. Major categories are defined in Table 4.1.

Agricultural regions in the province of Quebec (Figure 4.1) are areas defined primarily for administrative purposes (Dumas-Rosseau [1977]), but they also differ regarding the climate, the environmental conditions, and the level of management used in dairy farms. Possible differences between regions in reasons for disposal were tested by including the effect of agricultural region in the statistical model used in this study.

A logistic regression model, using the GENMOD procedure of SAS/STAT® (SAS Institute Inc. 1993), was fitted to analyse the effects of milk recording option, parity, agricultural region and year on each of the ten major reasons for disposal specified in Table 4.1. The dependent variable was defined as the ratio between the number of cows discarded for a certain major reason during a given year and the total number of cows ending a lactation any time that same year (number of events / number of trials). The model used was:

$$\log\left(\frac{P_{ijklm}}{1-p_{ijklm}}\right) = \mu_i + OP_j + PA_k + RE_l + YR_m + (OP \times YR)_{im} + (PA \times YR)_{km} + (RE \times YR)_{lm}$$

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where p_{ijkm} is the probability of being disposed for major reason i, during the kth parity, in year m, in region l and in milk recording option j; μ_i is the overall mean log odds-ratio for the ith major reason for disposal; OP_j is the fixed effect of milk recording option j (j=1, for owner sampler herds, and j=2, for official herds); PA_k is the fixed effect of parity k (k=1,...,10); RE₁ is the fixed effect of agricultural region l (l=1,...,12); YR_m is the fixed effect of the mth year in which lactation ended (m=1, for 1981,...,m=14, for 1994); (OP×YR)_{jm} is the option-year interaction effect; (PA×YR)_{km} is the parity-year interaction effect; (RE×YR)_{lm} is the regionyear interaction effect. Linear trends for each disposal reason were assessed by fitting the interactions between year and the other parameters in the model and were tested by means of linear contrasts.

The GENMOD procedure fits a generalized linear model to the data by maximum likelihood estimation of the parameter vector. There is, in general, no closed form solution for the maximum likelihood estimates of the parameters, which are estimated numerically through an iterative fitting process (SAS Institute Inc. 1993). It is possible, however, to calculate appropriate incidence predictors for a given level of a given effect by taking the parameter solutions estimated by maximum likelihood, then estimating marginal means for that level of the effect using a methodology equivalent to the one used to estimate least squares means in linear models, and finally calculating the fitted probability of failure for that level of the effect by using the inverse of the logit link function

$$p = \frac{e^{LSM}}{1 + e^{LSM}}$$

where p is the fitted probability of failure and LSM is the marginal mean estimate.

The Type 3 analysis of the GENMOD procedure was used to test the significance of the effects included in the model (SAS Institute Inc. 1993). This Type 3 analysis is similar to

Type III sums of squares used in the GLM procedure of SAS/STAT® (SAS Institute Inc. 1989), except that likelihood ratios are used instead of sums of squares.

RESULTS AND DISCUSSION

Logistic Regression Analysis

Goodness of fit of each logistic regression model was assessed using the scaled deviance divided by the number of degrees of freedom in the model (Table 4.2). When such a ratio is approximately one, the model is considered to be satisfactory (Collett 1991). The logistic regression model was satisfactory in explaining variation in most of the major reasons for disposal. Some lack of fit was observed for culling for low production (LOWP), sale codes (SALES) and involuntary culling (INVOL), but since the goal here was to describe general phenotypic trends, results are still interpretable. Inclusion of triple interactions did not improve significantly the goodness of fit of the models and it would have made the interpretation of results extremely complicated. Most of the extra variation would probably disappear if the effect of herd was included in the model, but this was not computationally feasible because of the large number of herds with data. Additionally, large portions of the data would have to be to deleted for the analysis of reasons with the lowest incidences in order to have both successes and failures in each herd-year class.

Table 4.3 shows the Type 3 analysis of significance of the effects included in the model. All main effects and interactions significantly affected culling for most of the major reasons. The exceptions were milk recording option for reproductive problems (REPRO), the interaction between option and year for sickness codes (SICK), old age (OLD) and injury

Culling Reason ²	Number of Cows ^y	MM ¹ (%)	Scaled Deviance	df	Ratio"
LOWP	139898	8.52	4566.09	3052	1.4961
REPRO	94789	7.24	3737.52	3052	1.2246
MAST	35595	3.18	3630.66	3052	1.1896
UDBR	43345	3.16	3434.96	3052	1.1255
SICK	29783	2.43	3351.14	3052	1.0980
F&L	29123	2.11	3531.55	3052	1.1571
OLD	- 13316	1.21	3655.84	3052	1.1978
INJUR	9711	0.73	3192.94	3052	1.0462
SALES	79323	2.00	4912.97	3052	1.6098
INVOL	291426	27.71	4136.00	3052	1.3552

Table 4.2 - Total number of cows receiving a major code, predicted incidence for the intercept solution and goodness of fit statistics for the logistic regression models used to analyse major reasons for disposal.

²LOWP = low production; REPRO = reproductive problems; MAST = mastitis; UDBR = udder breakdown; SICK = sickness; F&L = feet and leg problems; OLD = old age; INJUR = injury; SALES = sales; INVOL = involuntary reasons.

^yTotal number of lactation records = 1,558,080.

^{*}MM = marginal mean of the logistic regression solutions for the intercept back-transformed to the linear scale (overall predicted incidence).

"Ratio = (scaled deviance) / (df).

Table 4.3 - Logistic regression statistics (Chi squares) for type 3 analysis of the effects in the model^z.

Source	d.f.	LOWP	REPRO	MAST	UDBR	SICK	F&L	OLD	INJUR	SALES	INVOL
Option	1	114.9***	1.9	212.6***	31.2***	48,5***	44,7***	9,7**	48,9***	16042.4***	4.5*
Parity	9	2743.7***	5572.9***	9785.2***	3836.8***	4966,9***	4136.4***	37631,0***	472.0***	6189,9***	47526.7***
Region	11	1158.2***	314.4***	156.4***	221.9***	374.8***	269.1***	207.5***	201,7***	738.4***	431.8***
Year	13	1736.6***	283.9***	630,9***	158.9***	78,7***	566,3***	104,6***	40.5 **	281.3***	2012.5***
Option*Year	13	256.4***	110.3***	43.9***	25.2*	19.3	30.9**	18,1	17.6	270.3***	105,4***
Parity*Year	117	356.5***	143.7*	147.7*	283.3***	106,8	167.4**	423.2***	127.3	237.6***	208.0***
Region*Year	143	970,8***	335.2***	353.8***	322,0***	324.5***	318.4***	199,0**	205.7**	1443.7***	570,7***

LOWP = culling for low production; REPRO = culling for reproductive problems; MAST = culling for mastitis; UDBR = culling for udder breakdown; SICK = culling or death for sickness; F&L = culling for feet and leg problems; OLD = culling or death for old age; INJUR = culling or death for injury; SALES = sales; INVOL = culling for involuntary reasons.

*Effect significant at P < 0.05. **Effect significant at P < 0.01.

***Effect significant at P < 0.0001.

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codes (INJUR), and the interaction between parity and year for SICK and INJUR.

The aim of the present investigation was to describe annual variation in culling for different reasons associated with milk recording options, parities and Quebec agricultural regions. It was not intended to be a detailed description of factors affecting each type of culling. Therefore, interpretation was focussed on predicted incidences in different classes of effect-year interactions, which are an estimate of the phenotypic culling trends from 1981 to 1994.

Milk Recording Options

Figure 4.2 shows the proportions (marginal means back-transformed into the linear scale) of cows being culled for INVOL, LOWP, and SALES according to milk recording option and year. These are, perhaps, the most important results reported here, because they represent the trends for voluntary (LOWP) and involuntary culling (INVOL), and the ratio between the two greatly affects profitability in the dairy industry (Rogers et al. 1988). Figure 4.2 also shows trends for SALES, which are not considered in any of the two previously mentioned categories of culling. Cows that are sold for dairy purposes (which account for more than 90% of the cases in SALES) include not only the best cows in the herd, which have a high market price, but also those below-herd-average cows that still have a place in other herds with a different level of management, and that would have been replaced for LOWP otherwise. Therefore, SALES was treated as a third category of culling in the present study. Although the option-year interaction and the linear contrasts testing the trends were statistically significant for all three major reasons for disposal, clearly different trends between owner sampler and official herds were observed only for SALES. Official herds are known to have an important source of income from sales of breeding stock, as opposed to owner sampler herds, which depend almost exclusively on milk sales. Not surprisingly, therefore,

CHAPTER 4. PHENOTYPIC TRENDS IN REASONS FOR DISPOSAL

while SALES in owner sampler herds stayed around 1% during the whole period of study, SALES in official herds was around 3% from 1982 to 1987, increasing then up to 7% in 1992, and staying around 5% later. This increase in SALES could be related to the large number of ROP herds that joined PATLQ after 1990, assuming that most of them became enrolled in the official option. The herds on the ROP testing program were thought to be breeder herds where sale of breeding stock was an important source of income (Van Doormaal et al. 1985). As Figure 4.2 shows, trends for INVOL and LOWP were very similar in both milk recording options. Involuntary culling had a clearly ascending trend, going from 23% in 1981 up to 32% in 1994. Since dairymen are limited in the number of cows they can replace by the number of replacement heifers they can raise and by the need to maintain herd production level, this increase in INVOL was accompanied by a decrease in voluntary culling. LOWP went from about 16% in 1981 to 4.5% in 1994. Even though official herds culled 1% to 2% more cows for LOWP than owner sampler herds in most of the years, the trends followed the same pattern in both options. A general conclusion from Figure 4.2 is that Quebec dairy herds in both milk recording options have annually increased the proportion of cows discarded for involuntary reasons, which means that every year producers have had less room for selection or voluntary culling. Such an increase in INVOL certainly implies that Quebec dairy herds have moved apart from their economically optimum scenario, and that profitability has decreased (Rogers et al. 1988). Dekkers (1991), using economic parameters from the Ontario dairy industry, estimated an optimum annual culling rate of 30.1%, of which 50.1% was voluntary and 49.9% involuntary (the amount of voluntary culling was optimized for a given level of involuntary culling). Assuming that these results can be applied in Quebec, it can be concluded that net revenues have been decreasing due to an increase in involuntary disposal. Finally, it is also evident from Figure 4.2 that official herds have been culling more intensively their cows than owner sampler herds due to a greater emphasis on SALES, especially after 1988.

CHAPTER 4. PHENOTYPIC TRENDS IN REASONS FOR DISPOSAL

Culling rates (marginal means transformed to the linear scale) for each major involuntary reason by milk recording option are shown in Figure 4.3. Regarding differences between the two options, it can be observed that owner sampler herds have indicated to have culled more cows for mastitis (MAST), but, in general, trends were very similar for the two milk recording options. The primary question to be answered here is which major reasons have caused the overall trend for INVOL to go up. The answer is REPRO, MAST, feet and leg problems (F&L) and, to some extent, sickness (SICK). Reproductive failure is the most important reason for involuntary culling in Quebec and this increasing trend should be a warning message for producers to pay more attention to heat detection and other techniques that can improve the reproductive performance of their herds. Despite all efforts to improve the health of the mammary gland of dairy cows in North America, mastitis remains as the most costly disease affecting dairy cattle (Miller and Dorn 1990). Trends for MAST in Figure 4.3 show that Quebec producers have to re-evaluate their milking procedures and sanitary programs as soon as possible in order to reverse this situation. F&L were below 2% from 1981 to 1986, increasing in 1987 and staying around 3% after that. SICK were around 2% from 1981 to 1989, increasing up to 5% in 1990, decreasing during the 1991-1991 period and increasing again later. Other involuntary reasons did not present clear trends during the period of study.

Parities

Culling trends for LOWP, INVOL and SALES for different parities are shown in Figure 4.4. Since trends after the fifth parity were very similar, only the ones for the first 6 parities are shown for LOWP and SALES. Trends up to the tenth parity are presented for INVOL. The proportion of cows being culled for LOWP in first parity has been consistently higher than in later parities, but all parities had a descending trend during the period of study. This decrease in voluntary culling had been already revealed by the trends for milk recording options, but it is interesting to note that LOWP decreased even in first parity, usually the period in which the most drastic selection for production occurs. The proportion of cows with sale codes was also higher in first parity and gradually decreased in importance as parity number increased. Trends were ascending for SALES, especially in the first three parities. Trends for INVOL in all lactations were ascending. The proportion of involuntary culling increased with lactation number, being more than 50% in the tenth parity. This confirms that the risk of being culled for INVOL (diseases and other problems) increases with age.

Figure 4.5 shows culling rates for some of the major involuntary reasons by parity number. Only parities 1 through 6 are shown because parities after the fifth had similar values. For all major involuntary reasons, culling rate increased with parity number, in agreement with trends for INVOL. Trends were ascending for REPRO and F&L, and for MAST in second and later parities. After 1987, trends were descending for udder breakdown (UDBR). OLD and INJUR are not shown in Figure 4.5, but culling for OLD increased with parity number, and no differences in culling for INJUR were observed between parities.

Agricultural Regions

All agricultural regions had similar trends for the different major reasons for disposal over the period of study. Graphic representations of the trends did not reveal any clear difference between regions and, therefore, were not included in this discussion. Table 4.4 shows the least squares means for the proportions of cows culled for the different major reasons from 1981 to 1994. Although variation between regions was statistically significant, the values were of the same magnitude throughout all regions and trends followed closely the general trends shown in Figures 4.2 and 4.3 for owner sampler and official herds.

	Proportion of cows culled ⁷ (%)									
Region	LOWP	REPRO	MAST	UDBR	SICK	F&L	OLD	INJUR	SALES	INVOL
T	10.3	7.1	2.8	3.4	2.2	2.0	1.2	0.7	2.2	27.3
2	8.8	7.0	3.0	3.2	2.0	1.9	1.3	0.7	2.1	26.2
3	9.7	6.5	3.2	3.5	2.2	2.3	1.2	0.7	2.1	26.9
4	8.8	7.9	3.1	3.4	2.6	2.2	1.1	0.6	2.2	27.8
5	9.0	7.0	3.4	3.3	2.2	2.3	1.5	0.7	2.4	28.2
6	8.6	7.6	3.1	3.0	2.7	2.6	1.3	0.7	2.4	28.9
7	8.6	7.6	3.2	2.8	2.9	2.6	1.2	0.8	1.9	28.9
8	9.0	7.3	3.2	2.9	2.3	2.0	1.0	1.0	1.4	26.9
9	7.2	6.8	3.6	2.6	2.6	1.9	0.8	1.0	1.9	26.8
10	7.5	7.4	3.3	3.5	2.1	2.1	1.5	0.6	2.1	29.1
11	8.1	7.3	- 2.7-	3.0	2.6	2.0	1.3	0.8	1.5	27.0
12	7.2	7.5	3.7	3.4	2.9	1.7	1.4	0.6	2.6	28.6

Table 4.4 - Proportion of cows culled for each major reason in different Quebec agricultural regions^z.

^{*}LOWP = culling for low production; REPRO = culling for reproductive problems; MAST = culling for mastitis; UDBR = culling for udder breakdown; SICK = culling or death for sickness; F&L = culling for feet and leg problems; OLD = culling or death for old age; INJUR = culling or death for injury; SALES = sales; INVOL = culling for involuntary reasons.

⁷Marginal means of the logistic regression solutions back-transformed to the linear scale.

CONCLUSIONS

Results from the present investigation are a valuable description of culling trends in Quebec Holstein herds, and they could be used by the dairy industry to re-evaluate current management strategies. This study shows a decrease in culling for low production (voluntary culling) and an increase in some of the major involuntary reasons for disposal in Quebec Holsteins from 1981 to 1994, namely reproductive problems, mastitis and feet and leg problems. These results indicate that improvements in management and breeding practices are needed to counterbalance the observed trends, as an effort to decrease involuntary culling and to allow for more intensive selection within dairy herds. Another important result shows that differences in overall culling between official and owner sampler herds are mostly due to sales, not due to voluntary or involuntary reasons. Dairy producers have been culling more intensively for low production in first than in later parities, but a decrease in voluntary culling was observed for all parities. Culling rate increased with parity number for all major involuntary reasons, as opposed to SALES, in which proportion of cows culled decreased with parity number.

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Figure 4.1 - Map of Quebec agricultural regions.



Figure 4.2 - Culling trends for involuntary culling, low production and sales by milk recording option (solid lines = owner sampler herds; dashed lines = official herds; \blacktriangle = culling for involuntary reasons; \blacksquare = culling for low production; \blacklozenge = sales).





Figure 4.3 - Culling trends for each major reason by milk recording option (\blacksquare = owner sampler herds; \blacktriangle = official herds; REPRO = reproductive problems; MAST = mastitis; UDBR = udder breakdown; SICK = sickness codes; F&L = feet and leg problems; OLD = old age; INJUR = injury).



Figure 4.4 - Culling trends for low production, involuntary culling and sales by parity (LOWP = low production; INVOL = involuntary culling; SALES = sales). Curves for parities greater than 6 are shown only for INVOL.



Figure 4.5 - Culling trends for each major involuntary reason by parity (REPRO = reproductive problems; MAST = mastitis; UDBR = udder breakdown; SICK = sickness; F&L = feet and leg problems).

CHAPTER 5

Genetic Analysis of Herd Life in Quebec Holsteins Using Weibull Models

This chapter describes the genetic study of herd life in Quebec Holstein herds utilizing Weibull regression models. Models and methodology were similar to those used by Ducrocq (1994) for the French Normand population. Some of the results, such as the estimates of the mean survival time and of the effect of year, are used to complement trends described in Chapter 3. Studies in the following two chapters will be based on modifications of the models from the present chapter, one including type traits to assess the impact of type on the culling decision (Chapter 6) and the other using competing risks analyses to study reasons for disposal (Chapter 7).

The objectives of this study were: a) to apply the "state-of-the-art" methodologies to analyze survival time in Quebec data; b) to produce genetic evaluations for Holstein bulls following the recent apprach by Ducrocq and Casella (1996); c) to compare sire solutions obtained from the survival analysis with Canadian official genetic evaluations for herd life and other traits.

MATERIALS

Lifetime Records Layout

Lactation records extracted from PATLQ files were utilized to create lifetime records for Holstein cows in Quebec dairy herds. Before discussing editing procedures, a general description of the lifetime records layout seems appropriate because of the particularities associated to the use of censoring and time-dependent covariates in survival analysis. As opposed to test-day records or lactation records, in which all records have exactly the same number of variables or fields, lifetime records with time-dependent covariates have a variable length, depending on the number of changes associated with each of these covariates. The "SURVIVAL KIT" (Ducrocq and Sölkner, 1994), which was the statistical package used here, requires that each change in a time-dependent covariate be described by a triplet (three elements), in which the first element refers to the relative position of the variable changing, the second element indicates when the change occurred, expressed as the time from origin (first calving) in the same unit of time used for the survival variable, and the third element indicates the new value of the time-dependent covariate. Table 5.1 shows examples of short lactation records of three cows from the same herd, and Table 5.2 shows the corresponding lifetime records for the same cows. Cow 501 had three parities and was culled due to mastitis at the end of her third lactation; cow 502 was a contemporary of cow 501 that was culled due to low milk production after 120 days in milk in first lactation; and cow 599 had at least 2 parities and was lactating normally when data collection stopped or when data was analyzed. In this example, cow, herd and sire are examples of time-independent covariates which will not change value over time, herd life is the dependent variable, censoring flag tells whether the record is complete or incomplete, and year and parity are examples of time-dependent covariates which may or may not have triplets associated with. If a time-independent and a time-dependent covariates are combined before being included in the model (e.g., herd-year



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effect), the resultant variable would also be a time-dependent covariate. In summary, the general layout of lifetime records (Table 5.2) consists of a first part with a fixed number of fields (dependent variable, time-independent covariates and initial values of time-dependent covariates), an indicator variable containing the number of changes or triplets, and a variable number of triplets per cow.

Table 5.3 shows the final layout of lifetime records used in the genetic study of herd life. Details on how each variable was treated will be given in the model specification section.

Cow	Herd	Sire	Calving		Parity		Cul	ling		
			Day	Month	Year		Codeª	Day	Month	Year
501	1	101	1	1	1982	1	0	0	0	0
501	I	101	4	2	1983	2	0	0	0	0
501	1	101	11	3	1984	3	54	15	9	1984
502	1	199	1	2	1982	I	50	1	6	1982
599	1	111	1	1	1994	1	0	0	0	0
599	1	111	4	2	1995	2	97	31	3	1995 ⁶

Tat	ole	5.1	_	Example	les of	lactat	ion	record	ls.
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^aCulling codes: 0 = lactation ended normally; 50 = culled due to low production; 54 = culled due to mastitis; 97 = lactation in progress.

^bDate in which data collection stopped.

Cow	Herd	Herd Sire Herd Flag ^b Year Parity		Sire	Herd Flag ^b Year Parity #	#		Triplets	ie 	
			Life*				Changes	Field	DPL	New Value
501	1	101	988	0	1982	1	4	6	365	1983
								6	730	1984
								7	400	2
								7	800	3
502	1	199	120	0	1982	1	0			
599	1	111	455	1	1994	1	2	6	365	1995
						-		7	400	2

Table 5.2 - Lifetime records corresponding to the lactation records in Table 1.

^{*}Herd life is expressed here as number of days from first calving to disposal or censoring. ^bFlag for right censoring: 0 = not censored; 1 = censored.

"Each triplet refers to a single change in a time-dependent covariate: 'field' indicates which variable is changing (e.g., 6 = year; 7 = parity); 'DPL' indicates days of productive life at the time of change; 'new value' indicate the covariate level associated to the cow after the change.

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Variable	Description *	Number of Classes
Cow	Record ID	331147
Censoring Flag	Indicator Variable	2
Stage of Lactation vs. Lactation Number	TDC	(4)(4)=16
Sire of Cow	TIC-Random	1664
Milk Recording Option	TIC	2
Age at First Calving	TIC	19
305-Day Yield Deviated from Herd-Year-Parity Average	TDC	5
Year	TDC	14
Herd-Year	TDC-Random	28629
Annual Change in Herd Size	TDC	7
Disposal Code	Censoring Criteria ^b	30
Length of Productive Life	Dependent Variable	Continuous (days)
Number of Changes in TDC	Indicator Variable	-
Triplets:		
First Element	Relative Position of TDC	-
Second Element	DPL at Change	-
Third Element	New Value of TDC	

 Table 5.3 - Final layout of lifetime records used in survival analysis.

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2 ÷ŀ ł productive life.

^bCulling codes were used to define if a given record should be considered as censored or uncensored.

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Data Edition

Table 5.4 shows a detailed description of the various edits performed on the original 2,157,180 lactation records in order to obtain the final 331,147 lifetime records used in the survival analysis. Although Table 5.4 seems to be quite clear, some edits deserve comment. Records from the Canadian Record of Performance (ROP) testing program were edited out because one of the interests of the present investigation was to compare different milk recording options (official vs. owner sampler herds) and the ROP herds would have to be considered as a third category of testing. Since only a reduced number of records were from -ROP herds and the program was discontinued in 1990, it was decided not to include the records. To be included in the study, herds were required to have at least 5 years of data, and because annual changes in herd size were included as an effect in the survival models, records from the first year of the herd in milk recording were not included (herd size was unknown prior to that). Another reason to disregard the first year of the herd in milk recording was given by Nieuwhof et al. (1989) who argued that producers tend to cull more intensively soon after they start receiving the information from the DHI center (more accurate selection tools). Records from herds that discontinued milk recording for a period and then re-joined the program were also deleted because the reliability of the lifetime records would be compromised. Years were considered to begin in March 1 instead of January 1 to avoid starting the year in the middle of the winter. For instance, year '1986' includes records realized from March 1 1986 to February 28 1987. Since the original lactation records were created from test-day records collected from January 1980 to March 1995, all cows having calved for the first time prior to March 1st 1981 were deleted because, as explained before, only the second year with data of each herd was to be included. Cows with calving date after March 1995 were deleted.

Editing Criteria	Records Deleted	Records
		Remaining
Initial number of lactation records*	-	2157180
Records from herds outside Quebec	208443	1948737
Records from breeds other than Holstein	268885	1679852
Records from ROP ^b herds	10338	1669514
Cows without registration or ID number	168367	1501147
Records from herds with <5 years of data	74723	1426424
Records from herds with irregular data collection	18719	1407705
First calving prior to 1981 and after 1994	24599	1383106
Records from herd's first year in milk recording	174807	1208299
Parity number = 0	449	1207850
Lactations longer than 305 days without 305-day production	138	1207712
Lifetime records obtained after editing lactation records	-	374682
Cows with unknown sire	3799	370883
Daughters of sires with <30 offspring	22607	348276
Cows from herd-year with <5 cows	9401	338875
Cows with wrong termination code	403	338472
Age at first calving <17 months or >40 months	2772	335700
Cows with more than 1 lifetime record ^e	2967	332733
Further edition for sires with <30 offspring or in <5 herds	1586	331147

Table 5.4 - Number of records edited out to create the data used in the survival analysis.

These records had been previously edited to delete records with no cumulative yields, cows calving before birth, cows discarded before calving, and cows with unknown birth dates.

^bRecord of performance national testing program.

^cCows could have more than one lifetime record if: several cows had the same identification number: same cow had two different calving dates for first parity; heifers reported as sold for dairy remained in the same herd; and cows reported as culled remained in the same herd.

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METHODS

Weibull Models

Two herd life traits were defined: true herd life, or the ability to delay culling regardless the reason for disposal, and functional herd life, or the ability to delay involuntary culling. Since culling for low production is the most important type of voluntary disposal, it has been proposed that functional herd life can be approximated by correcting true herd life for phenotypic production (Ducrocq et al., 1988a). Since lifetime records utilized in this study were derived from typical milk recording data (no information prior to first calving), the measure of herd life utilized (failure time variable) was length of productive life or the time in days from first calving to culling or censoring. The proportional hazards model used to analyze true herd life was:

$$\lambda(t) = \lambda_0(t) \exp\{y_i(t) + p_i(\tau) + z_k(t) + o_l + a_m + h_n(t) + s_n\}$$

where $\lambda(t)$ is the hazard function at time t; $\lambda_0(t) = \lambda \rho (\lambda t)^{\rho_1}$ is a Weibull baseline hazard function with scale parameter λ and shape parameter ρ ; $y_i(t^2)$ is the effect of year i (i = 1981,...,1994), assumed to be piecewise constant with jumps arbitrarily chosen to occur at t^2 March 1 of each year; $p_j(\tau)$ is the effect of lactation number and stage of lactation combined into j = 16 classes (lactations 1, 2, 3 and $\geq 4 \times$ four stages), assumed to be piecewise constant with changes occurring at $\tau = 0$, 120, 240, and 305 days of each lactation; $z_k(t^2)$ is the effect of annual change in herd size k (k = 1, for a decrease in herd size of >25%; k = 2, for a decrease in herd size of 15 to 25%; k = 3, for a decrease in herd size of 5 to 15%; k = 4, for herd with no appreciable change (-5 to +5%), k = 5, for an increase in herd size of 5 to 15%; k = 6, for an increase in herd size of 15 to 25%; and k = 7, for an increase in herd size of >25%), which is assumed to be a time-dependent covariate, piecewise constant, and jumps happening at t^2 March 1 of each year; o_1 is the effect of the 1 milk recording option (l = 1, for owner-sampler herds; l = 2, for official herds); a_m is the effect of the m age at first calving (m = 1, for ≤ 22 months;...; m = 19, for 40 months); $h_n(t')$ is the random effect of the herd-year n (n = 1,...,28629), assumed to be piecewise constant with changes at t' = March 1 of each year; and s_q is the random effect of sire q (q = 1,...,1664). The thresholds defining the different stages of lactation were chosen because they represent important references for Canadian dairy farmers: after 120 days in milk, cows receive a Breed-Class-Average (BCA) estimate, which is a phenotypic index for production used to compare cows across herds; at 240 days in milk cows in official herds receive an official production certificate, and only cows that reach 240 days are included in the calculation of the official herd production average; and 305 days in milk has been used as the reference lactation length to compare cows in genetic evaluations for production traits.

The Weibull model used to analyze functional herd life was:

$$\lambda(t) = \lambda_0(t) \exp\{y_i(t) + p_j(\tau) + z_k(t) + o_l + a_m + w_r(\zeta) + h_n(t) + s_q\}$$

where the only difference from the model for true herd life is the inclusion of the term $w_r(\zeta)$, which is the effect of the rth within herd-year-parity class of milk production at 305 days of lactation. First, 305-day yields were obtained for milk, fat and protein: for cows whose lactation exceeded 305 days, the actual 305-day yields were used; for cows ending a lactation normally prior to 305 days in milk, the cumulative production was used; for cows still in milk when data collection stopped and for cows being culled, sold or dying prior to 305 days of lactation, 305-day yields were projected based on the official Canadian projection factors for the Holstein breed. Once obtained the 305-day yields for all cows, 305-day milk yields were standardized using the following formulae:

Standardized Yield=305M×[0.25+(0.125×305F)+(0.07576×305P)]

where 305M, 305F and 305P are the 305-day milk, fat and protein yields, respectively. This standardization is similar to the equation used by the PATLQ nutritional program, and it assures that cows' production levels would be contrasted in a comparable composition (4% fat and 3.3% protein). Five classes of within herd-year-parity (first or later lactations) were created: r = 1, for cows producing more than 1.5 standard deviations below the herd-year-parity average; r = 2, for cows producing between 1.5 and 0.5 standard deviations below the herd-year-parity average; r = 3, for cows producing between 0.5 standard deviation below and 0.5 above the herd-year-parity average; r = 4, for cows producing more than 1.5 standard deviations below the herd-year-parity average; and r = 5, for cows producing more than 1.5 standard deviations above the herd-year-parity average; and r = 5, for cows producing more than 1.5 standard deviations above the herd-year-parity average; and r = 5, for cows producing more than 1.5 standard deviations above the herd-year-parity average. Finally, $w_r(\zeta)$ is also a time-dependent covariate considered to be piecewise constant and changing value at $\zeta =$ beginning of a new lactation. Treating yield deviation as a time-dependent covariate accounts for changes in the within-herd rank for production during each cow's lifetime, whereas most studies using linear models compare cows based only on their first lactation yields.

Estimation

The "SURVIVAL KIT", a set of FORTRAN programs written by Ducrocq and Sölkner (1994), was used to run the Weibull models previously described. Details on the method of estimation are given in Ducrocq (1994), and the theoretical aspects are presented in Ducrocq and Casella (1996). Shortly, an empirical Bayesian approach was used to estimate fixed effects and dispersion parameters. A log-gamma prior density function was assumed for the herd-year random effect and a multivariate normal distribution with covariates between levels being introduced by genetic relationships was assumed for the random effect of sire. The pedigree file included only information on male parents (sires) and included a total of 1875 animals (1664 with data). The sire variance σ_a^2 was estimated as the mode of its marginal posterior density, which was approximated by Laplacian integration. The gamma parameter γ_h was estimated jointly with the other effects after exact algebraic integration of the log-gamma random effect of herd-year. The choice of using a sire model was mainly due to computing limitations, but the "SURVIVAL KIT" can handle animal models as well.

The importance of the covariates included in the models was tested using a likelihood ratio test for large samples, in which twice the change in the log-likelihood induced by the inclusion of a new effect is compared with a chi-squared distribution with ν degrees of freedom, where ν is the number of added estimable effects. Two types of likelihood ratio tests were performed, one testing the effects in sequential order, as they were included in the model (similar to the Type I sum of squares in linear models) and another comparing the full model with models excluding one effect at a time (similar to the Type III sum of squares in linear models).

Censoring

Censoring was based on the reported disposal codes for each cow. A lifetime record was considered to be completed (uncensored) if the cow received a termination code indicating that she was either culled or died due to any given reason. Censored records, therefore, represented: cows being sold, exported or rented to another herd (sale codes); cows from herds discontinuing data collection (stopping milk recording); and cows still alive in March 31 1995, when the data set was created. Although Ducrocq (1987) indicated that codes for condition affecting records in his data set were inaccurate and should not be used as censoring criteria, this is not the case for the test-day records provided by PATLQ. One could argue about the specific reason stated by the producer as being the major cause for culling a given cow, but the fact that she left the herd at that particular point in time is certain in most cases. PATLQ has traditionally emphasized the use of milk recording data for management purposes, which stimulates producers and field supervisors to keep "good"



records. Problem records (cows showing up in test after being culled) were only a small number and were edited out.

RESULTS AND DISCUSSION

From the 331,147 lifetime records, 42.9% (142149) were right censored, mostly because cows were still alive when data were created. The maximum observed failure time was 4808 days after first calving, and the average failure time was 788 days after first calving. The average censoring time was 683 days, and the maximum censoring time was 4969 days after first calving. Table 5.5 shows the likelihood ratio tests for the fixed effects included in the models for both true and functional herd life. All tests were significant at P=0.001, even for age at first calving, which did not significantly affect length of productive life of cows from the Normand breed (Ducrocq, 1994). Table 5.5 that age at first calving does have an effect on herd life of Quebec Holsteins. The fact that in the present study a larger number of classes for this effect were defined (19, compared with 7 in Ducrocq, 1994) might have helped to detect significant differences.

In the "SURVIVAL KIT", estimates are obtained for the shape parameter ρ and for the expression $\rho \log \lambda$, which can be viewed as the intercept term in the parametric part of the Weibull hazard function:

$$\lambda(t) = \rho t^{\rho-1} \exp\{\rho \log \lambda + w'_m \theta\}$$

The scale parameter λ is non-estimable and was arbitrarily set to 1. For true herd life, $\rho = 1.62$ and the intercept was -10.24. After the correction for yield, $\rho = 1.76$ and the intercept became -11.18. Although not presented here, the various covariates were fitted sequentially in separate models, and the effect of lactation number \times stage of lactation had the greatest impact on ρ , as in Ducrocq (1994).

		Model for True Ho	erd Life	Model for Functional Herd Life		
Effect	DF	-2 Change in Log- likelihood ^a	Prob ^b	-2 Change in Log-likelihood	Prob	
Year	13	629.6	0.0000	537.8	0.0000	
Lactation Number × Stage	15	19580.9	0.0000	26972.7	0.0000	
Annual Change in Herd Size	6	40.7	0.0000	31.4	0.0000	
Age at First Calving	18	313.2	0.0000	963.4	0.0000	
Milk Recording Option	1	42.1	0.0000	205.2	0.0000	
305-Day Yield Deviation	4	-	-	48361.4	0.0000	

 Table 5.5 - Results from the likelihood ratio tests comparing the full model with models

 excluding one effect at a time.

^aLogarithm of the marginal posterior odds ratio at the posterior mode.

^bProb = probability of being greater than the corresponding Chi-squared value for P=0.001.

Estimates for the Fixed Effects

The impact of the different fixed effects on the hazard function will be presented graphically. Since the solutions for the fixed effects from the two models were similar, only the estimates from the model for functional herd life will be presented, unless specified otherwise. In order to compare different classes of a given effect, it is convenient to consider a situation in which all other effects are contrasted with an "average" or reference level. In this study, the reference classes were: 1987, for the year effect; 0 to 120 days in first lactation, for the lactation number \times stage of lactation effect; no change in herd size, for the annual change in herd size effect; official herds, for the milk recording option effect; and average herd-year-parity standardized production level at 305 days in milk, for the 305-day yield

deviation effect.

The effect of lactation number × stage of lactation is illustrated in Figure 5.1, which shows the hazard rate of an average cow in an average official herd throughout her first four lactations, considering that she had calving intervals of 400 days. The most evident deduction from Figure 5.1 is that the hazard rate in first lactation follows a different pattern than in later lactations, especially in the first 240 days in milk. The hazard rate for first-calf heifers increases sharply during the first 120 days, continues increasing at a slower rate up to 240 days, then decreases markedly and stays low until the conventional end of the lactation at 305 days, and finally increases again during the dry period. Most cows are dried off later than 305 days when calving interval is 400 days, but we will refer to the last stage as 'dry period' herein to facilitate discussion. In later lactations, hazard rate is low at the beginning of the lactation (0 to 120 days), increases in the second stage (121 to 240 days), decreases in the last part of the lactation to raise again in the dry period. The same shape of alternating low and high hazard rate is observed for lactations 2, 3 and 4, the only difference being the scale, since the hazard rate also increases with age. The behavior of the hazard rate was different than that reported by Ducrocq (1994), who found that hazard increased almost linearly during the lactation, regardless of the lactation number. These results confirm what was observed in the study of phenotypic trends in herd life (Chapter 3): cows that survive up to 240 days in milk would probably be kept until the end of the lactation, even if the producer has already decided to cull her. A logical explanation for this is the current practice of calculating the official herd production averages only with data from cows reaching the 240-days threshold. Producers would always be tempted to get rid of the low producing cows just in time to make the herd average look better. The sharp increase in the hazard observed in the beginning of first lactation seems to be related to the fact that most cases of voluntary culling (based on low production) tend to occur early in first lactation. Another possible explanation for that relates to the publication of BCAs for cows with more than 120 days in lactation. Especially for

those producers interested in selling breeding stock, the first BCA of a cow will most likely determine her market value. All possible explanations presented here are related to culling for low production. Considering that the results shown in Figure 5.1 come from the model for functional herd life, it seems that the adjustment for 305-day yield is not accounting properly for culling on low production. This topic will be discussed in more detail in the competing risks study (Chapter 7).

A more intuitive way of interpreting the solutions from Weibull models is by looking at the exponential of the estimates, which may be viewed as relative culling rates. For instance, if the relative culling rate for a given class of fixed effect is 2, it means that cows in that class have twice as many chances of being culled than cows in the reference class of the same effect. Relative culling rates for the year effect are shown in Figure 5.2. The reference year was arbitrarily chosen to be 1987, simply because it is situated approximately in the middle of the time period analyzed. A truncation effect caused by the manner in which data was created (lifetime records starting in 1981 or later), forced the hazard rate to be artificially low in 1981. For this reason, only estimates for 1982 and later are shown in Figure 5.2. Two periods of higher relative culling rates are clearly observed. The first one, which peaks in 1985 with a relative culling rate 12% higher than the reference year, had been observed in the previous study on phenotypic trends in herd life (Chapter 3), and seems to be related to a cut in production quotas which would have encouraged Canadian producers to cull more intensively especially their heifers. The second period in which relative culling rate was significantly higher than the reference year included the years 1991 and 1992. One fact that might explain such increase in culling rates is the termination of the Canadian ROP testing program in 1990 and subsequent incorporation of a large number of those herds by the PATLQ. The entry of a significant number of new herds (with different culling policies) in the data could cause changes in the hazard rates.

Figure 5.3 displays relative culling rates for the different ages at first calving. A linear increase of relative culling risk is observed as age at first calving increases. The older the heifer calves, the higher the risk of being culled. As mentioned previously, Ducrocq (1994) found that age at calving had no influence on length of productive life, which is obviously not the case for Quebec Holsteins. Often first-calf heifers calving later than 34 months are excluded from the data used in animal breeding studies under the suspicion of being in fact second-calf cows with a missing record (first parity). In this data set, however, this criteria was not adopted. Instead, checks were made on the distribution of ages per each lactation and on the existence of repeated lactation numbers or of more than one calving date per lactation. Therefore, cows included in the final data set are believed to have an accurate record of age at first calving. The number of "late calvings" that were actually cases of abortion was not checked, and might be of interest in future studies on reproductive performance. Nevertheless, the trend is clearly ascending not only for cows calving later than 34 months of age, but for the whole range of ages studied.

The relative culling risk associated with cows in owner sampler herds was about 9% lower than for cows in official herds. Although this difference is statistically significant, it is numerically very small and does not provide any conclusive evidence that cows in the two different milk recording options of PATLQ are subjected to distinct hazard rates. In other words, milk recording option does not have a great influence on the culling intensity practiced in Quebec dairy herds. In an attempt to check whether cows in owner sampler and official herds followed different baseline functions, a Weibull model was fitted treating milk recording options as two different strata, but both strata had very similar Weibull parameters (ρ and the intercept).

A surprising result came from the estimates for the effect of annual change in herd size. Intuitively, one would expect that the culling rates be higher than average in herds decreasing in size and lower than average in herds increasing in size. Figure 5.4 shows a different scenario. Cows from herds in both extremes (accretion or reduction in herd size of more than 25% from one year to another) were at a higher risk of being culled than cows in herds with a stable number of cows. The relative culling rate was approximately 1.11 in "shrinking" herds (class 1) and 1.06 in "expanding" herds (class 7). These values were significantly different from the stable herds (class 4), but, in practice, changes in herd size had a small impact on the hazard rate. These results disagree with Ducrocq (1994), who found that changes in herd size had a big effect on culling rates in the Normand breed. One reason for these differences may be the way changes in herd size were accounted for in the two different studies. While in the French study changes in herd size were combined with season into one effect, here changes in herd size were fitted across the different years. Another interpretation for such a small impact of variation in herd size on culling rates could be that culling rates are already very high in Quebec herds, leaving little room for producers to adjust herd size by changing culling intensity.

Finally, Figure 5.5 shows relative culling rates for the 305-day yield deviation effect, and the estimates are as expected: cows producing below 1.5 standard deviations than the herd-year-parity average have a 4.9-fold higher risk of being culled than average producers. The difference in relative culling risk is still high (1.8-fold) for cows producing 0.5 to 1.5 standard deviations less than the average group. Although it is not evident from Figure 5.5 (due to problems of scale), cows producing above the herd-year-parity average did have a significantly lower relative culling risk (26% for class 4 and 29% for class 5) than cows in the average class (class 3). Production level and lactation number \times stage of lactation were the most important factors affecting culling rates in Quebec herds.

Random Effects

The main interest of the present chapter is to discuss the possibilities of improvement on the genetic evaluations for herd life currently published for Canadian bulls through the use of Weibull models. The first aspect to compare is the degree of heritability or how much genetic gain can be expected from selection. As a rule of thumb, the better the model used to estimate genetic parameters, the higher should be the heritability estimates. Heritability estimates for milk yield, for example, were around 0.25 when sire linear models were still used for official genetic evaluations in North America, then changed to 0.30 to 0.35 with the implementation of animal models, and now are expected to raise again (above 0.40?), because of the imminent adoption of test-day models in most of the developed countries (Jamrozik et al., 1997). These changes in heritability occurred because the models have improved their ability to account for environmental effects and, consequently, to isolate the additive variance associated with the trait of interest. Therefore, if survival analysis really provides a better description of the failure times of dairy cows than the popular linear models, one should expect to get higher heritability estimates for the herd life traits by using survival models. Table 5.6 shows the sire variance σ^2 , and the gamma parameter for the herd-year effect γ_h estimated for true and functional herd life.

Model	0 ² ,	Y
True Herd Life	0.04023	15.3685
Functional Herd Life	0.03321	11.4707

Table 5.6 - Estimates of the sire variance and the gamma parameter for the herd-year effect^{*}.

*Assymptotic standard errors were not available when random effects of both sire and herd-year were included.

Using the parameter estimates from Table 5.6, heritability in the logarithmic scale was calculated according to Ducrocq and Casella (1997):

$$h_{\log}^2 = \frac{4 \sigma_s^2}{\sigma_s^2 + \psi^{(1)}(\gamma_h) + \frac{\pi^2}{6}}$$

where $\psi^{(1)}(\gamma)$ is the trigamma function evaluated at γ_h , and $\pi^2/6$ is the variance of an extreme value distribution. Therefore, for true herd life,

$$h_{\log}^2 = \frac{(4 \times 0.04023)}{(0.04023 + 0.06723 + 1.64493)} = 0.09183$$

and for functional herd life

$$h_{\log}^2 = \frac{(4 \times 0.03321)}{(0.03321 + 0.09109 + 1.64493)} = 0.07508$$

These values are within the range of estimates found in the literature for studies using length of productive life as the herd life trait. Hence, heritability in the logarithmic scale is not significantly higher than estimates already published and is quite difficult to interpret. However, heritability in the original scale can be approximated using a Taylor series expansion of h_{log}^2 around its mean (Ducrocq, 1997- personal communication):

$$h^{2} = \frac{4 \sigma_{s}^{2}}{\left(e^{\left(\frac{1}{\rho}\right)v}\right)^{2} \times \left(\sigma_{s}^{2} + \psi^{(1)}(\gamma_{h}) + \frac{\pi^{2}}{6}\right)}$$
$$= \frac{h_{\log}^{2}}{\left(e^{\left(\frac{1}{\rho}\right)v}\right)^{2}}$$

where $v = \psi(\gamma) - \log(\gamma)$ - Euler's constant, and $\psi(\gamma)$ is the digamma function evaluated at γ . Thus, for true herd life we have:
CHAPTER 5. GENETIC ANALYSIS OF HERD LIFE

$$h^{2} = \frac{0.09183}{\left(e^{\left(\frac{1}{1.62189}\right)-0.61009}\right)^{2}} = 0.19485$$

and for functional herd life:

$$h^{2} = \frac{0.07508}{\left(e^{\left(\frac{1}{1.75780}\right)-0.62142}\right)^{2}} = 0.15227$$

These values are much higher than estimates obtained with different methodologies and they reinforce the idea of moving from linear models towards survival (Weibull) models to analyze herd life traits in dairy cattle. For instance, Canadian official genetic evaluations for herd life assume an heritability of 0.03 for functional survival in the first three lactations (Jairath and Dekkers, 1994). Estimating genetic parameters with Weibull models would certainly improve the expected genetic progress if selection to increase herd life was one of the breeding objectives.

When survival analysis is used, sire estimated transmitting abilities (ETA) for herd life may be expressed in several ways: genetic standard deviations; relative culling rates; percentage of daughters still alive at the end of lactations 1, 2 or 3; days of productive herd life at which specific values of the survivor curve are reached for an 'average' daughter (e.g., the median survival time is observed when S(t) = 0.50); etc. In the present study, sire ETA for herd life are expressed as relative culling rates, so that if a bull has an ETA of 1.3, his daughters have, on average, 30% higher risk of being culled than the daughters of an average bull (ETA=1.0). Sire relative culling risk for true (ETA_{true}) and functional (ETA_{func}) herd life ranged from 0.51 to 1.41 and from 0.52 to 1.35, respectively. A plot of ETA_{func} for the 1875 sires included in the pedigree file sorted in ascending order is shown in Figure 5.6. To

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illustrate genetic differences between sires, Figure 5.7 shows the expected survivor curve of an average daughter in an average herd for three bulls, **A**, **B** and **C**, which have relative culling rates of 0.6, 1.0 and 1.3, respectively. The chosen bulls have approximately the same number of uncensored records (215, 300 and 215), which implies similar reliability, and they have entered the progeny testing program at approximately the same time (year of birth: 1981, 1979 and 1979). It is clear, from Figure 5.7, that the herd life expectation is significantly different for daughters of the different sires. For example, while 85% of the daughters of sire **A** are expected to be alive at the beginning of second lactation (400 days), the same expectation for daughters of sires **B** and **C** is 77% and 71%, respectively. If the comparison is made at the beginning of third lactation (800 days), the survival expectation is 74% for daughters of sire **A**, 60% for daughters of sire **B** and 52% for daughters of sire **C**. These differences in survival can also be expressed in terms of time at which specific values of the survivor curve are reached for each bull (Table 5.7). For instance, while the median survival time for daughters of bull **C** occurs at 860 days after first calving, for daughters of bull **A** it happens only at 1550 days from first calving, almost 2 lactations later.

Bull	S(t) = 0.75	S(t) = 0.50
A .	769	1550
В	471	1078
С	341	860

Table 5.7 - Expected times at which daughters of bulls A, B and C reach different values of the survivor curve.

An attempt to estimate the genetic trend for sires was made by grouping sires according to their year of birth (only bulls with ≥ 20 uncensored records) and then calculating the within-year average ETA for true and functional herd life. The estimated trends are shown in Figure 5.8, which also indicates the number of sires born in each year. Sires born before and in 1970 were combined in one single class. Prior to 1977 and for the last year of birth (1989), estimates of the average ETAs per year were based on less than 30 bulls, and should be interpreted with care. From 1977 to 1988 the genetic trend is descending, which is favorable because ETAs are expressed as relative culling rates. Genetic trends were similar for true and functional herd life. Although further research is needed to confirm the observed tendency, Figure 5.8 is an indication that the sire selection in Canada has improved (or at least not deteriorated) the genetic merit of dairy sires for herd life traits.

Rank Correlations Between Proofs

Sire solutions from the univariate Weibull models (ETA_{true} and ETA_{fune}) were correlated with official genetic evaluations for the same bulls published in May 1997 by the Canadian Dairy Network (Table 5.8). These correlations are not an approximation of the genetic correlation between the traits, but they serve as an indication of how the rank of bulls changes when different traits are considered. ETA_{true} and ETA_{func}, had a rank correlation of 0.90, which indicates that although true herd life and functional herd life are not the same trait, sire ranks are very similar, meaning that sires whose daughters are at a higher-thanaverage risk of being culled for any reason would be the same sires whose daughters are more prone to be discarded for involuntary reasons. Figure 5.9 shows a plot of ETA_{true} against ETA_{fine} for sires with ≥ 20 uncensored records (daughters with completed herd life records), and the rank correlation in this case is 0.89, which is very close to the one obtained when all bulls were included in the analysis. Both ETA_{mue} and ETA_{fune}, had similar rank correlations with the official rating for herd life (0.62 and 0.66), which are quite low if one considers that they refer to different definitions of the same trait. As mentioned in the literature review, the official rating for herd life is a combination of a direct herd life evaluation (based on daughter survival) and an indirect herd life index (based on type traits correlated with survival). The

use of type traits to predict herd life in the official rating for herd life explains why the rank correlation of this trait with type proofs were higher than rank correlations between EBVs for type traits and ETA_{true} and ETA_{fune}. Correlations of both ETA_{true} and ETA_{fune}, with EBVs for capacity and feet and legs were low and with EBVs for conformation and for mammary system were only moderate. Correlations with production traits ranged from 0.45 to 0.51 for ETA_{me} but were ≤ 0.21 for ETA_{fime}. This result is not surprising, since functional herd life is 'corrected' for production traits. Correlations with the rating for somatic cell score, milking speed rating and rating for service sire calving ease were low for both herd life traits. Finally, while rank correlations between ETA_{fune} and the two official economic sire selection indices used in Canada (LPI and TEV) were low (0.36 and 0.35), ETA_{true} had moderate to high rank correlations with the same indices (0.61 and 0.63). Selection based on the current economic indices indices seems to improve herd life mostly through the high weight given to production traits, which influences directly voluntary culling. No evidence was found, however, that the adoption of LPI or TEV by producers would increase functional herd life in their herds.

	ETA ^b for Functional Herd Life	ETA for True Herd Life	Official Rating for Herd Life
ETA for True Herd Life	0.90	1.00	-
Official Rating for Herd Life	0.66	0.62	1.00
LPI ^b	0.36	0.61	0.47
TEV ^b	0.35	0.63	0.44
EBV [₺] for Milk	0.18	0.45	0.17
EBV for Fat	0.14	0.45	0.17
EBV for Protein	0.21	0.51	0.20
EBV for Conformation	0.46	0.43	0.70
EBV for Capacity	0.19	0.18	0.27
EBV for Feet and Legs	0.27	0.23	0.45
EBV for Mammary System	0.43	0.41	0.70
Rating for Somatic Cell Score	0.30	0.38	0.30
Milking Speed Rating	0.29	0.33	0.26
Rating for Service Sire Calving Ease	0.02	0.00	0.04

Table 5.8 - Pearson correlation estimates between sire ETA for true and functional herd life and official genetic evaluations published by the Canadian Dairy Network in May 1997^a.

^aNumber of bulls included in the survival analysis that also have official genetic evaluations = 1721. ^bETA = estimated transmitting ability; LPI = lifetime profitability index; TEV = total economic value; EBV = estimated breeding value.

SUMMARY

- Survival analysis was successfully used to describe length of productive life of Quebec Holstein cows, and genetic differences between sires regarding the hazard function of their daughters were also demonstrated and quantified.
- Culling in first lactation follows a different pattern than in later lactations, particularly in the first 240 days in milk.
- Relative culling rates were higher in 1985 and in the 1991-1992 period than in the rest of the years studied.
- The older the heifers calved, the higher was the risk of being culled.
- Milk recording option does not seem to affect culling intensity in Quebec herds.
- Changes in herd size had a small impact on the hazard function of dairy cows.
- The hazard decreases as cow's production (as a deviation from herd average) increases.
- Heritability in the log scale was 0.09 for true herd life and 0.08 for functional herd life, but when heritability was expressed on the original scale, the estimates for the two traits were 0.19 and 0.15, respectively.
- ETA_{true}, expressed as relative culling rates, ranged from 0.51 to 1.41, and ETA_{func}. ranged from 0.52 to 1.35.
- The difference in the median survival time between a bull with $ETA_{func.} = 0.6$ and another bull with $ETA_{func.} = 1.3$ was 690 days or 1.7 lactations.
- Descending genetic trends for both herd life traits indicate that Canadian sire selection programs did not have a deleterious effect on the genetic merit for herd life.
- Rank correlations of the official proofs for functional herd life with ETA_{func} and ETA_{nue} were only 0.66 and 0.62, and imply that selection based on the two methods would necessarily lead to different responses.
- Selection based on LPI and TEV seem to favor true herd life, but was not related to

functional herd life.

• Weibull models should be considered for genetic evaluation of herd life traits in Canada.

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Figure 5.2 - Estimates of the year effect.



Figure 5.3 - Estimates of the effect of age at first calving (first age class combines cows calving from 17 to 22 months of age).



Figure 5.4 - Estimates of the effect of annual change in herd size.

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Figure 5.5 - Estimates of the effect of within herd-year-parity class of standardized milk production (4% fat and 3.3% protein).



Figure 5.6 - Sire estimated transmitting ability (ETA) for functional herd life expressed as relative culling rates.

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Figure 5.7 - Expected survivor curves of three sires with different relative culling rates ($w_i = \exp[s_i]$). Sire A (dashed line) has $w_i = 0.6$; sire B (solid line) has $w_i = 1.0$; sire C (thick line) has $w_i = 1.3$.



Figure 5.8 - Genetic trends for the herd life traits based on sire birth year (only bulls with ≥ 20 uncensored records). Bars = number of sires born in each year; \blacksquare = trend for functional herd life; \circ = trend for true herd life.



Figure 5.9 - Plot of sire estimated transmitting ability for functional herd life against sire estimated transmitting ability for true herd life (rank correlation = 0.89; only sires with ≥ 20 uncensored records).

CHAPTER 6

Phenotypic Impact of Conformation Traits on Herd Life Assessed by Survival Analysis

Many farmers believe that selection of dairy cows based on conformation traits will increase herd life indirectly. Although only few type traits have been reported to have significant genetic correlations with herd life traits, conformation still influences the culling decision-making process in dairy herds. This study is an attempt to quantify how important each of the eight composite type traits used in Canada actually is in terms of selection criteria among Quebec dairymen. In order to achieve that, type classifications for individual cows were included as explanatory variables in Weibull models similar to those used in Chapter 5. Including the actual type scores of the cows in the survival models used to study functional herd life might be an effective way of accounting for voluntary culling based on conformation.

MATERIALS

Since this part of the thesis is practically an extension of the Chapter 5, there is no need to repeat details on the materials and methods and, therefore, only the aspects related specifically to the present topic will be given. The 331,147 lifetime records described in the previous chapter were merged with conformation records obtained from the Canadian Dairy Network files to study the phenotypic effect of type traits on herd life. Conformation records included information on 8 composite type traits and 15 linear type traits. Because summary traits are more likely to be used as selection criteria than specific linear traits, only the composite traits were included in the survival analysis. Composite traits are recorded in an 18-point scale and named 'Final Score', 'Frame-Capacity', 'Rump', 'Feet and Legs', 'Fore Udder', 'Rear Udder', 'Mammary System' and 'Dairy Character'. If sire registration number in the conformation record of a given cow was different than in her lifetime record, her type data was not included (only 233 cases). Only first classifications made in the first lactation of the cow were used. A total of 191,190 matched type-lifetime records were obtained. Figure 6.1 shows the number of cows (or lifetime records) with data on type traits per year and by milk recording option. The proportion of cows with type information in the official herds is much higher than in the other option, and this would probably have a confounding effect on the estimates for the effect of milk recording if it was included in the model. The increase in the number of records observed in 1991 is due to the ingress of a significant number of new herds in the PATLQ system coming from the former Canadian Record of Performance (ROP) program, which was terminated in 1990. Finally, it is also evident from Figure 6.1 that the number of cows with type information is close to 0 for calving year 1981, increases in 1982 and then stabilizes in 1983. This reflects the fact that the current linear type classification adopted in Canada started being used only in 1982. All lifetime records, even the ones without type information, were included in the analysis.

METHODS

A Weibull model similar to the ones used in Chapter 5 was utilized to analyze the lifetime records:

$$\lambda(t) = \lambda_0(t) \exp\{y_i(t) + p_j(\tau) + z_k(t) + a_m + w_r(\zeta) + d_u + fs_{b1} + fcap_{b2} + rump_{b3} + fl_{b4} + fu_{b5} + ru_{b6} + ms_{b7} + dc_{b8} + h_n(t) + s_a\}$$

where $\lambda(t)$ is the hazard function at time t; $\lambda_0(t) = \lambda_p (\lambda t)^{p-1}$ is a Weibull baseline hazard function with scale parameter λ and shape parameter ρ ; $y_i(t')$ is the effect of year i (i = 1981,...,1994), assumed to be piecewise constant with jumps arbitrarily chosen to occur at t'= March 1 of each year; $p_i(\tau)$ is the effect of lactation number and stage of lactation combined into j = 16 classes (lactations 1, 2, 3 and $\geq 4 \times$ four stages), assumed to be piecewise constant with changes occurring at $\tau = 0$, 120, 240, and 305 days of each lactation; $z_k(t)$ is the effect of annual change in herd size k (k = 1, for a decrease in herd size of >25%; k = 2, for a decrease in herd size of 15 to 25%; k = 3, for a decrease in herd size of 5 to 15%; k = 4, for herd with no appreciable change (-5 to +5%), k = 5, for an increase in herd size of 5 to 15%; k = 6, for an increase in herd size of 15 to 25%; and k = 7, for an increase in herd size of >25%), which is assumed to be a time-dependent covariate, piecewise constant, and jumps happening at t'= March 1 of each year; a_m is the effect of the m age at first calving $(m = 1, \text{ for } \le 22 \text{ months}; ...; m = 19, \text{ for } 40 \text{ months}); w_r(\zeta)$ is the effect of the rth within herdyear-parity class of milk production at 305 days of lactation (r = 1, for cows producing more than 1.5 standard deviations below the herd-year-parity average; r = 2, for cows producing between 1.5 and 0.5 standard deviations below the herd-year-parity average; r = 3, for cows producing between 0.5 standard deviation below and 0.5 above the herd-year-parity average; r = 4, for cows producing between 0.5 and 1.5 standard deviations above the herd-year-parity average; and r = 5, for cows producing more than 1.5 standard deviations above the herd-

year-parity average), considered to be piecewise constant and changing value at ζ = beginning of a new lactation; d_u is an indicator (dummy) variable for the presence or absence of type information (u = 1, for records without type and u = 2, for records with type); fs_{b1} is the class of the composite trait 'Final Score' assigned to that cow (b1 = 1, for absence of typeinformation; b1 = 2, for Final Score 1;...;b1 = 16, for Final Score 15); fcap_{b2} is the class of the composite trait 'Frame-Capacity' assigned to that cow (b2 = 1, for absence of typeinformation; b2 = 2, for Frame-Capacity class 1;...;b2 = 19, for Frame-Capacity class 18); $rump_{b3}$ is the class of the composite trait 'Rump' assigned to that cow (b3 = 1, for absence of type information; b3 = 2, for Rump class 1;...;b3 = 17, for Rump class 16); f_{b4} is the class of the composite trait 'Feet and Legs' assigned to that cow (b4 = 1, for absence of typeinformation; b4 = 2, for Feet and Legs class 1;...; b4 = 16, for Feet and Legs class 15); fu_{b5} is the class of the composite trait 'Fore Udder' assigned to that cow (b5 = 1, for absence of type)information; b5 = 2, for Fore Udder class 1;...;b5 = 16, for Fore Udder class 15); ru_{b6} is the class of the composite trait 'Rear Udder' assigned to that cow (b6 = 1, for absence of type)information; b6 = 2, for Rear Udder 1;...;b6 = 16, for Rear Udder class 15); ms_{b7} is the class of the composite trait 'Mammary System' assigned to that cow (b7 = 1, for absence of type)information; b7 = 2, for Mammary System class 1;...;b7 = 16, for Mammary System class 15); dc_{b8} is the class of the composite trait 'Dairy Character' assigned to that animal (b8 = 1, for absence of type information; b8 = 2, for Dairy Character class 1;...;b8 = 19, for Dairy Character class 18); $h_n(t^2)$ is the random effect of the herd-year n (n = 1,...,28629), assumed to be piecewise constant with changes at t' = March 1 of each year; and s_a is the random effect of sire q (q = 1,...,1664).

The actual scale for all composite traits ranged from 1 to 18, but for some traits there were no cows classified in the higher classes. The inclusion of the indicator variable d_u and the imposition of two different constraints for each type trait included as explanatory variable in the model made it possible to consider all lifetime records in the analysis, even from cows

without type information. In order to get meaningful estimable effects, the two constraints were always in the first class (absence of information) and in an intermediary class of the conformation trait. A model including all the effects described above and the effect of milk recording option was fitted. As expected, the effect of milk recording was confounded with the indicator variable for presence or absence of type information, being removed from the model for this reason. The Weibull model was analyzed with the "SURVIVAL KIT" (Ducrocq and Sökner, 1994), and the censoring criteria used was the same as in the previous chapter. A log-gamma prior density function was assumed for the herd-year random effect and a multivariate normal distribution with covariates between levels being introduced by genetic relationships was assumed for the random effect of sire. The pedigree file included only information on male parents (sires) and included a total of 1875 animals (1664 with data). The sire variance σ^2 , was estimated as the mode of its marginal posterior density, which was approximated by Laplacian integration. The gamma parameter γ_h was estimated jointly with the other effects after exact algebraic integration of the log-gamma random effect of herd-year.

RESULTS AND DISCUSSION

Table 6.1 shows the likelihood ratio tests for the fixed effects included in the model. All explanatory variables significantly affected the failure time, with the exception of the composite type traits Rear Udder and Mammary System. A simplistic interpretation for these results would be that producers do not pay much attention to Rear Udder and Mammary System when making their culling decisions. One has to realize, however, that these are 'composite' traits, and as the predicative implies, they are a combination of different linear type traits (which are measured) into more general traits. Different composite traits may include information on the same linear trait, but with a different emphasis. Udder linear

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characteristics, for example, are incorporated into Final Score, Mammary System, Fore Udder, Rear Udder and Dairy Character. Therefore, the fact that cows' classification for Rear Udder and for Mammary System did not affect significantly their hazard rates probably reflects the fact that udder characteristics had been already considered in other composite traits. In practical terms, it is not unrealistic to think of most dairy managers considering Final Score as their main (conformation) criterion to keep or discard cows from their herds. Even if a given cow has a reasonably decent udder but received a low Final Score from the classifier, the producer will likely disregard the classification for Mammary System and get rid of the animal. On the other hand, Fore Udder significantly affected the failure time, which could be an indication that producers pay more attention to specific factors related to the udder conformation. In fact, fore udder attachment has been reported as one of the type traits with the highest genetic correlation with herd life (see literature review), which is in agreement with the present results.

Effect	-2 Change in Log-likelihood*	DF	Prob
Year	694.1	13	0.0000
Lactation Number × Stage	25753.6	15	0.0000
Annual Change in Herd Size	19.1	6	0.0003
Age at First Calving	780.8	18	0.0000
305-Day Yield Deviation	44171.2	4	0.0000
Indicator for Type Information	3129.5	1	0.0000
Final Score	474.3	14	0.0000
Frame-Capacity	70.4	17	0.0000
Rump	51.0	15	0.0000
Feet and Legs	60.7	14	0.0000
Fore Udder	30.7	14	0.0011
Rear Udder	13.0	14	0.6546
Mammary System	19.3	14	0.1666
Dairy Character	102.2	17	0.0000

Table 6.1 - Results from the likelihood ratio tests comparing the full model with models excluding one effect at a time.

Logarithm of the marginal posterior odds ratio at the posterior mode.

^bProb = probability of being greater than the corresponding Chi-squared value for P =0.001.

The obtained estimates of the Weibull parameters ρ and $\rho log \lambda$ were 1.80 and -11.93, respectively.

Estimates for the Fixed Effects

Estimates for the effects of year, lactation number × stage of lactation, annual change in herd size, age at first calving and 305-day yield deviation were very similar to the ones

obtained with the model for functional herd life in Chapter 5, and will not be discussed here. Before addressing the effects of type traits on the hazard function, it is important to consider the estimates obtained for the indicator variable for presence or absence of type information. The relative culling rate for cows without type classification was 2.4-fold higher than for cows that had conformation records. Before the breed associations start using this value to convince producers to classify more cows, some comments are worth making. The inclusion of animals not classified (or with unknown classification values) in the model avoided biases in the estimates of the effects other than type traits, and the presence of an indicator variable makes the comparison among classified animals still valid. The consequence of this procedure is that not only cows from grade herds are considered in the group without type, but also all those cows from registered herds being culled prior to the visit of the classifier are included in the same class. Therefore, it is not surprising that the estimated hazard rate is higher for cows with no conformation records, since a good number of them were discarded before being classified. In any case, these results should be interpreted with caution and further investigation is needed before conclusions can be drawn about the culling rates in herds that classify or not their cows.

Figure 6.2 shows the relative culling rate associated to the different classes of Final Score. The number of uncensored records per class is also displayed in Figure 6.2 to give an idea about the reliability of the estimates. Particularly in the case of Final Score, an unexpectedly low number of cows being classified as class 8 was observed. No reasonable explanation was found to justify that. The picture for the estimates, however, is clear: producers do take into consideration Final Score when making their culling decisions. The higher the Final Score of the cow, the lower the risk that she is going to the slaughterhouse. Considering only the interval with a reasonably high number of uncensored records per class, which goes from class 3 to class 12, there is a difference in relative culling rate of more than 100%. Final Score is the composite type trait that receives more emphasis as a culling

criterion among Quebec dairy producers.

Relative culling rates for Frame-Capacity classes are shown in Figure 6.3. Although statistically significant, the estimates for this effect did not show any clear trend, suggesting that producers do not pay much attention to the Frame-Capacity classification when deciding whether to cull a cow or not. Particularly when only estimates for the classes with a higher number of uncensored records are analyzed (class 7 to class 16), relative culling rates are very similar, implying that this trait is not important as a selection criteria in Quebec Holstein herds. Again, some linear traits contribute to the calculation of both Frame-Capacity and Final Score, and farmers might acknowledge that by considering just Final Score in their culling decisions.

Figure 6.4 shows the relative culling rates for the composite trait Rump. Even though the effect of Rump on the failure time was statistically significant, there is no clear indication that producers consider classification for Rump when choosing which cows should be culled. The relative culling rate from class 4 to class 13 (the two extremes of the interval with a higher reliability of the estimates) had values between 1.05 and 0.96, indicating that the culling probability is similar for cows with different classification for Rump.

The estimates of Feet and Legs (Figure 6.5) follow the same pattern as the estimates for Rump. There is a 10% difference in relative culling rate between classes 4 and 13 of Feet and Legs, which indicates that cows in the higher classes have a slightly higher chance of surviving than cows in the lower classes but, in general, dairymen do not put a lot of emphasis on classification for Feet and Legs when culling decisions are made.

After Final Score, the composite trait that seems to influence most producers, regarding their culling policies, is Fore Udder. Figure 6.6 clearly shows that the higher a cow

is classified for Fore Udder the lower is her risk of being discarded. For example, a cow classified 4 has 25% more chance of being culled than a cow classified 13 for Fore Udder.

Finally, relative culling rates for Dairy Character are shown in Figure 6.7. Most cows are classified between 7 and 14 for Dairy Character, and there is no clear trend for the estimates within this interval. Dairy Character is not used by Quebec breeders to decide which cows should be culled from their herds.

Estimates for the Random Effects

The inclusion of type information in models to estimate genetic parameters for herd life traits might be of interest in populations where a significant number of cows are culled due to conformation characteristics regardless of their biological ability to delay involuntary culling. The model for functional herd life in the preceding chapter carries the assumption that all voluntary culling is based on production, which is probably not true in most situations. The results from the present study may help to clarify whether or not type traits should be included as explanatory variables in survival models used to calculate genetic evaluations for herd life.

The estimated sire variance σ_s^2 was 0.034 and the gamma parameter for the herd-year effect γ_h was 6.241. These values were used to estimate the heritability of the herd life trait in the logarithmic scale, $h_{log}^2 = 0.073$, and an approximation of the heritability in the original scale, $h^2 = 0.153$. These estimates are very similar to the ones obtained for functional herd life in Chapter 5.

Since heritability estimates were not affected by the inclusion of type traits in the model, it would be interesting to see whether sire solutions presented appreciable changes. Solutions for the sire effect, expressed as relative culling rates, ranged from 0.61 to 1.46,

which is about the same variation observed for sire solutions for true and functional herd life. Sire ETA for herd life "corrected for type" were correlated with sire ETA for true and functional herd life (Table 6.2). The rank correlation of sire ETA for herd life corrected for type with functional herd life was high (0.89), and the correlation with true herd life was a bit lower (0.80). Therefore, small changes in the sire ranking occurs after correcting for type, but they might have an impact on sire selection. Phenotypic adjustment of herd life for conformation traits probably improves the way survival models describe the culling process in dairy farms, but it is not clear whether eventual genetic correlations between type and herd life are accounted for in this procedure.

Table 6.2 - Pearson correlation estimates between sire ETA for herd life corrected for type, functional herd life and functional herd life.

	ETA* for Herd Life Corrected for Type			
ETA for Functional Herd Life	0.89			
ETA for True Herd Life	0.80			
*FTA = estimated transmitting ability				

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SUMMARY

- Inclusion of composite type traits as explanatory variables in survival models seems to be an effective way of accounting for culling based on conformation in dairy herds.
- Quebec dairymen use Final Score as the primary conformation criterion to decide whether to cull or not a cow. The higher the class for Final Score, the lower the risk of being culled.
- Classification for Fore Udder is also considered by producers when choosing which cows should be replaced. The lower the classification for Fore Udder, the higher the chances of being discarded.
- The other composite traits are not considered directly in culling decisions. Dairy managers probably acknowledge the fact that some linear traits incorporated in the different composite traits contribute, at the same time, in the calculation of Final Score.
- Heritability of herd life adjusted for type was 0.07 in the log scale and 0.15 in the original scale.
- Rank correlations between sire ETA for herd life adjusted for type and sire ETA for true and functional herd life were high, but the inclusion of information on type in the model did cause up to 20% rearrangements in sire rankings.



Figure 6.1 - Number of cows with a type classification record by year of first calving. Solid lines = cows with type data; dashed lines = cows without type data; \blacksquare = official herds; \circ = owner sampler herds.



Figure 6.2 - Estimates of the effect of class of Final Score. Bars = number of uncensored records; \blacksquare = relative culling rate.



Figure 6.3 - Estimates of the effect of class of Frame-Capacity. Bars = number of uncensored records; \blacksquare = relative culling rate.



Figure 6.4- Estimates of the effect of class of Rump. Bars = number of uncensored records; = relative culling rate.



Figure 6.5 - Estimates of the effect of class of Feet and Legs. Bars = number of uncensored records; \blacksquare = relative culling rate.



Figure 6.6 - Estimates of the effect of class of Fore Udder. Bars = number of uncensored records; \blacksquare = relative culling rate.



Figure 6.7 - Estimates of the effect of class of Dairy Character. Bars = number of uncensored records; \blacksquare = relative culling rate.

CHAPTER 7

Competing Risks Analysis of Reasons for Disposal in Quebec Dairy Herds

In this chapter, the use of survival analysis to model the risk of a dairy cow being culled for different reasons is described. This is possible by applying an extension of survival models known as competing risks analysis, in which cause-specific hazard functions are fitted. In Chapter 4 the proportion of cows being culled for each different major reason in Quebec herds was modeled by logistic regression, one reason at a time. A more realistic approach, however, would acknowledge that the occurrence of one type of culling prevents the happening of all other types of disposal. If a cow is culled for low production, for example, it is reasonable to think that she could have been discarded due to mastitis later, had she stayed in the herd. In the competing risks framework, this cow's failure time will be treated as right-censored at the time she was culled for low production, in order to compute her 'mastitis' hazard function. In other words, all we know about the risk of failure due to mastitis is that she managed to avoid culling for mastitis up to the point she failed due to low production. The results from the present study are closely related to those reported in Chapter 5, since the same Weibull models (and same data) are used here just changing the censoring criteria. Competing risks analyses may help to clarify whether the inclusion of 305-days yield deviation in the model for functional herd life is enough to correct for culling based on low production (voluntary).

The objectives of this chapter are: a) to study how explanatory variables (more specifically the fixed effects) affect the cause-specific hazards represented by culling codes used in PATLQ herds; b) to consider the feasibility of producing genetic evaluations for reason-specific culling in dairy cattle; c) to evaluate the potential contribution of recorded

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reasons for disposal in the definition of a herd life trait which reflects functional survival more accurately than length of productive life adjusted for phenotypic production.

MATERIALS AND METHODS

The lifetime records used in this study were the same 331,147 records described in Chapter 5. Disposal reasons were defined based on the PATLQ disposal codes described in Chapter 4. Only those disposal reasons of higher incidences were studied, namely culling due to low milk or low fat production (LOWP), culling due to reproductive problems (REPRO), culling due to mastitis and/or high cell counts (MAST), culling due to udder breakdown and milking problems (UDBR) and culling due to feet and leg problems (F&L). A sixth class of culling reasons was defined including all disposal codes but LOWP. This general reason is a crude approximation of involuntary culling, if voluntary culling is assumed to be based only on production. As already pointed out in the review of literature (Chapter 2), classifying dairy cows disposals into voluntary and involuntary can be very misleading if the "real intention" of the herd manager is to be taken into consideration. Assuming that culling for low production is the only form of voluntary culling is an oversimplification of what really happens at the farm level, but it allows lifetime records to be classified according to clearly defined criteria. Involuntary culling would be abbreviated as INVOL herein. Note that INVOL is a competing risk only for LOWP, since it includes all the other reasons.

Initially, non-parametric estimates of the survivor and the hazard functions for the different competing risks were obtained using the Life-Table method in the LIFETEST Procedure of SAS (SAS Institute Inc., 1988). Then, a parametric model was used to analyze the effect of different covariates on the failure time of each competing risk:

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$$\lambda_{d}(t) = \lambda_{0d}(t) \exp\{y_{i}(t) + p_{i}(\tau) + z_{k}(t) + o_{l} + a_{m} + w_{r}(\zeta) + h_{n}(t) + s_{a}\}$$

where $\lambda_d(t)$ is the cause-specific hazard function for disposal reason d, at time t; $\lambda_{od}(t)$ is a cause-specific Weibull baseline hazard function with scale parameter λ_d and shape parameter ρ_d , $y_i(t')$ is the effect of year i (i = 1981,...,1994), assumed to be piecewise constant with jumps arbitrarily chosen to occur at t' = March 1 of each year; $p_i(\tau)$ is the effect of lactation number and stage of lactation combined into j = 16 classes (lactations 1, 2, 3 and $\ge 4 \times four$ stages), assumed to be piecewise constant with changes occurring at $\tau = 0$, 120, 240, and 305 days of each lactation; $z_k(t)$ is the effect of annual change in herd size k (k = 1, for a decrease in herd size of >25%; k = 2, for a decrease in herd size of 15 to 25%; k = 3, for a decrease in herd size of 5 to 15%; k = 4, for herd with no appreciable change (-5 to +5%), k = 5, for an increase in herd size of 5 to 15%; k = 6, for an increase in herd size of 15 to 25%; and k = 7, for an increase in herd size of >25%), which is assumed to be a time-dependent covariate, piecewise constant, and jumps happening at t' = March 1 of each year; o_1 is the effect of the l milk recording option (l = 1, for owner-sampler herds; l = 2, for official herds); a_m is the effect of the m age at first calving (m = 1, for 17 months;...; m = 19, for 40 months); $w_r(\zeta)$ is the effect of the rth within herd-year-parity class of milk production at 305 days of lactation (r = 1, for cows producing more than 1.5 standard deviations below the herd-year-parityaverage; r = 2, for cows producing between 1.5 and 0.5 standard deviations below the herdyear-parity average; r = 3, for cows producing between 0.5 standard deviation below and 0.5 above the herd-year-parity average; r = 4, for cows producing between 0.5 and 1.5 standard deviations above the herd-year-parity average; and r = 5, for cows producing more than 1.5 standard deviations above the herd-year-parity average), considered to be piecewise constant and changing value at ζ = beginning of a new lactation; $h_n(t)$ is the random effect of the herdyear n (n = 1,...,28629), assumed to be piecewise constant with changes at t^2 = March 1 of each year; and s_q is the random effect of sire q (q = 1,...,1664). The effect $w_r(\zeta)$ was not

included in the model for LOWP, because it would be confounded with the dependent variable.

In practice, the competing risks analysis was carried out by fitting the same Weibull model to the data after changing the censoring criteria. For example, to obtain estimates of the Weibull parameters and of the different effects for the competing risk LOWP, records of cows being culled for low milk and low fat production are considered as completed (uncensored) and all the remaining records are treated as censored.

When the effect of lactation number \times stage of lactation was included in the model for REPRO, the Hessian matrix was not semi-positive definite, causing the computations to stop without reaching convergence. Several different parametrizations and sets of constraints were tried, but none succeeded. Models without lactation number \times stage of lactation were fitted and estimates were obtained, but the comparison with results obtained for the other competing risks would probably be inappropriate. Hence, although REPRO is the most important reason for disposal after low milk production, results for this competing risk will not be presented here.

The Weibull model was analyzed with the "SURVIVAL KIT" (Ducrocq and Sölkner, 1994). A log-gamma prior density function was assumed for the herd-year random effect and a multivariate normal distribution with covariates between levels being introduced by genetic relationships was assumed for the random effect of sire. The pedigree file included only information on male parents (sires) and included a total of 1875 animals (1664 with data). The sire variance σ_s^2 was estimated as the mode of its marginal posterior density, which was approximated by Laplacian integration. The gamma parameter γ_h was estimated jointly with the other effects after exact algebraic integration of the log-gamma random effect of herd-year.

RESULTS AND DISCUSSION

Non-parametric estimates of the survivor function for the different competing risks are shown in Figure 7.1. Note that, instead of obtaining estimates for INVOL, two extra classes of competing risks were defined in the non-parametric analysis for illustrative purposes: SICK, which refers to the risk of receiving a disposal code for sickness, milk fever, displaced abomasum or bloat, and INJUR, which allude to the chances of being culled or dying due to injury, poisoning or electrocution. Even in this preliminary analysis, it becomes clear that the probability of survival is distinct when different culling reasons are considered. The survival curve for LOWP drops sharply in first lactation and then continues decreasing at a slower rate. The survival probability for REPRO starts dropping only at the end of first lactation, and then decreases more rapidly than for any other reason. All other competing risks present similar survivor functions, with the exception of INJUR, which has an almost flat survival curve (very low risk of failure). A bit more confusing but certainly more illustrative than the survival curves, the estimated hazard curves for each of the competing risks are shown in Figure 7.2. The effects of lactation number and stage of lactation are readily apparent for most of the competing risks. The risk of being culled for LOWP is really high at the beginning of first lactation, reaching its peak between 120 and 240 days after first calving and then dropping sharply until the beginning of next lactation, when it raises again. The hazard associated with LOWP follows a cyclic pattern, with peaks at the first half of each lactation. It is interesting to note that LOWP is the only competing risk in which the hazard decreases with age, demonstrating that if a cow is able to survive until later lactations, she is certainly a good producer and will not be culled for low production. The competing risk REPRO also shows a cyclic variation on the hazard curve, but with peaks occurring at the end of each lactation (the first peak happens between 300 and 390 days after first calving, for example). Cows that fail to conceive or that have late abortions will likely be kept (open) in

the herd until the end of the lactation and then be discarded. Even if the culling decision is made at the beginning of the lactation, cows with reproductive problems tend to be culled at the end the lactation. Figure 7.2 confirms the importance of stage of lactation and lactation number for REPRO and, even though these effects could not be demonstrated using a parametric analysis, their influence must be acknowledged. An interesting result is the hazard curve for UDBR. It seems that the identification and consequent removal of cows with udder breakdown and milking problems happen right after first calving. Although the risk of being culled for UDBR does increase with age, a good number of cows tend to be discarded for this competing risk as soon as they reach their first peak of production (after 60 days in milk), period in which udder problems become more evident as the volume of milk produced is maximum. Cyclic hazard functions are also observed for F&L, MAST and SICK. The hazard for INJUR is constant over time, which is exactly what one should expect, considering that injury, poisoning and electrocution are random events that can happen at any moment in a lifetime.

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Statistic	LOWP*	MAST	UDBR	F&L	INVOL
Right censored records	268116	317739	311919	318529	214577
Average censoring time ^b	786	731	739	736	649
Uncensored records	63031	13408	19228	12618	116570
Average time at culling ^b	557	1022	795	916	915
Percent censored	81.0	96.0	94.2	96.2	64.8
Shape parameter (p)	1.54	1.66	1.56	1.70	1.77
Intercept (plog)	-10.33	-13.72	-11.96	-13.58	-11.90

Table 7.1 - Descriptive statistics and Weibull parameters for the different competing risks.

⁶LOWP = culling due to low milk or low fat production; MAST = culling due to mastitis and/or high somatic cell counts; UDBR = culling due to udder breakdown and milking problems; F&L = culling due to feet and leg problems; INVOL = culling for reasons other than LOWP.

^bTime measured in days after first calving.

Table 7.1 shows descriptive statistics and the estimated Weibull parameters for each competing risk obtained from the parametric analysis. The amount of censoring is really high for all competing risks, except for INVOL, which presents a reasonable proportion of uncensored records. This low incidence for each individual culling code, however, did not prevent the Weibull model from detecting differences in the hazard rates and demonstrating how the failure time for each competing risk is affected by the covariates included in the model.

Table 7.2 - Results from the likelihood ratio tests comparing the full model with models excluding one effect at a time.

Effect	-2 Change in Log-likelihood*				DF	
	LOWP	MAST	UDBR	F&L	INVOL	
Year	752.3†	151.9†	225.8†	275.0†	552.0+	13
Lactation Number × Stage	38426.0†	1902.5†	2586.5t	1752.0†	27058.01	15
Annual Change in Herd Size	23.8†	7.9	2.0	12.8	24.0 1	6
Age at First Calving	93.1 †	25.7	31.5	161.9 †	457.4†	18
305-Day Yield Deviation ^c	-	1414.4†	2211.5 †	1129.4†	7879.2†	4
Milk Recording Option	313.7†	25.4†	66.6†	65.0†	50.8†	1

Logarithm of the marginal posterior odds ratio at the posterior mode.

^bLOWP = culling due to low milk or low fat production; MAST = culling due to mastitis and/or high somatic cell counts; UDBR = culling due to udder breakdown and milking problems; F&L = culling due to feet and leg problems; INVOL = culling for reasons other than LOWP.

Effect not included in the model for LOWP.

†Significant at P<0.001.

Table 7.2 shows the likelihood ratio tests for the fixed effects included in competing risks analysis. Annual change in herd size had the smallest impact on the failure time of all competing risks, not reaching statistical significance for MAST, UDBR and F&L. Age at first calving was also not significant at P < 0.001 for MAST and UDBR. The covariate with the largest impact was always lactation number × stage of lactation, followed by the effect of

305-day yield deviation. The change in the log-likelihood caused by the effect of 305-day yield deviation was 6-fold smaller in the model for INVOL than the change caused by the same covariate in the model for functional herd life in Chapter 5 (Table 5.5), demonstrating that censoring records of cows culled for LOWP drastically reduces the variation in the failure time explained by within herd-year-parity yield deviation. Interestingly, there is still a significant change in log-likelihood caused by 305-day yield deviation in the model for INVOL, indicating that culling due to low production is not the only disposal reason affected by production level.

Estimates for the Fixed Effects

Since there are in fact two competing risks scenarios being analyzed here, the first one comparing LOWP with INVOL, and the second one comparing LOWP with components of INVOL (REPRO, MAST, UDBR and F&L), the interpretation of the estimates will focus in the comparison between voluntary (LOWP) and involuntary culling (INVOL) and in the particularities of the other reason-specific hazards.

Figures 7.3 through 7.7 show the estimated hazards for the different competing risks for an average cow in an average herd throughout her first four lactations, considering that she had calving intervals of 400 days. The estimated hazard curve for LOWP (Figure 7.3) has a unique shape, confirming what has been shown by the non-parametric analysis. The risk of failure due to low production is very high in the first 240 days of first lactation, and then decreases to a very low level for the rest of the lactation. In second and later lactations, the hazard rate for LOWP starts at a low level and then becomes high from 121 to 240 days in milk, when it drops and stays low until the cow reaches the same stage in the next parity. These results confirm all that has been previously said about the importance given to the 240-days threshold by Quebec dairymen. Since official production certificates are only issued once
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cows have reached 240 days in milk, and also because the official herd production average includes only cows with more than 240 days in milk, herd managers do cull their poor producers before 240 days, using a legitimate marketing strategy to make their herds look better. On top of that, cows that are really below the herd average should be culled as soon as their daily yield drops below a certain level (e.g., the break-even point) and a replacement heifer is available. This point of "minimum losses" seems to occur prior to 240 days in milk for an average Quebec dairy herd.

The estimated hazard rate for INVOL (Figure 7.4) is similar to the estimates for functional herd life (Figure 5.1), except that the hazard from 121 to 240 days after calving is much lower for INVOL. The explanation is simple: the higher hazard between 121 and 240 days for functional herd life was due to the higher risk of being culled for low production (Figure 7.3), which is not present in the hazard estimates for INVOL (Figure 7.4). This is a very important finding, because it indicates that the adjustment for herd-year-parity class of milk production at 305 days does not account for all voluntary culling based on low production. In other words, Figure 7.4 (INVOL) might be a better representation of the hazard experienced by a dairy cow, regardless her production, than Figure 5.1 (Functional Herd Life). These results suggest that disposal codes can be used to improve inference on functional herd life.

Estimated hazard rates for MAST (Figure 7.5), UDBR (Figure 7.6) and F&L (Figure 7.7) have yet a different graphical form than the estimates for INVOL (Figure 7.4). While the hazard rate is highest at the end of the lactation and dry period for INVOL, cows are at a higher risk of being culled for mastitis, udder breakdown and feet and leg problems between 121 and 240 days after calving. This difference happens because INVOL includes REPRO, which is highly concentrated at the end of the lactation and has a higher incidence than the other reasons for disposal. A high risk of being culled due to UDBR and F&L right after first

calving is also evident in Figures 7.6 and 7.7, confirming what had been pointed out in the non-parametric analysis (Figure 7.2).

Estimates of the year effect (expressed as relative culling rates) for the various competing risks are shown in Figures 7.8 through 7.12. The only competing risk with a clearly descending trend in the period studied is LOWP. For instance, cows in 1982 had a 30% higher risk of being discarded for low production than cows in 1993. This decreasing trend had been already described in Chapter 4. Note that in Figure 7.8 two peaks of relative culling rate are observed, one in 1985 and the other in 1991, which are coincident with the peaks observed for the year effect in the functional herd life model (Figure 5.2). Relative culling rates were high for all competing risks in 1991, but the 1985 peak is definitely related to LOWP. Therefore, the hypothesis of a cut in quotas occurred in 1985 causing a more intensive voluntary culling policy seems to hold.

The relative culling rate for INVOL had a conclusively ascending trend from 1982 to 1994. The combination of a descending trend for LOWP and an ascending trend for INVOL caused the relative culling rate for functional herd life to be approximately stable (with two peaks, in 1985 and 1991). Year after year, Quebec dairymen have culled more cows for reasons other than production and less cows for LOWP. If INVOL represents, in fact, involuntary culling, then these estimates should be a cause of concern for the dairy industry in Quebec.

Ascending trends were also observed for MAST (Figure 7.10) and F&L (Figure 7.12), indicating that either the number of mammary infections and problems with feet and legs are increasing in Quebec herds, or that dairymen are giving more weight to these competing risks when making culling decisions. In the case of mastitis, it could be a combination of both. An increase in the average somatic cell counts among PATLQ herds was reported during the

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period included in the present study (Baril, 1994), which could be considered as an indication of higher mastitis incidence and, therefore, more cases of culling due to udder infections. On the other hand, the industry has increased the penalties related to high somatic cell counts in milk during the past decade, and producers may have been compelled to put more weight on mastitis in their culling policies.

The estimates of the year effect for UDBR (figure 7.11) followed a distinct pattern: relative culling rate increased rapidly from 1982 to 1987 (variation of 37%), stayed approximately constant and then dropped 20% after 1992. It is not clear which factors would cause such variation in the probability of being culled due to udder problems over the years of study.

Another intriguing result is presented in Figure 7.13. The effect of age at first calving for LOWP is higher than the average for heifers calving at a very young age (17 to 22 months), then decreases and stays constant from 23 months to 34 months of age. After 34 months, the relative culling rate increases rapidly up to 30% above the average for cows calving at 39 months of age. A higher risk of being discarded for low production for cows calving at a very young age could be related to the fact that these animals had not reached the ideal body condition at the parturition, having their productive potential reduced because of that. In other words, heifers with early conceptions did not receive an adequate management to guarantee their future performance. The unexpected result was the increase in risk for cows calving after 34 months of age. It is unexpected because there is no obvious reason why late calvings would increase the probability of failure due to LOWP. However, if one considers that many producers base culling for low production on the BCA (Breed-Class-Average) points that each cow has received, then it becomes clear that heifers calving at an older age will be penalized for production even if their actual milk yield is higher than for heifers calving younger.

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The effect of age at first calving did not significantly affected MAST and UDBR, but it had a clearly ascending trend for INVOL (Figure 7.14) and F&L (Figure 7.15). The risk of involuntary culling probably increases with age at first calving due to an increase in the risk of reproductive failure. However, no reasonable explanation was found to clarify why latecalving heifers would be more prone to be culled for feet and leg problems.

Estimates of the effect of 305-day herd-year-parity yield deviation for the different competing risks are shown in Table 7.3. Yield deviation from the herd-year-parity average significantly affects culling for reasons other than low production. The lower the relative production level of the cow, the higher the risk of being culled for whatever reason. Milk, fat and protein yields are the traits with the highest economic importance in any dairy farm, and herd managers will naturally have different limits of tolerance (regarding their culling criteria) for poor and for top producing cows. A cow with pendulous udder that can still manage to produce significantly more milk that the herd average would likely avoid culling for udder problems much longer than a poor producer with the same udder conformation. In this scenario, recording secondary reasons for disposal would help to separate cases in which production plays an important role in the culling decision from the truly involuntary removals. Meanwhile, correction for yield deviation is the only alternative to account for the impact of production on culling for reasons other than production in models to analyze herd life.

The effect of changes in herd size was statistically significant only for LOWP and INVOL, but even for these competing risks, the estimates obtained for the different classes of annual change in herd size were very close to each other. The only exception was for herds with a decrease in size of >25% (class 1), which had a 15% higher than average risk of being culled for reasons other than production (INVOL).

Competing Risk -	Class of 305-day Yield Deviation ^b					
	1	2	3	4	5	
INVOL°	2896	1.249	1.000	0.898	0.879	
MAST	3.417	1.402	1.000	0.879	0.881	
UDBR	3.098	1.441	1.000	0.792	0.770	
F&L	3.001	1,375	1.000	0.861	0.802	

Table 7.3 - Estimates of the effect of within herd-year-parity class of standardized milk production (4% fat and 3.3% protein)^a.

^aEstimates expressed as relative culling rates, having class 3 as the reference level. All estimates were significantly different than the reference level at P < 0.0001.

^bClass 1 = >1.5 standard deviations below the herd-year-parity average; class 2 = from 0.5 to 1.5 standard deviations below the herd-year-parity average; class $3 = \pm 0.5$ standard deviations from the herd-year-parity average; class 4 = from 0.5 to 1.5 standard deviations above the herd-year-parity average; class 5 = >1.5 standard deviations above the herd-year-parity average.

TNVOL = culling for reasons other than low production; MAST = culling due to mastitis and/or high somatic cell counts; UDBR = culling due to udder breakdown and milking problems; F&L = culling due to feet and leg problems.

Finally, Figure 7.16 shows the estimates for the milk recording option effect for the various competing risks. The risk of being discarded for LOWP, UDBR and F&L is higher in official than in owner sampler herds. This might indicate that supervised herds pay more attention to both production and conformation characteristics in their culling policies. MAST is the only competing risk in which the risk of being culled is higher in owner sampler herds. Apparently, producers in the official option have better mastitis control programs than owner samplers in Quebec dairy herds. Relative culling rate for INVOL is similar in owner sampler and official herds, as it was for functional herd life in Chapter 5. It seems that, although producers in the two options cull their cows for different reasons, on average they end up having similar culling intensities.

Estimates for the Random Effects

The estimates of the sire variance σ_{ϵ}^2 and the gamma parameter for the random effect of herd-year γ_h for the different competing risks are in Table 7.4. Following the expressions for heritability described in Chapter 5, estimates were obtained for heritability in the logarithmic scale and the corresponding approximation of heritability in the original scale.

Table 7.4 - Estimates of the sire variance, the gamma parameter for the herd-year effect, heritability in the log scale and heritability in the original scale.

Competing Risk*	0 ² ,	Yь	h ² ieg	b²
LOWP	0.1222	2.8042	0.2227	0.6030
INVOL	0.0322	7.1681	0.0706	0.1467
MAST	0.0953	1.3803	0.1368	0.4470
UDBR	0.0866	2.4066	0.1543	0.4311
F&L	0.1465	1.4236	0.2097	0.6528

^{*}LOWP = culling due to low milk or low fat production; MAST = culling due to mastitis and/or high somatic cell counts; UDBR = culling due to udder breakdown and milking problems; F&L = culling due to feet and leg problems; INVOL = culling for reasons other than LOWP.

With the exception of the estimates for INVOL (which still has a reasonably high proportion of uncensored records), the values shown in Table 7.4 must be interpreted with extreme caution. LOWP has only 20% of records which are uncensored, and this proportion drops to approximately 5% for MAST, UDBR and F&L. Therefore, the amount of information available to estimate sire variances is really limited. Often, there will be no daughter of a given sire being culled for a particular reason, e.g., feet and leg problems, and his ETA will be based only on censored records (daughters sold from their herds, still alive, or culled for other reasons). Even though it is possible to compute genetic parameters and sire estimated transmitting abilities for the failure time associated with different reasons for

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disposal in dairy cattle, the reliability of such evaluations would likely be very low, and little confidence could be granted to the resulting genetic evaluations. It may seem logical that differences exist between sires regarding the ability of their daughters to avoid specific types of disposals, but direct selection to decrease reason-specific culling rates would be very inefficient. Note that there is no interest in direct selection to decrease culling for low production, because selection to increase yield is already prioritized by the dairy industry. Further research should look at the impact of selection on type traits to decrease culling due to udder breakdown and feet and legs, for example.

More attention will be given to the estimates obtained for INVOL. Both h^2_{log} and h^2 were similar to the estimates obtained for functional herd life in Chapter 5, meaning that censoring records of cows culled for low production did not affect the magnitude of the heritability of the herd life trait. Table 7.5 shows the rank correlations of sire solutions for the competing risks LOWP and INVOL with sire ETA for true and functional herd life obtained in Chapter 5 and with official sire EBV for various traits. Rank correlation between sire ETA_{INVOL} and sire ETA_{LOWP} was really low, indicating that sires whose daughters are able to delay voluntary culling (LOWP) are not the same sires whose daughters are able to delay involuntary culling (INVOL). Sire ETA_{INVOL} was highly correlated with ETA for functional herd life, and in a smaller proportion with ETA for true herd life. These results are not surprising, and reflect the changes in both the survival model and the censoring criteria used to estimate these traits. The rank correlation of ETA_{INVOL} and the official rating for herd life is similar to the correlations of the official proof with ETA for functional and true herd life. The correlations of ETA_{INVOL} with all the other traits were low. Rank correlations of ETA_{LOWP} with other proofs illustrate some interesting points. ETA_{LOWP} had a higher correlation with ETA for true herd life than with ETA for functional herd life, indicating that adjustment for yield deviations account for at least part of culling based on production. ETALOWP had relatively high correlations with LPI and TEV, illustrating the importance of production traits

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in the official indices (top LPI and TEV sires would tend to have less daughters culled for low production). Pearson correlations between ETA_{LOWP} and the remaining official proofs were as expected: relatively high with production traits and low with all the others.

The results from the competing risks analysis have demonstrated the feasibility of using regularly recorded disposal codes to improve genetic evaluations for functional herd life. If a given cow was certainly culled due to low production, it does not seem reasonable to consider her failure time as completed (uncensored) if the trait of interest is the ability to delay involuntary culling. The accuracy of the disposal codes is often questioned by researchers because it relies on information given voluntarily by producers. The analysis of the effect of various covariates on the risk of being culled for different reasons have shown that there is no grounds to disbelieve what was reported by producers. The system could be improved, though. A secondary culling code would help producers to express a little bit better the complexity of a culling decision. It would be particularly important to reveal cases in which low production is combined with other reasons. Finally, should culling codes be accounted for in survival models that estimate genetic parameters for herd life traits, an educational campaign among producers would be advisable in order to improve the quality of the information collected.

Table 7.5 - Pearson correlation estimates between sire ETA for INVOL, LOWP, true and
functional herd life and official genetic evaluations published by the Canadian Dairy Network
in May 1997 [*] .

	ETA ^b for INVOL	ETA for LOWP	ETA for Functional Herd Life	ETA for True Herd Life
ETA for LOWP	0.11	1.00	-	-
ETA for Functional Herd Life	0.86	0.53	1.00	-
ETA for True Herd Life	0.69	0.76	0.90	1.00
Official Rating for Herd Life	0.62	0.34	0.66	0.62
LPI	0.14	0.68	0.36	0.61
TEV	0.14	0.71	0.35	0.63
EBV for Milk	0.05	0.66	0.18	0.45
EBV for Fat	0.03	0.59	0.14	0.45
EBV for Protein	0.02	0.68	0.21	0.51
EBV for Conformation	0.37	0.27	0.46	0.43
EBV for Capacity	0.13	0.13	0.19	0.18
EBV for Feet and Legs	0.28	0.08	0.27	0.23
EBV for Mammary System	0.35	0.26	0.43	0.41
Rating for Somatic Cell Score	0.17	0.37	0.30	0.38
Milking Speed Rating	0.18	0.29	0.29	0.33
Rating for Service Sire Calving Ease	0.03	0.02	0.02	0.00

*Number of bulls included in the survival analysis that also have official genetic evaluations = 1721. ^bETA = estimated transmitting ability; LPI = lifetime profitability index; TEV = total economic value; EBV

= estimated breeding value; LOWP = culling due to low milk or low fat production; INVOL = culling for reasons other than LOWP.

SUMMARY

- Competing risks analysis is well suited for studies of culling trends in dairy cattle populations, providing an intuitive way of describing the impact of different covariates on the failure time and, at the same time, a solid theoretical framework for hypothesis testing.
- The cause-specific hazard functions for Quebec Holsteins follow distinct patterns and are affected differently by the covariates included in the model.
- Lactation number × stage of lactation is the covariate with the largest impact on the hazards of the different competing risks.
- Cows are at risk of being culled for low production almost exclusively from 121 to 240 days in milk, but the risk of being discarded for other reasons is maximum at the end of the lactation.
- The risk of leaving the herd due to low production presented a descending trend from 1982 to 1994, and this trend was accompanied by an increasing risk of culling for reasons other than production.
- The older the first calf-heifer calves, the higher the risk of being discarded for reasons other than low production.
- Poor producing cows are not only candidates to voluntary culling, but they are also at a higher risk of being culled for all other reasons.
- Owner sampler herds tend to cull more cows for mastitis and less cows for low production, feet and legs and udder breakdown than official herds. Culling for involuntary reasons is similar in both milk recording options.
- If the goal of a breeding program is to identify bulls whose daughters are able to delay culling due to reasons other than production, then considering records of cows culled for low production as censored is recommended.



Figure 7.1 - Survivor curves for different competing risks. \blacksquare = culling due to low production; + = culling due to reproductive problems; \bullet = culling due to udder breakdown; — = culling due to mastitis; \forall = culling for feet and leg problems; × = culling or death due to sickness, milk fever, displaced abomasum or bloat; \blacktriangle = culling due to injury, poisoning or electrocution.



Figure 7.2 - Hazard curves for different competing risks. \blacksquare = culling due to low production; + = culling due to reproductive problems; \bullet = culling due to udder breakdown; --- = culling due to mastitis; ∇ = culling for feet and leg problems; × = culling or death due to sickness, milk fever, displaced abomasum or bloat; \blacktriangle = culling due to injury, poisoning or electrocution.



Figure 7.3 - Estimated hazard rate for culling due to low production for an average cow with calving intervals of 400 days.





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Figure 7.5 - Estimated hazard rate for culling due to mastitis for an average cow with calving intervals of 400 days.





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Figure 7.7 - Estimated hazard rate for culling due to feet and leg problems for an average cow with calving intervals of 400 days.



Figure 7.8 - Estimates of the year effect for culling due to low production.



Figure 7.9 - Estimates of the year effect for involuntary culling.



Figure 7.10 - Estimates of the year effect for culling due to mastitis.



Figure 7.11 - Estimates of the year effect for culling due to udder breakdown.



Figure 7.12 - Estimates of the year effect for culling due to feet and leg problems.



Table 7.13 - Estimates of the effect of age at first calving for culling due to low production.







Figure 7.15 - Estimates of the effect of age at first calving for culling due to feet and leg problems.



Figure 7.16 - Estimates of the effect of milk recording option for the different competing risks. Solid bars = owner sampler herds; blanc bars = official herds.

CHAPTER 8

Survival Analysis of 'First-Crop' Daughters of Holstein Bulls

In the process of selection of dairy sires, the first crop of daughters of young bulls provide the information that will be used to rank these bulls according to their genetic merit for various economically important traits, which will finally determine their fate in the A. I. Industry. The group of bulls selected will then start to be heavily used as sires of the future cows, contributing significantly to the population genetic makeup. These bulls will have their initial genetic evaluation for herd life based mostly on the survival of their first-crop daughters in first lactation. Should herd life receive more importance in the future selection indices to be used by the dairy industry, then accurate predictions of completed herd life from first-crop daughters data will be needed. This chapter describes the use of a Weibull model to study the factors affecting the survival of first-crop daughters of Holstein bulls from first calving to the end of first lactation and to assess genetic differences between bulls regarding the survival of their first-crop daughters in first lactation. These genetic evaluations will then be correlated with the ETA's for true and functional herd life obtained for the same sires in Chapter 5, to evaluate the potential use of survival in first lactation as a predictor of completed herd life.

MATERIALS AND METHODS

The 'first-crop' daughters of Holstein bulls that calved in herds enrolled in the Programme d'Analyse des Troupeaux Laitiers du Québec (PATLQ) from 1981 to 1994 were identified based on bull's birth date (all daughters calving for the first time up to 72 months after bull's birth date were considered to integrate the first batch of daughters). A minimum of 20 daughters per sire was imposed. Information on survival in first lactation and on all covariates included in the analysis were obtained from lactation records from PATLQ files. Records of 67,198 daughters of 1401 bulls were included in the edited data. Information on bulls' birth dates was obtained from the Canadian Dairy Network public files. Two traits were analysed: true stayability, defined as the ability to delay culling in first lactation regardless the disposal reason, and functional stayability, considered as the ability to delay involuntary culling (Ducrocq, 1987) in first lactation. A mixed Weibull model without relationships among sires was used to analyse true stayability in first lactation:

$$\lambda(t) = \lambda 0(t) \exp\{y_i(\tau) + g_i(t') + o_k + a_l + h_m(\zeta) + s_n\}$$

where $\lambda(t)$ is the hazard function at time t; $\lambda_0(t) = \lambda \rho(\lambda t)^{p-1}$ is a Weibull baseline hazard function with parameters λ and ρ ; $y_i(\tau)$ is the effect of year i (i=1, for 1981,...,i=14, for 1994), assumed to be piecewise constant (jumps chosen arbitrarily to occur at τ = March 1 of each year); $g_j(t')$ is the time-dependent effect of stage of lactation (j=1,...,4), assumed to be piecewise constant, changes occurring at t' = 120, 240, and 305 days in milk; o_k is the effect of milk recording option (k=1, for owner sampler herds; k=2, for official herds); a_i is the effect of age at first calving (l=1, for ≤ 22 months,...l=19, for ≥ 40 months); $h_m(\zeta)$ is a random piecewise constant effect of herd-year-season, and jumps occur at ζ = March 1 and ζ = September 1 of each year (m=1,...,32564); and s_n is the random effect of sire n (n=1,...,1401). For functional stayability in first lactation, the model used (relationships between sires not included) was

$$\lambda(t) = \lambda 0(t) \exp\{y_i(\tau) + g_i(t') + o_k + a_l + p_q + h_m(\zeta) + s_n\}$$

where the only difference from the model for true stayability is the inclusion of p_q , which is the effect of the within herd-year-season class of 4% fat corrected milk yield at peak. Nine classes were defined on the basis of the deviation from the herd-year-season peak yield average: <10 kg below the average, 7 to 10 kg below the average, 4 to 7 kg below the average, 1 to 4 kg below the average, 1 kg above to 1 kg below the average, 1 to 4 kg above the average, 4 to 7 kg above the average, 7 to 10 kg above the average, and \geq 10 kg above the average.

In both models, a log-gamma prior density function was assumed for both random effects, s_n and $h_m(\zeta)$. The gamma parameter for the sire effect γ_s was estimated as the mode of its posterior density, which was approximated by Laplacian integration. For a justification of assuming a log-gamma distribution for the sire effect (when relationships are not considered), see Ducrocq et al. (1988b). The gamma parameter γ_{hys} was estimated jointly with the other effects after exact algebraic integration of the log-gamma random effect of herd-year-season. Right censored records were: records of cows sold from their original herds during first lactation, records of cows finishing normally their first lactation, and records of cows with their first lactation in progress when data were collected (March 1995). The survival analysis was carried out using the "Survival Kit", a set of FORTRAN programs specially adapted to animal breeding needs (Ducrocq and Sölkner, 1994).

RESULTS AND DISCUSSION

The average censoring time was 304.5 days after calving and the average time at culling was 196.2 days after calving. Right censored records were 75.8% of the total number

of records, meaning that approximately 24% of first-crop daughters were culled during first lactation. The importance of the different explanatory variables included in the models was verified by likelihood ratio tests. All tests were significant at P=0.001. The Weibull shape parameter ρ for true stayability was 1.691 and ρ =1.824 for functional stayability, indicating that the baseline hazard function for involuntary culling in first lactation has a higher inclination than the baseline hazard function when all reasons for disposals are considered. The intercept ($\rho \log \lambda$) was -11.840 for functional stayability and -10.507 for true stayability. The inclusion of stage of lactation in the models caused the greatest change in ρ , in agreement with the results of Ducrocq (1994), who pointed out that this illustrates the sharp change of the baseline hazard function when changes in hazard during a lactation are accounted for.

Estimates for the Fixed Effects

Estimates for the fixed effects will be shown only for functional stayability, unless specified otherwise. The risk of being culled during first lactation was approximately 20% higher for first-crop daughters raised in official herds than for those raised in owner sampler herds. This result might indicate the existence of different selection goals and different culling policies between the two milk recording options. It could also be a consequence of the fact that only 27% of the records were realized in owner sampler herds, and this may not be a representative sample. Figure 8.1 shows the estimated hazard rate for an average cow in an average official herd, illustrating the variation in the hazard as the stage of lactation changes. The hazard rate increases faster in early lactation (less than 120 DIM), continues increasing at a slower rate from 121 to 240 DIM, and then decreases markedly from 241 to 305 DIM to increase again after 305 DIM. The thresholds separating different stages were chosen to be coincident with important references used by Canadian dairy farmers: 120 DIM is when a cow receives her first BCA (Breed-Class-Average); 240 DIM is when the cow becomes

eligible for an official production certificate; and 305 DIM is the conventionally adopted lactation length in which cows are compared regarding production traits. It is not surprising that producers tend to cull more intensively before cows reach 240 DIM, avoiding that the official herd production average be penalized by the inclusion of the poorest producers in the herd. Cows kept longer than 240 DIM have a significant lower risk of being culled, but the hazard rate increases sharply for those animals still in milk after 305 DIM (a typical case would be cows with reproductive problems that will not have a subsequent lactation and will be kept lactating while their milk production is not too low). Several diseases tend to occur right after calving, what could help to explain why the highest relative risk of being culled is in the first 120 DIM. However, previous studies on culling reasons in Quebec Holstein cows (Chapters 4 and 7) have shown that most of the culling in early lactation is due to low production. The shape of the hazard curve for first-crop daughters in first lactation is guite different from the hazard rate in first lactation shown for functional herd life in Figure 4.1, indicating that producers might have a different attitude towards the offspring of unproven bulls. Differences in the two curves occur especially after 305 days in milk (the hazard is relatively higher for first crop daughters at the end of the lactation). However, in the survival analysis of first-crop daughters all records of cows still alive at the end of the lactation were censored, and this may have inflated the estimate of the hazard associated with the last stage of lactation (all completed records in the last stage are failures).

The exponential of the solutions for the different effects can be viewed as relative culling rates (w), which are easier to interpret than hazard estimates (the reference class has a relative culling rate of 1, and all the other values represent the relative difference in risk of being culled). Figure 8.2 shows the relative culling rate associated with different years. Relative culling rates for 1981 and 1994 were artificially lower than for other years due to problems of truncation, and estimates for these two years are not included in Figure 8.2. Culling rates did not vary much over the years included in this study, with the exception of 1985, which presented a relative culling rate almost 50% above the reference year (1987). This increase in the culling intensity of first lactation cows had been already pointed out in a previous study using different methodologies (Chapter 2), and it seems to be related to a cut in quotas occurred in the Canadian dairy industry, which would have stimulated producers to cull more intensively their heifers.

Estimates of relative culling rate associated with different ages at calving are shown in Figure 8.3 for functional stayability and in Figure 8.4 for true stayability. The risk of being culled for any given reason in first lactation (true stayability) is constant for cows calving from 25 to 35 months of age, but for functional stayability an ascending trend is observed for the same range of ages (the older the heifer at calving, the higher the risk of being discarded). The change in the estimates for age at calving is even more accentuated for heifers calving younger than 25 months of age, which are significantly higher than average for true stayability and significantly lower than the reference age (26 months) for functional stayability. These changes in the estimates of one effect (age at calving) after another effect is added in the model (yield deviation) indicates the existence of some sort of interaction between the two covariates. Suppose that heifers calving at early ages have lower milk production than their contemporaries who were older at calving (first-calf heifers are still growing, and older females might have a physical advantage to express their genetic potential for milk yield). In this case, it would be reasonable to assume that younger first-calf heifers are actually at a lower risk of being culled for reasons other than production, as it is shown in Figure 8.3, and that not accounting for herd-year-season yield deviation would cause the hazard for early calvings to be overestimated and the hazard for late calvings to be underestimated (Figure 8.4). In other words, age at first calving has a greater importance for functional stayability than for true stayability. First-crop daughters calving after 35 months of age represented less than 4% of the total, and they were clearly more prone to be discarded than other cows regardless the presence of yield deviation in the model. This result is not surprising, because

females in this situation have their lifetime performance jeopardized due to reproductive problems.

The effect of milk production on the hazard function of first-crop daughters (model for functional stayability) is represented in terms of relative culling rates in Figure 8.5. Production at peak has a reasonably high correlation with lactation yield, and its use to rank cows for production is justified because it would be recorded for the majority of the cows (except for those being culled right after calving). Hence, the utilization of 4%FCM at peak avoids the need for projections in order to compare cows production in a fair basis. The risk of being culled was significantly lower for those cows producing more than the herd average, although it may not be apparent in Figure 8.5. The result which can be easily seen is that the relative culling rate of the low producing cows is tremendously higher than for average producers (class 5). The difference in risk reaches the extreme of being 41 fold when comparing classes 1 (less than 10 kg below the herd-year-season average) and 5 (average class). These results confirm that the most important reason for culling in first lactation is low milk production.

Estimates of the Random Effects

A major goal of this study was to investigate possible genetic differences between bulls regarding the stayability in first lactation of their first crop of daughters. Figure 8.6 shows sire Estimated Transmitting Ability (ETA) for functional stayability, expressed as relative culling rates. Sire ETAs for true stayability ranged from 0.74 to 1.32 and sire ETAs for functional stayability ranged from 0.81 to 1.25. Since functional stayability is an attempt to assess cow's ability to delay culling for involuntary reasons, it is not surprising that solutions for the sire effect for true stayability (all types of culling reasons) have wider range of values. Figure 8.7 shows the correlation between sire ETAs for true and functional stayabilities, and it indicates a good agreement between the two traits (r=0.86). Sires whose first-crop daughters are more prone to be culled for involuntary reasons in first lactation (functional stayability) seem to be the same sires whose daughters are at a higher risk of being discarded for any reason. The present results indicate that there is significant genetic variation among sires regarding survival of their first-crop daughters in first lactation. Daughters of a bull with a relative culling rate of 0.80 would have a risk of being culled 50% lower than cows who's sire has a relative culling rate of 1.30. Another way of expressing differences between sires is illustrated in Figure 8.8, where expected survivor curves of daughters of three bulls with different relative culling rates are shown. For instance, 83% of the daughters of sire A are expected to be alive at 360 days after first calving, whereas the same expectation for daughters of bulls B and C would be 76% and 68%, respectively.

The sire effect was assumed to follow a log-gamma distribution, and the estimated dispersion parameter was $\gamma_s = 27.47$ for true stayability and $\gamma_s = 32.09$ for functional stayability. These values correspond to variances of s_n equal to $\psi^{(1)}(\gamma_s) \approx 0.037$ and $\psi^{(1)}(\gamma_s) \approx 0.032$, respectively. $\psi^{(1)}(\gamma_s)$ is the trigamma function evaluated at γ_s . The estimated gamma parameter for the effect of herd-year-season was $\gamma_{hys} = 4.61$ for true stayability and $\gamma_{hys} = 2.34$ for functional stayability, corresponding to variances of $\psi^{(1)}(\gamma_{hys}) \approx 0.242$ and $\psi^{(1)}(\gamma_{hys}) \approx 0.532$, respectively. Using the definition of heritability of the survival trait in the log scale developed by Ducrocq and Casella (1996),

$$h_{\log}^{2} = \frac{4 \psi^{(1)}(\gamma_{s})}{\psi^{(1)}(\gamma_{s}) + \psi^{(1)}(\gamma_{hys}) + \frac{\pi^{2}}{6}}$$

 $h_{kg}^2 = 0.08$ for true stayability and $h_{log}^2 = 0.06$ for functional stayability. From these estimates it is possible to approximate the heritability in the original scale using the expression given in Chapter 5. For true stayability, $h^2 = 0.17$ and for functional stayability, $h^2 = 0.14$. These

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estimates are higher than any estimate published for survival in first lactation, and reflect the fact that survival analysis makes a better use of the information available for the analysis of failure times than other methodologies.

In an attempt to evaluate how sire ETA for stayability traits in first lactation of their daughters relate to the sire ETA for the completed herd life traits estimated in Chapter 5, Pearson correlation coefficients were calculated and are shown in Table 8.1. All correlation estimates were quite low (from 0.50 to 0.59), particularly if the goal was to use stayability of first-crop daughters to rank bulls for completed herd life. Several factors might have caused these correlations to be low: the two studies used different adjustments for milk yield deviation, and this could alter the sire ranking because of the extremely high impact that relative production level has on the hazard rate; in the present study, cows were compared only with other first-crop daughters, whereas in real life dairymen compare them with all other first-calf heifers in the herd to make their culling decisions; relationships between bulls were not included here, and doing so could improve the accuracy of the evaluations through the information on completed herd life coming from the ancestors¹; and finally, correlations might be low because survival in first lactation only provides limited information about length of productive life of dairy cows.

 Table 8.1 - Pearson correlation estimates between sire ETA for stayability in first lactation

 traits and sire ETA for herd life traits.

	ETA for True Stayability	ETA for Functional Stayability	
ETA for True Herd Life	0.5882	0.5174	
ETA for Functional Herd Life	0.4952	0.5353	

¹On the other hand, including relationships in this case might dilute the information on survival coming from the daughters, and the effect of sire is then determined mostly by the information on the pedigree relatives.

SUMMARY

- Differences in survival in first lactation of first-crop daughters of Holstein bulls have been successfully described with the use of a proportional hazards model. This is the state-of-the-art methodology for analysis of herd life traits and should be used more often in animal breeding studies.
- The risk of being culled for reasons other than production increases with age at calving for first-crop daughters.
- Genetic variation among sires regarding true and functional stayabilities of their daughters was found to be significant, and heritability estimates were higher than estimates from the literature.
- The rank correlations between sire ETA for stayability of first-crop daughters in first lactation and sire ETA for herd life traits were low (0.50 to 0.59). Survival in first lactation does not seem to be a good predictor of completed herd life.
- If a more complete follow-up data on first-crop daughters (including daughters culled or dead prior to first calving) were available, the methodology used here could certainly provide valuable information to the young sires selection program.



Figure 8.1 - Estimated hazard rate for an average cow in an average official herd.



Figure 8.2 - Estimates of the year effect.



Figure 8.3 - Estimates of the effect of age at first calving in the model for functional stayability (first age class combines cows calving ≤ 22 months and the last age class combines cows calving ≥ 40 months of age).



Figure 8.4 - Estimates of the effect of age at first calving in the model for true stayability (first age class combines cows calving ≤ 22 months and the last age class combines cows calving ≥ 40 months of age).



Figure 8.5 - Estimates of the effect of within herd-year-season class of 4% fat corrected milk production at peak.



Figure 8.6 - Sire transmitting ability (ETA) for functional stayability expressed as relative culling rates.

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Figure 8.7 - Sire estimated transmitting ability for functional stayability plotted against sire estimated transmitting ability for true stayability (rank correlation = 0.86).



Figure 8.8 - Expected survivor curves of theree sires with different relative culling rates $(w_i = \exp[s_i])$. Sire A (dashed line) has $w_i = 0.77$; sire B (solid line) has $w_i = 0.94$; sire C (thick line) has $w_i = 1.27$.

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CHAPTER 9

Conclusions

The process of culling dairy cows was studied from several viewpoints in this thesis. In Chapter 3, simple statistics were used to evaluate how intensively were the Quebec farmers culling their cows, and which were the consequences in terms of herd life. The average productive herd life was approximately 33 months (about 3 parities), and it was very similar for owner sampler and official herds. This herd life corresponds to an average replacement rate of 36.3%. Cows in official herds had longer calving intervals than cows in owner sampler herds, but this probably reflects more differences in the reproductive management than in the fertility of their cows. Herds in the official option culled their first-calf heifers earlier and had a higher proportion of cows being culled prior to 240 days in milk than herds in the owner sampler option. Official herds have a significant portion of their total income coming from sales of breeding stocks (this is readily seen in the results from Chapter 4), and culling low producing cows as early as possible avoids that the herd performance records be influenced by these animals. However, phenotypic trends in herd life were generally stable over the years and quite similar in both milk recording options.

In Chapter 4, the reasons why Quebec Holsteins leave their herds was the main topic. It was observed that culling due to low milk or fat production had a clearly descending trend from 1981 to 1994, and that culling for other reasons (combined in what was named involuntary culling) increased in the same period. The combination of all reasons for disposal yielded a total culling rate approximately constant over the years, as was pointed out in Chapter 3. It became clear, therefore, that culling rates are quite limited tools, unless they are broken down in terms of reasons for disposal. Generally, the number of replacement heifers that is available in a given herd sets the limit for the total number of cows that can be culled in that herd, and any increase in involuntary culling will cause the proportion of cows culled for voluntary reasons to go down. Hence, there is motive for concern among Quebec farmers, because they are having less room for selection and more "forced" disposals year after year. When disposal reasons are analyzed separately, it is readily apparent that the general ascending trend in involuntary culling is caused by an increase in culling for reproductive problems, for mastitis and for feet and leg problems. Extensionists can use this information to alert producers and to focus their educational programs on reproductive management, mastitis control and measures to decrease lameness, for instance.

In chapters 5, 6, 7 and 8, survival analysis techniques were used to investigate different problems related to culling. First, a sire Weibull model was fitted to estimate variance components and sire estimated breeding values for true and functional herd life. The estimated heritability for true herd life was 0.09 in the log scale and 0.19 in the original scale. For functional herd life, heritability in the log and in the original scales were 0.08 and 0.15, respectively. These values are higher than estimates from previous studies using different methodologies, and they reinforce the idea that survival models should be the method of choice in studies of herd life. When differences between sires are expressed in terms of the median survival time of their daughters, the difference between a top bull and a bull in the bottom of the rank was 690 days or 1.7 lactations, which can have a big effect in lifetime profitability. Selection programs carried out in Canada for the past 15 to 20 years had no deleterious effect on sire genetic merit for herd life traits. The models used in Chapter 5 resemble the models used to estimate official genetic evaluations for herd life in France and Austria (Vincent Ducrocq, personal communication), and should be considered as an alternative to the current linear models used in Canada for genetic evaluations of direct herd life. The main advantages of adopting Weibull models for sire evaluation in Canada are: survival models are theoretically superior to linear models for the analysis of failure time

traits; there is only one trait analyzed, which is length of productive life, instead of survival within first, second and third lactations; survival models treat incomplete records as censored. and all the information from partial records is taken into consideration; the inclusion of timedependent covariates accounts for changes in the hazard function that occur during the lifetime of each cow, instead of having within-class comparisons based solely on first parity values (e.g. milk yield deviation in first lactation, herd-year-season of first calving); heritability estimates from the Weibull models are considerably higher than the heritability for direct herd life currently assumed for Canadian evaluations (0.03); and finally, the statistical package "SURVIVAL KIT" (Ducrocq and Sölkner, 1994) opened the possibility of running sire and animal survival models in large data sets, eliminating the implementation difficulties that were often used to justify the utilization of linear models. The analysis of the estimates for the fixed effects included in the Weibull models of Chapter 5 provided some interesting results. Age at first calving has a pronounced effect on the hazard rate of Quebec Holsteins: the older the heifer calves, the higher the risk of being culled. Confirming the results from Chapter 3, milk recording option did not have an important effect on the overall culling rate. Surprisingly, the effect of changes in herd size on the hazard rate were quite small. The factors which have the strongest impact on length of productive life are lactation number×stage of lactation and milk vield deviation from the herd-year-parity average.

Culling based on conformation traits was assessed through the inclusion of cows' classification for composite traits in the survival model used to analyze length of productive life (Chapter 6). Producers who classify their cows use mainly Final Score to account for conformation in their culling decisions. To a lesser extent, classification for Fore Udder is also taken into consideration when determining which cows should be replaced. In populations where type classification is performed in most of the herds, including Final Score class in survival models is an effective way of accounting for culling based on conformation.
For the first time in the literature, competing risks analysis was utilized to study the cause-specific hazard function associated with different reasons for disposal in dairy cattle (Chapter 7). Competing risks are an extension of survival analysis in which the hazard for individuals failing due to each of many reasons is modeled separately, and this methodology provides a very rich framework to study reasons for disposal of dairy cows. The causespecific hazard functions for Ouebec Holsteins follow distinct patterns and are affected differently by explanatory variables. While the risk of being culled due to low production is concentrated from 121 to 240 days after calving, cows are at a greater risk of being discarded for other reasons at the end of the lactation. The general time trends observed in Chapter 4 (decrease in culling for low production and increase in involuntary culling) were confirmed by the competing risks analyzes. The risk of being discarded increases with age at first calving, with the exception of the risk of being culled for low production, which only increases for heifers calving after 34 months of age. Yield deviation from herd-year-parity average has a significant impact on culling for reasons other than production, suggesting that dairy farmers do not use all the alternatives to avoid involuntary culling if the cow is a poor producer. Although differences in length of productive life were similar for herds in both milk recording options, owner sampler herds tend to cull more cows for mastitis and fewer cows for low production, feet and legs and udder breakdown than official herds. Solutions for the sire effect (ETAs) were obtained for the various reason-specific hazards. Although it is possible to compute "proofs" for the risk associated with each reason for disposal, the reliability of the evaluations is very low for most of the bulls, because of the amount of censoring present when a single type of culling is considered. Ranking sires according to their cause-specific hazards would be the best approximation to the "cull rates" envisioned by dairy producers. However, publishing ranks of bulls with such low reliability would not serve any purpose but to confuse the producers. A more useful approach seems to be pulling together reasons for disposal into major categories such as voluntary and involuntary culling. It is shown in Chapter 7 that considering records of cows culled for low production as censored,

accounts for a significant portion of culling based on production that is not explained by the adjustment for yield deviation used in the functional herd life model. In other words, if the goal is to identify bulls whose daughters are able to delay culling due to reasons other than production, then records of cows that are known to have left their herds for low production should be considered as right-censored.

Survival in first lactation of first-crop daughters of Holstein bulls was studied with the use of Weibull models (Chapter 8). Looking at survival of first-crop daughters was an attempt to evaluate bulls for herd life at the same time they receive their first proof for other traits. Differences between bulls were found to be significant, but survival in first lactation does not seem to be a good predictor of completed herd life, and considerable changes can be expected in sire proofs as more daughters with known length of productive life are added to the data.

Based on the results from this thesis, some recommendations for the Canadian dairy industry can be made:

- survival analysis techniques should be used for national genetic evaluations for herd life;
- treating records of cows culled for low production as censored in models for functional herd life should be considered;
- primary and secondary reasons for disposal should be recorded by milk recording agencies in order to get a better approximation of the actual incidence of the different reasons;
- new disposal codes should be defined with the producers in order to include important reasons that are not in the current list (e.g. culling for low protein test and culling for undesirable conformation);
- if culling codes are going to be used as censoring criteria in models for herd life,

educational programs should be carried out to instruct producers about the importance of recording reasons for disposal more accurately;

- competing risks analysis could be used as the standard procedure for monitoring trends on reasons for disposal in dairy cattle;
- extensionists and practitioners should evaluate the possible causes for the ascending trend observed for involuntary culling in Quebec and urge herd managers to revert the situation mainly for economic reasons.

CHAPTER 10

Statement of Originality

To the best of the author's knowledge, the following results from this thesis constitute an original contribution to the scientific literature.

- Phenotypic trends in reasons for disposal in Quebec dairy herds were described for a 15-year period, using logistic regression models. Previous studies included only few years of data and did not use generalized linear models to analyze the incidences of reasons for disposal (binary responses).
- Survival analysis techniques had not been used to describe herd life traits in a large set of Canadian Holstein data. Sire proofs and heritability estimates for true and functional herd life were obtained for the first time in Canada using the state-of-the art methodology for analysis of length of productive life.
- The importance of cows' classification for conformation as culling criteria had not been studied before in Canada, particularly with the use of survival models. It was shown that among the composite type traits, Final Score is the most important culling criteria used by dairy farmers.
- This is the first time that competing risks analysis is applied to dairy cattle data to study reasons for disposal. It was demonstrated that this methodology describes the culling process in a very elegant manner, providing very useful results for both researchers and extensionists. Future studies on reasons for disposal in dairy cattle should take advantage of competing risks techniques.

• Survival of first-crop daughters of A. I. bulls had not been studied before. Differences in the genetic merit of sires regarding the survival of their daughters in first lactation was demonstrated using Weibull models.

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IMAGE EVALUATION TEST TARGET (QA-3)









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