Competing Risks Analysis of Reasons for Disposal in Quebec Dairy Herds

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Introduction

In this study, 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. This is a realistic approach, because it acknowledges 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. This is the first time competing risks analysis is used to describe cause-specific culling in dairy cattle.

Objectives

The objectives of this study were: 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 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.

Experimental Procedures

The lifetime records used in this study were of 331,147 Holstein cows from herds enroled in the PATLQ. Disposal reasons were defined based on the PATLQ disposal codes, which are reported by dairy producers every time a cow leaves the herd. 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 legs 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. 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 hazard functions for the different competing risks were obtained using the Life-Table method in the LIFETEST Procedure of SAS. 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. Then, a parametric Weibull model was used to analyze the effect of different covariates on the failure time of each competing risk. The covariates included in the model were: the time-dependent effects of year, lactation number × stage of lactation, annual change in herd size, within herd-year-parity yield deviation at 305 days in milk and herd-year (random), the fixed effects of age at first calving and milk recording option, and the random effect of sire. The effect of 305-day yield deviation 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. Although REPRO is the most important reason for disposal after low milk production, the model for REPRO did not converge and 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 was estimated as the mode of its marginal posterior density, which was approximated by Laplacian integration. The gamma parameter was estimated jointly with the other effects after exact algebraic integration of the log-gamma random effect of herd-year.

Results and Discussion

The non-parametric estimates of the hazard curves for each of the competing risks are shown in Figure 1. 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. 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 1 shows 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. 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.

The amount of censoring was really high for all competing risks (from 81 to 96%), except for INVOL, which presents a reasonable proportion of uncensored records (35%). This low incidence for each individual culling code, however, did not prevent the Weibull models 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. 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 a separate study with the same data, 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.

Figures 2 and 3 show the estimated hazards for LOWP and INVOL 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 2) 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. This confirms previous results which emphasized the importance given to the 240-days threshold by Quebec dairymen. Since official production certificates are only issued once 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 2) is similar to the estimates for functional herd life in a separate study, 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 1), which is not present in the hazard estimates for INVOL (Figure 2). 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, INVOL might be a better representation of the hazard experienced by a dairy cow, regardless her production, than functional herd life defined as true herd life corrected by production level. These results suggest that disposal codes can be used to improve inference on functional herd life. Estimated hazard rates for MAST , UDBR and F&L have yet a different form than the estimates for INVOL. 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 legs 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. Estimates of the year effect (expressed as relative culling rates) for LOWP and INVOL are shown in Figures 4 and 5, respectively. 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. In contrast, the relative culling rate for INVOL had a conclusively ascending trend from 1982 to 1994. 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. 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 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 are more restrict in their culling policies regarding both production and conformation characteristics. 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. 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 were obtained for heritability in the logarithmic scale and the corresponding approximation of heritability in the original scale. However, with the exception of the estimates for INVOL (which still has a reasonably high proportion of uncensored records), the values obtained 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 legs 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 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. More attention will be given to the estimates obtained for INVOL. Both h^2_{log} (0.07) and h^2 (0.15) were similar to the estimates obtained for functional herd life in a separate study, meaning that censoring records of cows culled for low production did not affect the magnitude of the heritability oftheherd life trait. 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. ETA_{LOWP} had relatively high correlations with LPI and TEV, illustrating the importance of production traits 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.

Impact

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 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 are no grounds to disbelieve what was reported by producers. The system could be improved, though. A secondary culling code would help producers to express 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.

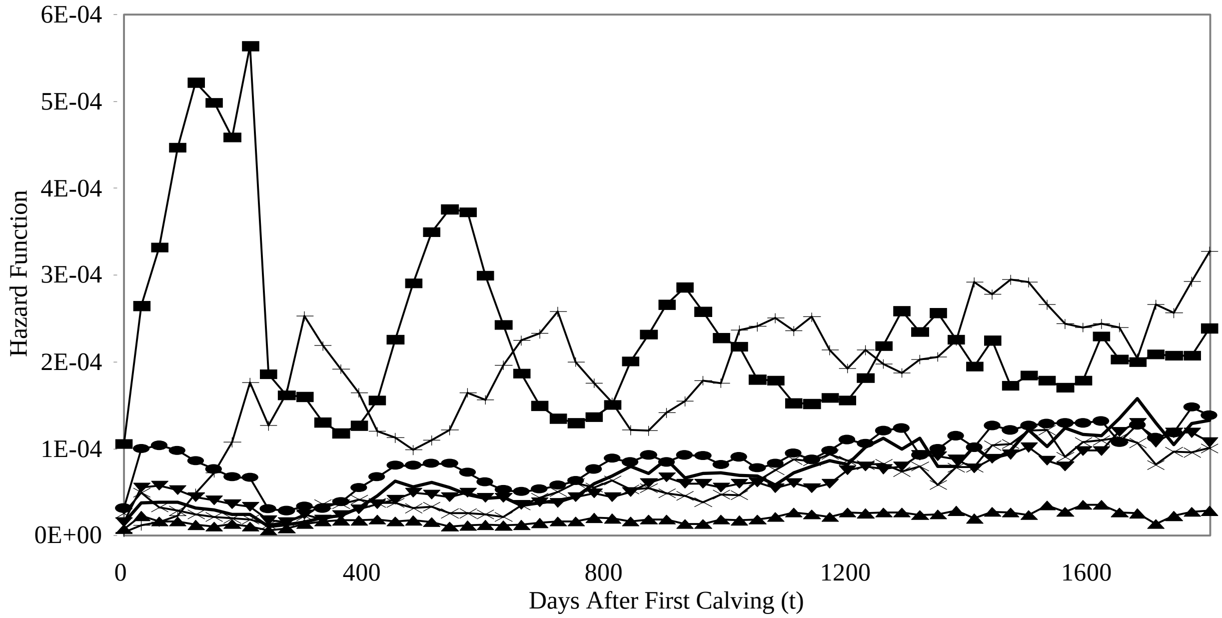

Figure 1 - Hazard curves for different competing risks. ■ = culling due to low production; + = culling due to reproductive problems; ● = culling due to udder breakdown; — = culling due to mastitis; ▼ = culling for feet and legs problems; × = culling or death due to sickness, milk fever, displaced abomasum or bloat; ▲ = culling due to injury, poisoning or electrocution.

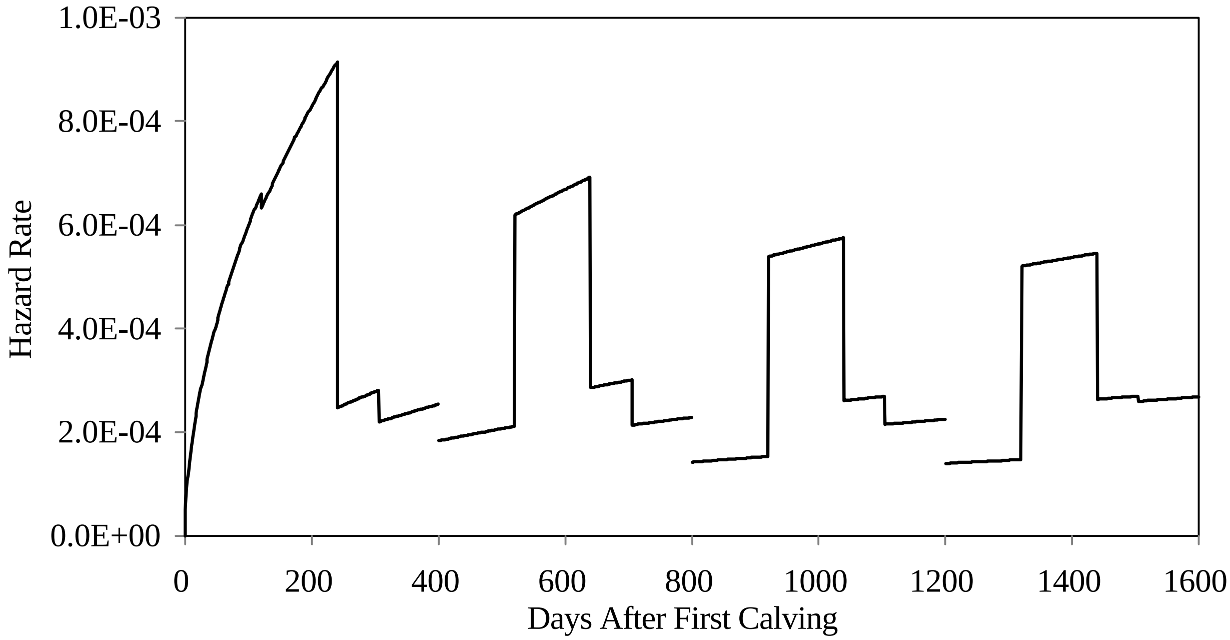

Figure 2 - Estimated hazard rate for culling due to low production for an average cow with calving intervals of 400 days.

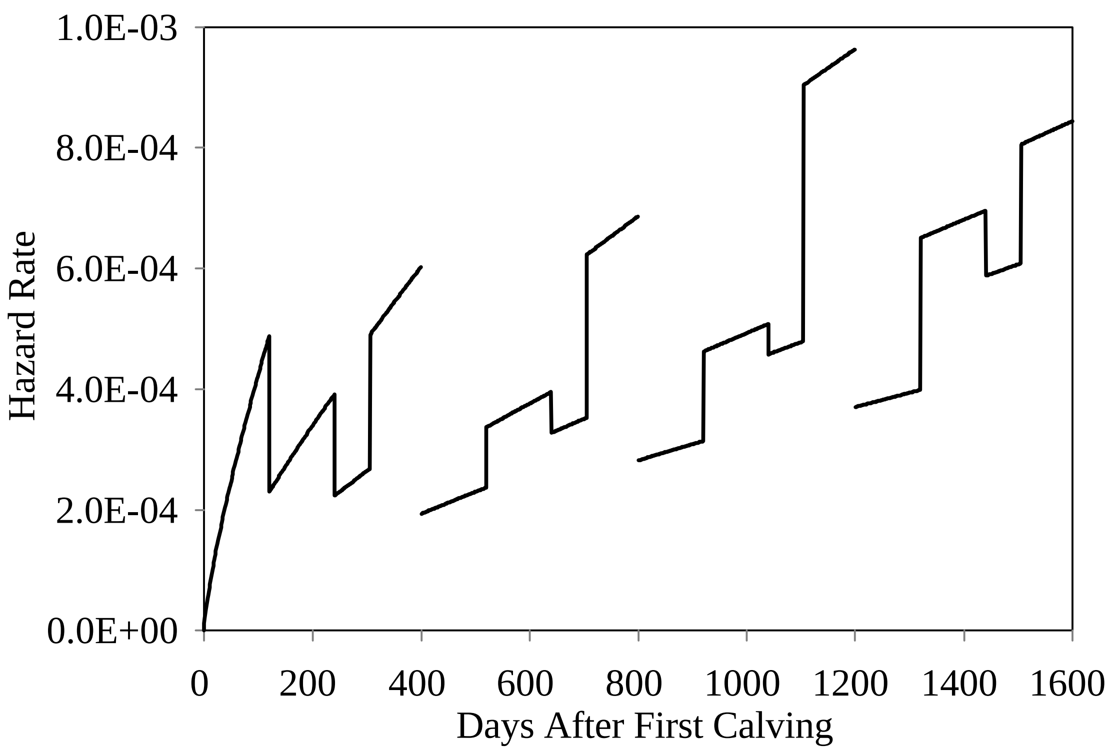

Figure 3 - Estimated hazard rate for involuntary culling for an average cow with calving intervals of 400 days.

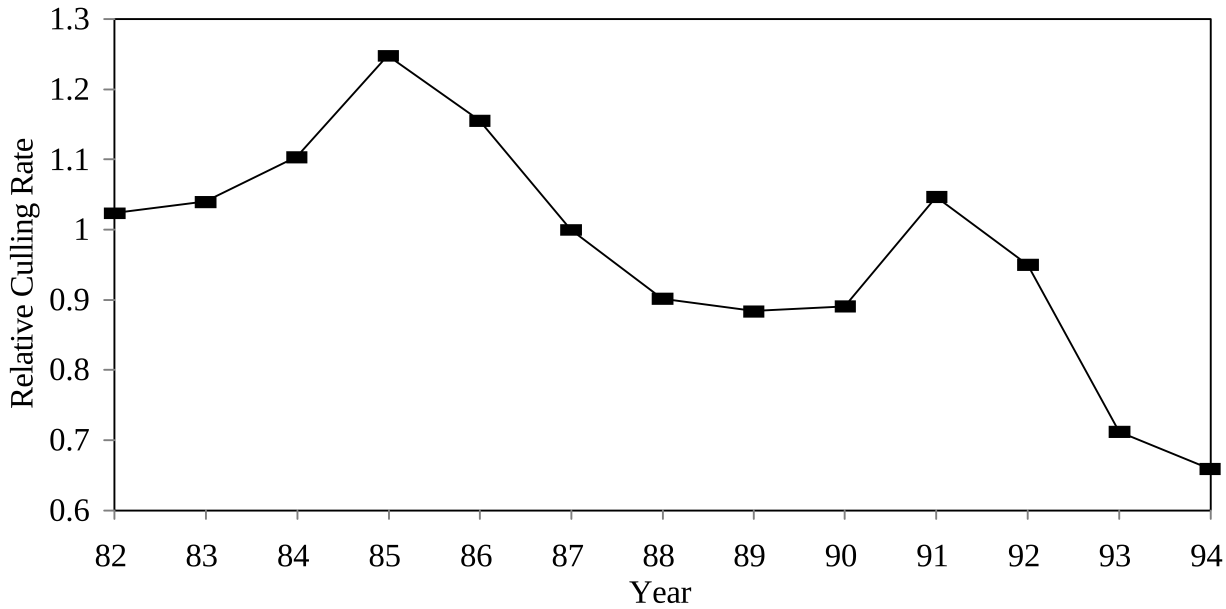

Figure 4 - Estimates of the year effect for culling due to low production.

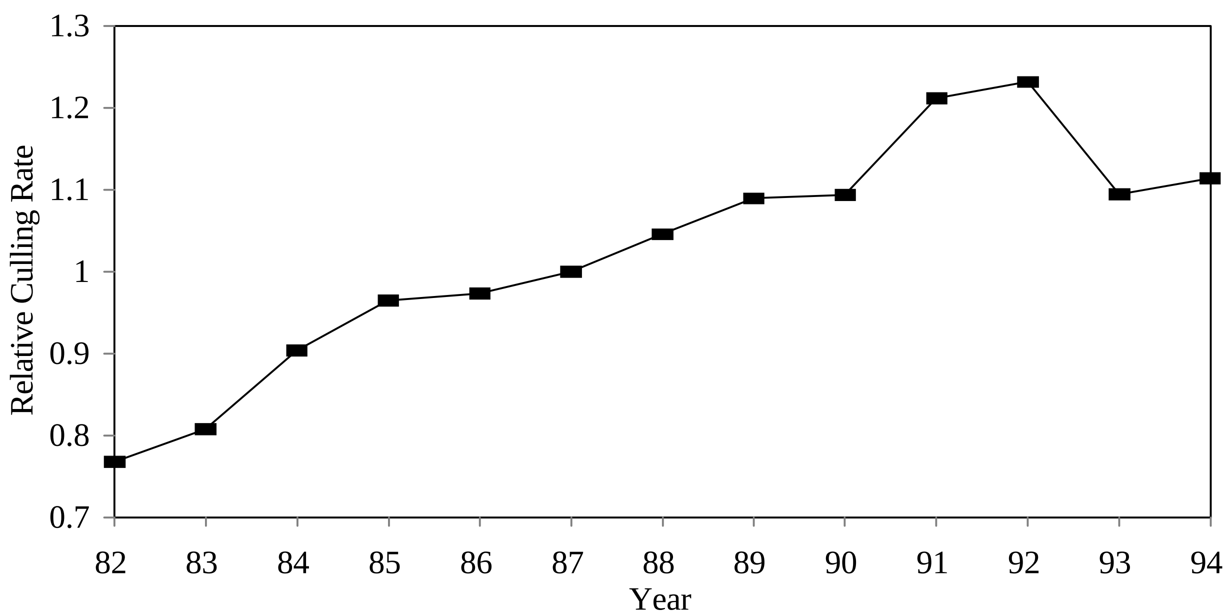

Figure 5 - Estimates of the year effect for involuntary culling.