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Changes in survival of Cattle *Bos taurus* in Trondheim during the Medieval period

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In the present study excavated bone material of *Bos taurus* from the Medieval City of Trondheim is used to investigate the slaughtering practice throughout the period from the 11th century to the 15th. The distribution of the proportion of bones with non-fused epiphyses in different bones gives information about the age-distribution of the animals. A method for estimation of survival curves, based on logistic regression, is proposed, and the density function is derived. We find that the slaughtering of young calves was reduced from the 11th century to early in the 14th century. Then, in the period just after the Black Death, the slaughtering of young calves increased, but it did not reach the high level of the 11th century.

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INTRODUCTION

Our knowledge about cattle breeding in the Middle Ages of Norway is very limited. Written sources from that time contain little information about the size, mortality or the milk production of the cattle. According to King Magnus' (the Lawgiver) law (1274), a cow should not be older than 8 years when used as means of payment. The cow should have given birth to at least two calves. The excavated bone material from that period has been dominated by small indiduals (Wiig 1981, Lie 1988). According to written sources from later periods, the milk production during the summer was small (about 500 liters) and the animals were extremely underfed during the winter season. There may have been geographical differences, but no striking differences in the excavated material from medieval layers in Oslo, Trondheim and Bergen have been found. Nevertheless, the conditions may have changed during the Middle Ages with respect to mortality (Wiig 1981), and the individual size may also have decreased.

The aim of this paper is to explore the changes in mortality rate and slaughtering pattern of cattle throughout the medieval period in the city of Trondheim using excavated bone material. We propose a method based on the distribution of non-fused epiphyses for different bones.

MATERIAL

The bone material which is the basis for this work was excavated in Trondheim during the period 1973 to 1985. The bones were collected on the site where the new library recently has been built. The site, approximately 3500 square meters, was divided into 22 smaller areas 7 of which are represented in the material forming a subarea of 700 square meters (see Fig. 1).

The material covers five hundred years, from late in the 10th century to about 1475. The period has been divided into 10 phases. A fire or a redisposition of the area or a building have marked the end of each phase. The phases 4 to 7 are not represented in the material. The bone samples from phase 1, the oldest one, and phase 9 are rather small. The latter is overlapping with phase 10, and the material from these two phases was therefore combined. The material from phase 1 was excluded from the investigation and so were the bones from phase 3. Phase 2 is dated to the middle of the 11th century (1025—1075). Phase 8 covers the period from about

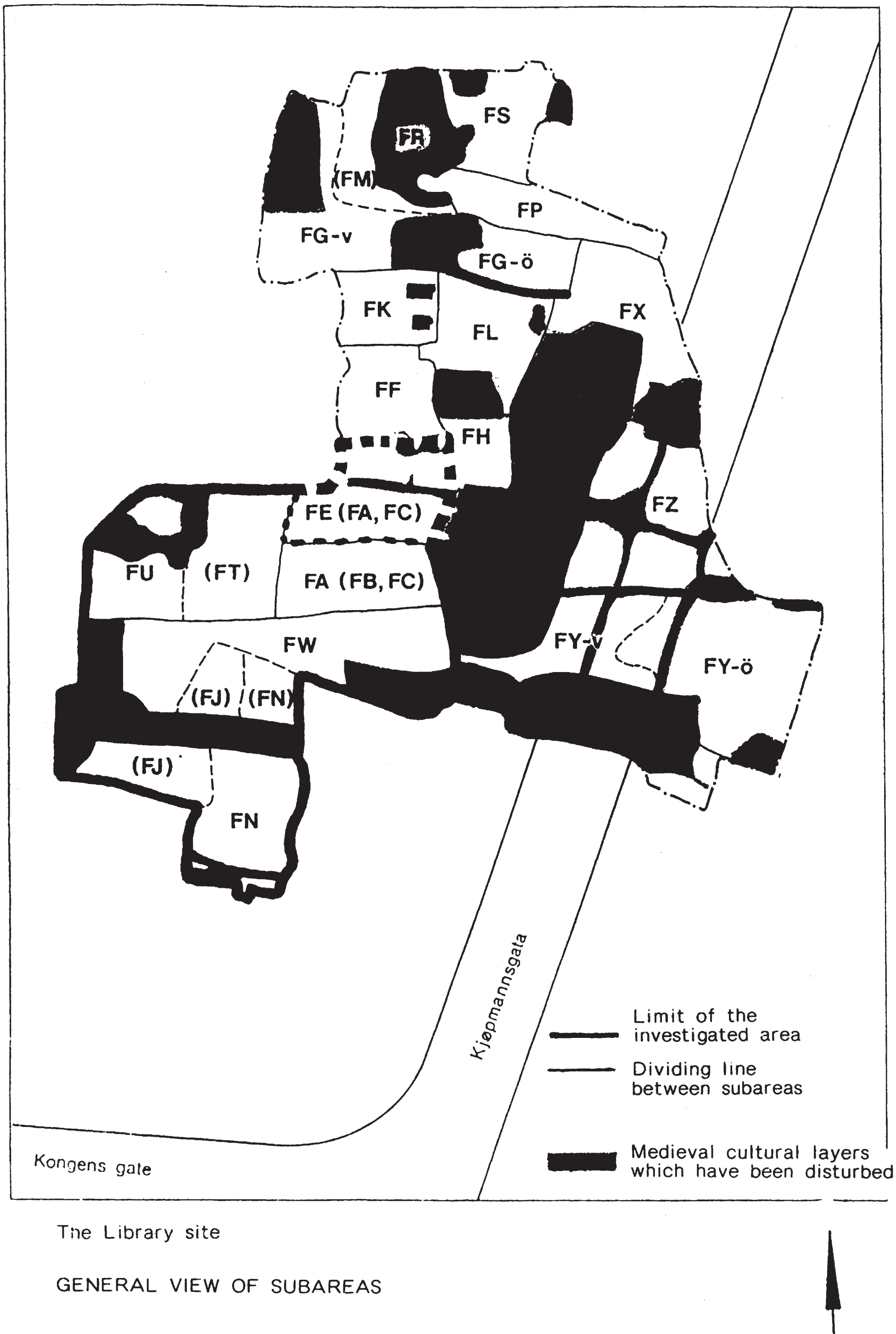

Fig. 1. Location map for the site of the excavation, Folkebibliotekstomten in Trondheim.

1225 to about 1325 while the phases 9 and 10 include the last 25 years of the 13th century towards the end of the 15th century (about 1475). The phases 8 to 10 are probably overlapping from an archaeological point of view, but probably most of the bones from phase 9 and 10 belong to the time just after the Black Death.

Osteological methods

Each bone was classified as belonging to an individual with an attained age of below or above a certain age, based on the condition of the epiphyses. According to Habermehl (1961), the age when the epiphyses fuse to the bones is different for different bones, and this age is assumed to be known and constant thoughout the study period.

On the basis of our experience we have made a few modifications to the method. The lumbal vertebrae epiphyses are fused at the age of 7 years, according to Habermehl, while the epiphyses of the other vertebrae are fused two years later. Material from medieval times seems to imply that all vertebrae epiphyses were fused at the same age, and we have assumed that it occurred at the age of 9 years. The distal end of humerus and the proximal end of radius appear without epiphyses with nearly the same frequency in medieval material. This may indicate that the epiphyses of these bones were fused at the same time, assumedly when the animal was about 18 months. With respect to the distal ends of the metapodials and tibia we have followed Habermehl's i.e. epiphyses fusion at the approximate age of two and a half years. All the other epiphyses were assumed to have been fused when the animals were approximately 4.5 years. These are the femur epiphyses, the proximal epiphyse of humerus and tibia and the distal epiphyse of radius. The bones used in the analysis and the age at which the epiphyses are assumed to fuse are shown in Table 1.

Table 1. Distribution of proximal and distal ends of different bones without or with fused epiphyses in phase 2, 8 and 9—10 from medieval Trondheim. The vertebrae were treated as one unit, and classified as missing epiphyses if at least one epiphyse was missing. All other bones in the table were either distal or proximal fragments of bones.

		Phase 2		Phase 8		Phase 9–10	
Bone	Assumed age for fusing of epiphyses	Not fused	Fused	Not fused	Fused	Not fused	Fused
Radius prox.	18 months	6	21	2	27	2	5
Humerus dist.	18 months	6	25	1	26	3	23
Metacarpus dist.	30 months	4	8	6	15	4	9
Tibia dist.	30 months	14	18	8	25	7	7
Metatarsus dist.	30 months	6	9	5	17	1	11
Calcaneum	54 months	14	16	14	6	5	6
Femur prox	54 months	19	10	6	18	1	4
Humerus prox.	54 months	15	10	1	10	2	2
Radius prox.	54 months	18	10	12	8	1	5
Ulna prox./dist.	54 months	16	8	6	8	4	2
Femur dist.	54 months	13	13	6	10	6	1
Tibia prox.	54 months	13	7	8	12	5	6
Cervical vertebrae	108 months	22	8	10	7	5	5
Thoracal vertebrae	108 months	80	30	24	12	16	11
Lumbal vertebrae	108 months	45	16	15	11	8	8

Statistical methods

For each type of bone ($i = 1$ — 15) (see Table 1), the proportion of bones without fused epiphyses was assumed to estimate the proportion of animals not surviving a certain fixed age t_i. The distal and proximal ends of the bones were treated as independent bones as none of the bones included in the analysis were complete the vertebrae and some of the metapodials (which have only one epiphyse). Futhermore, the probability that two fragments from the same bone are represented in the data is very low (Lie, 1980), and so is the probability that two bones from the same individual are represented. Thus the bone fragments are assumed to be independent, and the sampling is assumed to be binomial. The vertebrae were treated as one entity, and only those with two fused epiphyses were assumed to be due to animals with an attained age of 18 months or more.

A logistic regression model (Cox 1970) was used to estimate the mortality curves in each of the three phases from the excavation. To improve the fit of the model to the data, the inverse of the age of the animals, $1/t$, was introduced as a regressor. The inverse of the age was also used to test whether a difference in mortality between two phases n (measured by the odds-ratio) was not proportional with the age of the cattle. More specifically, the term $1/t$ was used to assess differences in mortality among calves between the phases. We choose to leave out the constant from the model because it has no simple interpretation and will probably not contribute much to the flexibility of the model.

We will require that the model shall predict survival curves $S(t)$ as non increasing functions of age (t) for $t \geq 0$ and that $S(t = 0) = 1$. Then

$$S(t) = 1 - p(t)$$

where $p(t)$ is the proportion of animals not surviving age t and

$$p(t) = \frac{e^{\beta t + \gamma \frac{1}{t}}}{1 + e^{\beta t + \gamma \frac{1}{t}}}$$

Obviously, we must require that $\gamma < 0$. Otherwise the value of p will be different from zero when $t = 0$. When $\gamma < 0, p(t)$ would have a maximum at $t = (\gamma/\beta)^{1/2}$. It then $\beta > 0$, the function $p(t)$ will be an increasing function for $t > 0$ and $p(t = 0) = 0$.

The model for phase 2 can be written:

$$log(\frac{p}{1-p}) = \beta_1 t_i + \gamma_1 \frac{1}{t_i}$$

or

$$p = \frac{e^{\beta_1 t_i + \gamma_1 \frac{1}{t_i}}}{1 + e^{\beta_1 t_i + \gamma_1 \frac{1}{t_i}}}$$

where p is the proportion of animals not surviving age t_i in the specified phase, β_1 is the regression coefficient for the log odds of death on the age in phase 2. γ_1 measures to what degree the mortality curve differs from the logistic function. For Phase 8 the model becomes

$$log(\frac{p}{1-p}) = (\beta_1 + \beta_2)t_i + (\gamma_1 + \gamma_2)\frac{1}{t_i}$$

where β_2 measures the logarithm of the ratio of the mortality odds in phase 9 vs. phase 2 as proportional with age. The parameter γ_2 measures to what extent there is a difference in mortality between phase 2 and phase 8 that is not proportional with age. For Phase 9—10, the model becomes

$$log(\frac{p}{1-p}) = (\beta_1 + \beta_3)t_i + (\gamma_1 + \gamma_3)\frac{1}{t_i}$$

where the parameters β_3 and γ_3 are analogous to β_2 and γ_2, now for phase 9—10 vs. phase 2.

Thus, the model was fitted to the data with the restrictions $\gamma_1 < 0$, $\gamma_1 + \gamma_2 < 0$, $\gamma_1 + \gamma_3 < 0$, $\beta_1 > 0$, $\beta_1 + \beta_2 > 0$ and $\beta_2 + \beta_3 > 0$ on the parameters. Note that if the constant terms were included in the model, these constraints would still guarantee that p was an increasing function of t for $t > 0$ and that $p(0) = 0$.

Maximum likelihood estimates for all parameters were obtained using a binomial likelihood, and the analysis was performed by the program PLR in BMDP (Engelman 1985). A backwards stepwise procedure was used to eliminate parameters that were not significant on the 5% level. If the constraints are violated in the estimation of the parameters by PLR, a search for the best model that satisfies the restrictions will be carried out by removing combinations of parameters.

Survival curves were obtained by subtrac-

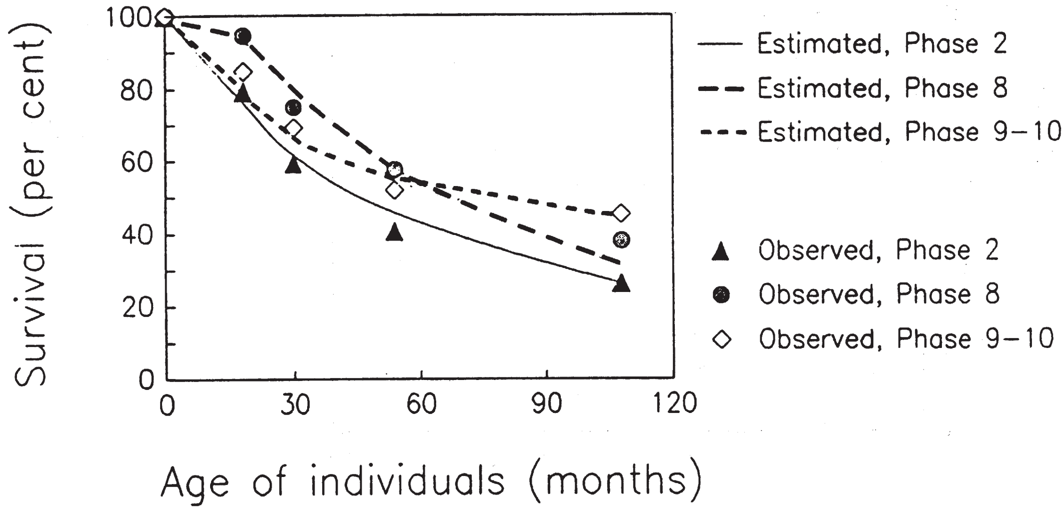

Fig. 2. Survival curves for cattle (*Bos taurus*) in three phases of the Medieval City of Trondheim.

ting the estimated mortality probabilities from one, and these curves were plotted together with the observed data. The density function was obtained by differentiation of the estimated function $p(t)$ with respect to t. The density function is the distribution of the slaughtering as a function of the age of the animals, not to be confused with the so called hazard rate function.

RESULTS

Highly significant differences in the slaughtering patterns between the three different phases were revealed by the logistic regression analysis (Table 2). The difference in the mortality between phase 9—10 and phase 2 (measured by the odds ratio) may be assumed to have been proportional with the age of the individuals with the lower mortality in phase

Table 2. Logistic regression estimates for the proportion of animals not surviving age t, by age, 1/age and phase. Phase 2 was used as baseline.

		Maximal model.		Reduced model		Final model.	
Parameter		Estimate	p-value	Estimate	p-value	Estimate	p-value
Age	(β_1)	0.01289	<0.0001	0.012714	<0.0001	0.01164	<0.0001
1/Age	(γ_1)	-24.191	<0.0001	-25.977	<0.0001	-24.682	<0.0001
Age, Phase 8	(β_2)	-0.003315	0.2204	-0.003641	0.1727		
1/Age, Phase 8	(γ_2)	-21.797	0.0038	-20.012	0.0043	-25.628	<0.0001
Age, Phase 9-10	(β_3)	-0.007284	0.0176	-0.008341	0.0015	-0.007519	0.0031
1/Age, Phase 9-10	(γ_3)	-5.5053	0.4980				

The value of the log likelihood for the fitted final model was -615.02
Using the Final model, 1 out of 24 cells had an expected value less than 5.

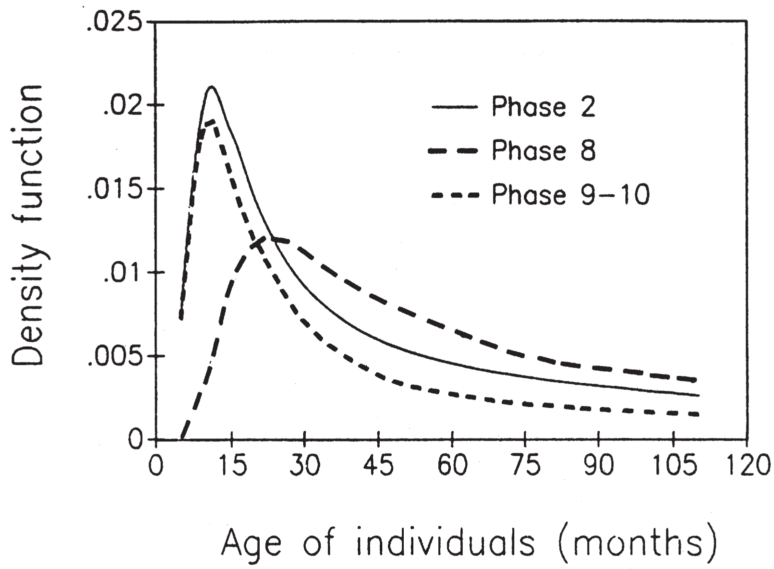

Fig. 3. Estimated slaughtering curves (density functions) by age for cattle (*Bos taurus*) in three phases in the Medieval City of Trondheim.

9—10 (β_3 = -0.0075, p=0.031, Final model). A different mortality pattern was seen in Phase 8, as the odds ratio relative to phase 2 was found not to be proportional with the age of the individuals (γ_2, $p<0.0001$, Final model). The slaughtering of calves has been less frequent in phase 8 compared to phase 2, but then the slaughtering has been relatively higher for older animals. These patterns are visualized in Fig. 2, where the estimated survival curves are shown together with the observed data. In Fig. 3, the density functions are shown for the three phases estimated according to the final model (Table 2). The phases 2 and 9—10 had a maximum slaughtering of one year old calves. However, in phase 8 slaughtering seems to have been postponed and the slaughtering was most profound on two year old cattle.

DISCUSSION

The assignment of bone-ends into four groups according to the age at which the epiphyses are fused to the bones, may seem a crude approach. However, considering the randomness of the actual age at fusing, which is not accounted for in this analysis, and the purpose, to compare the survival in the phases, this simplification may seem warranted. The assumption that the age at fusing of the epiphyses for the different bones has not changed throughout the time span of layer 2 to layer 9—10 is however vital for this analysis. Furthermore, if the assignment of the age at fusing of the different epiphyses into four ages was too crude, and the distribution of bones assigned to the same fusing age differend between the phases, our analysis might be disturbed. Thus a χ^2-test of homogeneity for the distribution of the bones with a fusing age of 54 months between the phases was performed. If, on the other hand, our analysis was confounded by the time-related factors, this could not explain the main result of the analysis. The mid-period (phase 8) was found to be very different from both other periods and could not be regarded as an intermediate between the two others.

The slaughtering curves are shown in Fig. 2 as smooth curves, but the actual slaughtering curves should probably have been functions with steps at the typical ages of cattle in the slaughtering seasons. Different transformations of the age variable (t) were used in the statistical model in addition to age, and finally the inverse ($1/t$) was chosen. A model with second order terms (t^2) predicted a much too high mortality at age 18 months, and the value of the log-likelihood for this model was -649.04. In contrast, the fitted model (i) had a log-likelihood of -615.02. Due to the high mortality of young animals in general, the variable $1/t$ will probably be appropriate for materials other than the present one. Note also that the p-value of a constant term to enter the Final model was 0.064 (Table 2). Thus, the initial requirement that the constant should be zero did not reduce the flexibility of the proposed model for the present material.

Our knowledge about cattle breeding during the Middle Ages is limited. The breeding economy may have developed towards The High Middle Age. Bones of small individuals are dominating the material from Oslo (Lie, 1988) and Bergen (Wiig, 1981). Until early in this century the animals in some parts of the country were extremely underfed during the winter season. However, the resources have gradually been better utilized, and more meat was produced from the same amount of food. The disease incidence among the younger age groups may also have been controlled. The population of Norway increased during the 13th century, but in spite of this there was a lack of agricultural workers. Perhaps these conditions have effected a better economy in he energy flow. The meat production seems anyhow to have increased. Meat as payment is often mentioned in written sources, and the trade of meat and skin seems to have increased before the Black Death (Øye 1976). The change in mortality during the first part of the middle age may be an effect of a reduced disease incidence and thus of natural mortality. It is interesting in this connection to observe that there are relatively fewer whole unfragmented bones in phase 8 compared to both phase 2 phase 9—10. When phases 2 and 9—10 are combined, the proportion of whole bones is significantly lower in phase 8 than in the phases 2 and 9—10 (p= 0.017, Fishers exact test, two sided). The whole bones may to a certain extent stem from animals which died from natural causes, and these were not used as food.

Some of the bones may be identified as undoubtedly stemming from males. It seems that relatively more males have survived 1.5—2 years in phase 2 compared to phase 8. The material from phase 9—10 is too small to give any information on this point. We known that oxes were used as draft animals in the middle age. Gradually, however, the oxes were replaced by horses, and this process may to some extent be reflected in the observed change in slaughtering pattern from phase 2 to phase 8. The material gives little information about the extent of the use of horses, as few horse bones are found in this excavation.

The most interesting finding in this study is the increasing slaughtering of calves in the period just after the Black Death (phase 9—10). After a period with better planning and postponement of the slaughtering (phase 8), the organization of the cattle breeding may have collapsed due to the Black Death. The result of this disintegration may have been a reduced net production of meat.

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