# Survival analysis of lambs using Cox's proportional hazards' modeling and Kaplan-Meier method

**Dariusz Piwczyński, Sławomir Mroczkowski, Beata Sitkowska**

Uniwersytet Technologiczno-Przyrodniczy,
Katedra Genetyki i Podstaw Hodowli Zwierząt,
ul. Mazowiecka 28, 85-084 Bydgoszcz; darekp@utp.edu.pl

**The present research was conducted on 1633 Polish Merino lambs reared in two herds from the Pomerania and Kujawy region. The data regarding the collapse date of lambs aged up to 56 days underwent scrutiny. In order to indicate those factors which influence lamb mortality, the Cox's proportional hazards modeling was utilised. By means of backward selection, the variables which were significantly linked with lamb mortality, i.e. type and year of lamb's birth, were determined. In addition, for the variables selected, the survival curves were established using the Kaplan-Meier method. The calculated arithmetic mean indicates that the average collapse time occurred on days 14 to 15 of a lamb's life. It was concluded that approximately 25% of the collapses took place by the third day of life. Four subsequent days of a lamb's life proved critical in lamb rearing. Altogether, 50% of collapses were recorded in the first week of a lamb's life. The escalation of collapses in the first week of a lamb's life is also indicated by the survival curves established applying the Kaplan-Meier method. The survival curves indicate lower survival among twins than lambs born as a result of multiple pregnancies. The probability of survival of a lamb up to 56 days old from a single pregnancy was 0.915, whereas for a twin-born lamb it was 0.825.**

**KEY WORDS: survival analysis / hazard / Kaplan-Meier / lambs**

Lamb mortality during the rearing period substantially reduces the economic feasibility of sheep production. Thus, indicating genetic and environmental factors responsible for lamb mortality rate is of key importance. The genetic improvement alone of the above mentioned trait is a long-lasting process due to low heritability. According to Maxa et al. [7] and Hatcher et al. [4], the additive direct heritability as regards lamb mortality rate in the first 24 hours after birth is from 0.035 to 0.07. As the latter authors [4] concluded, the lamb survival rate is even lower in lambs of up to 30 (0.02) or 110 (0.027) days of age. Lamb mortality rate in the rearing period is conditioned by a number of factors. These are breed [3, 7, 12], flock [14, 19, 20], sex [3, 10, 14, 20], birth type of lambs [8, 10, 13, 14, 20], weight at birth [2, 10], age of dam [3, 13, 20] and birth year effect [3, 12, 14, 20], but also season of birth effect [12, 13]. An important facet of scientific research is indicating the age of lambs at which the probability of mortality is the highest. A survival analysis is

carried out using a variety of techniques, i.e. life tables [18], logistic regression [1, 10, 13, 14] or Cox's proportional hazard model [2, 16]. The estimation of survival rate by means of the Kaplan and Meier method [6, 9, 14, 17] are all used as statistical tools in survival rate analysis, and particularly in medical research.

The objective of the present research was to analyze the Polish Merino lamb mortality rates using Cox's proportional hazards modeling and the Kaplan-Meier method.

## Materials and methods

The research was conducted on 1633 Polish Merino lambs reared in two flocks representing the public sector from the region of Pomerania and Kujawy. The lambs that were born in the years 1999-2004 were the progeny of mothers aged 2 to 10. The weaning usually occurred at the 100$^{th}$ day of a lamb's life. All studied lambs were of a general-purpose type. The data analyzed regarding the rate of mortality (survival) of lambs of up to 56 days of age were taken from breeding documentation. The Polish Merino lambs represent a maternal breed. Due to that reason, the basis for a selection process of these animals was a selection index effective at the time the research was carried out [14]. The basis for calculating this index for each lamb was its weight at the age of 56 days and life prolificacy of its mother.

The information on the age of lambs that survived up to 56 days was considered a censored observation, since their exact age at death remained unknown. The lack of information on the length of animals' lives was due to, among other things, the fact that some of them were cast and meant to be slaughtered or sold to other breeders. In turn, the measurement, regarding those lambs that did not survive until day 56 of their lives, were defined as uncensored values. The uncensored values represent the exact age of a lamb at the time of death.

In order to determine those factors that significantly influence when mortality occurs, the Cox's proportional hazard model was utilized [15]:

$$h(t) = \lambda(t) \cdot e^{(\beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k)}$$

where:
$h_0(t)$ – hazard function;
$\lambda(t)$ – unspecified initial hazard function;
$X_1, X_2, ... X_k$ – covariates;
$\beta_1, \beta_2, \beta_k$ – parameter coefficients of the $X_1, X_2, ... X_k$.

This model makes it possible to determine the risk of lamb mortality in *t* time for the independent variable system under analysis. The variables for the final regression model were chosen using the backward regression method. The variables (covariates) possibly influencing variation in mortality date that were taken into consideration were as follows: flock (A, B), sex (ram lamb, ewe lamb), type (single, multiple) and year of lambs birth (1999-2004) of a lamb, age of dam (2, 3, 4, 5, ≥6 years of age) and lambing season (spring-autumn, winter). In a type and year of birth that followed, with reference to individual levels of the factors selected, the risk (hazard) coefficients were named. The above mentioned

coefficient is defined as the ratio of lamb mortality hazard in one group compared with a reference group. With regard to the type of birth, a reference group comprised lambs from multiple births. In turn, in the case of a birth year, the lambs born in 2004 were a reference group. The significance of regression coefficients was verified using Wald test [15]. Then, with reference to the variables that were determined in this analysis (type and year of lamb's birth), the Kaplan-Meier product limit technique was used [15]. With this method, a survival function S(t) was estimated directly from continuous survival times (length of lambs' lives). This made it possible to determine the possibility that a lamb will not collapse earlier than before the *t* time provided (i.e. it will be reared until the *t* time). In the next step, the survival curves in relation to individual levels (e.g. in the case of a birth type: single, multiple) of significant factors (year and type of lamb's birth) were developed. The curves determined in relation to individual levels of a given factor were compared using the Wilcoxon statistics [15]. A statistical analysis was carried out using the SAS procedures, i.e. LIFETEST and PHREG [15].

**Results and discussion**

In the analyzed population of 1633 lambs aged up to 56 days, 223 of lambs collapsed, which comprised 13.66% of the initial population. The calculated percentage of mortalities should be considered relatively high – the Polish Sheep Breeding Association [5] provides an analogical rate of 9.1% (where lamb breeding rate = 90.9%) for Polish Merino lambs. In the earlier research of one of the authors [13] the share of lamb mortalities in the period from their birth to weaning (about 100$^{th}$ day) was around 6.74%. Casellas et al. [2] state, with reference to Ripollesa breed, that the mortality rate from birth up to 30-45 day of life equaled 9,6%. In Swedish research conducted by Petersson and Danell [12] on the survival rate until the age of up to 4-5 months, in the flock of 370 thousand sheep, the mortality rate determined was, depending on their breed (4 were studied), from 6.13 to 12.71%. A higher mortality rate in lambs from birth to the age of 60 days, depending on the breed, was found by Gama et al. [3], i.e. 12.4 to 21.1%. A high mortality rate of crossbred lambs from their birth to 49$^{th}$ day of life, born from Columbia, Hampshire and Suffolk crossbreeding, was reported to be 15.2% by Southey et al. [17].

In the present research the rate of lamb mortalities fluctuated clearly depending on the flock, year of a lamb's birth, and age of dam (Table 1). Yet, these differences were not verified statistically, as it was beyond the scope of the present paper.

The aim of the conducted research was to analyze statistically when mortalities occurred in the period from birth to the 56$^{th}$ day of life. It was demonstrated that the mortality most frequently occurred on the 14$^{th}$ to 15$^{th}$ day of life (Table 1). Based on the values of calculated quartiles it may be concluded that about 25% of the mortalities took place before 3$^{rd}$ day of life. A critical point in lamb breeding was the following 4 days of their life. In total, 50% of mortalities were recorded in the first week. It was demonstrated that among the analyzed lamb mortalities, 75% of cases happened before day 25 of a lamb's life. The research conducted by various authors [1, 11, 19] confirms the results of the authors' own research, pointing at the most critical first 7 days in lambs' lives. Binns et al. [1] demonstrated that lamb mortalities centered on the first 24 hours of life, accounting for 50%.

**Table 1 – Tabela 1**

Descriptive characteristics of the time of collapse
Charakterystyka opisowa terminu upadku

| Factor level<br>Poziom czynnika | N | n | % collapsing<br>% upadków | Mean<br>Średnia | Q1 | Median<br>Mediana | Q3 |
|---|---|---|---|---|---|---|---|
| Total – Razem | 1633 | 223 | 13.66 | 14.54 | 3 | 7.00 | 25.0 |
| **Flock – Stado** | | | | | | | |
| A | 799 | 95 | 11.89 | 14.52 | 3 | 6.00 | 24.0 |
| B | 834 | 128 | 15.35 | 14.64 | 3 | 7.00 | 25.0 |
| **Gender – Płeć** | | | | | | | |
| ram – tryczek | 781 | 107 | 13.70 | 12.50 | 2 | 6.00 | 22.0 |
| ewe – maciorka | 852 | 116 | 13.62 | 16.42 | 3 | 8.00 | 28.5 |
| **Type of lamb's birth – Typ urodzenia jagnięcia** | | | | | | | |
| 1 | 696 | 59 | 8.51 | 15.36 | 3 | 8.00 | 25.0 |
| ≥2 | 937 | 164 | 17.72 | 14.25 | 2 | 7.00 | 25.0 |
| **Year of lamb's birth – Rok urodzenia jagnięcia** | | | | | | | |
| 1999 | 319 | 34 | 10.66 | 10.65 | 2 | 4.50 | 9.0 |
| 2000 | 275 | 19 | 6.91 | 17.11 | 2 | 9.00 | 31.0 |
| 2001 | 307 | 22 | 7.17 | 12.91 | 2 | 8.00 | 18.0 |
| 2002 | 300 | 35 | 11.67 | 18.60 | 5 | 12.00 | 31.0 |
| 2003 | 246 | 64 | 26.02 | 11.69 | 2 | 6.00 | 23.5 |
| 2004 | 186 | 49 | 26.34 | 17.82 | 3 | 14.00 | 33.0 |
| **Type of dam's birth – Typ urodzenia matki** | | | | | | | |
| 1 | 745 | 100 | 13.42 | 14.44 | 3 | 7.00 | 25.0 |
| ≥2 | 888 | 123 | 13.85 | 14.63 | 3 | 8.00 | 25.0 |
| **Age of dam – Wiek matki** | | | | | | | |
| 2 | 296 | 44 | 14.86 | 16.80 | 2 | 7.00 | 30.5 |
| 3 | 292 | 32 | 10.96 | 17.66 | 6 | 9.00 | 32.0 |
| 4 | 271 | 27 | 9.96 | 15.00 | 3 | 7.00 | 29.0 |
| 5 | 213 | 27 | 12.68 | 11.37 | 2 | 6.00 | 16.0 |
| 6 | 175 | 27 | 15.43 | 15.07 | 3 | 5.00 | 31.0 |
| ≥7 | 386 | 66 | 17.10 | 12.42 | 2 | 8.00 | 20.0 |
| **Season of lambing – Sezon wykotu** | | | | | | | |
| spring, autumn<br>wiosna, jesień | 795 | 108 | 13.58 | 14.03 | 2 | 6.50 | 25.0 |
| winter – zima | 838 | 115 | 13.72 | 15.03 | 3 | 8.00 | 25.0 |

Q1 – lower quartile – kwartyl pierwszy
Q3 – upper quartile – kwartyl trzeci
N – number of lambs born in a group – liczba jagniąt urodzonych w grupie
n – number of lambs collapsing in a group – liczba jagniąt padłych w grupie

Further 30% took place between the first and third day of life, and then 11% between the fourth and seventh day. Niżnikowski et al. [11] in their research on Polish Merino lambs concluded in turn the mortality rate until the seventh day of life to be at 30%.

When analyzing in detail the value of quartiles depending on the levels of factors included in the research, it needs to be concluded that they varied significantly (Table 1). The first quartile, cutting off 25% of all mortalities, fluctuated from 2 does 6 days. The median value changed from 4.5 up to 14 days, and for the third quartile from 9 to 32 days.

Two variables that are significant in relation to the dates of lamb mortalities emerged as a result of applying a statistical analysis, conducted with the use of the Cox's proportional hazard method, namely the type and year of lamb's birth (Table 2). The risk of lamb's mortality in the *t* time with reference to the independent variables analyzed could be established by means of a regression model constructed and parameters obtained. At the same time, the risk ratio, i.e. the hazard index, was estimated (Table 2). The assessment of the indices estimated testifies that a significantly lower risk exists for those lambs that were born single as compared to those from multiple births. Moreover, it proves that the risk of mortality in the years 1999-2003 was in general statistically lower than in 2004.

The outcomes of the present research show that the twin lamb birth has adverse impact on the survival up to the age of 56 days. At the same time, the results of earlier studies conducted by the author [14] proved that sows from multiple births were characterized by more favourable reproductive traits than single-born lambs, the traits being prolificacy or reproductive performance. Unfortunately, the criteria for evaluation of sheep breeding value in effect now do not take into account the index of lamb rearing within the selection index. For that reason, based on the present and earlier studies [14], it can be concluded that there is a necessity to modify the effective selection index. This adjustment could entail, among other things, replacing ewe's life fecundity with its index of reproductive performance in the selection index. This index is a function of a number of lambs born and their survival rate.

**Table 2 – Tabela 2**

Assessment of the estimated model parameters
Ocena parametrów modelu

| Variable<br>Zmienne | Parameter<br>Parametr | SE | Wald $\chi^2$<br>$\chi^2$ Walda | P | Risk ratio<br>Współczynnik ryzyka | 95% CL |
|---|---|---|---|---|---|---|
| TB 1 | –0.7707 | 0.1494 | 26.616 | <0.0001 | 0.463 | 0.345-0.620 |
| RU 1999 | –1.0212 | 0.2144 | 22.680 | <0.0001 | 0.360 | 0.237-0.548 |
| RU 2000 | –1.4515 | 0.2667 | 29.618 | <0.0001 | 0.234 | 0.139-0.395 |
| RU 2001 | –1.4919 | 0.2523 | 34.958 | <0.0001 | 0.225 | 0.137-0.369 |
| RU 2002 | –1.0272 | 0.2130 | 23.253 | <0.0001 | 0.358 | 0.236-0.544 |
| RU 2003 | –0.0468 | 0.1841 | 0.065 | 0.7994 | 0.954 | 0.665-1.369 |

TB – type of lamb birth – typ urodzenia jagnięcia
RU – year of lamb birth – rok urodzenia jagnięcia
CL – confidence interval – przedział ufności

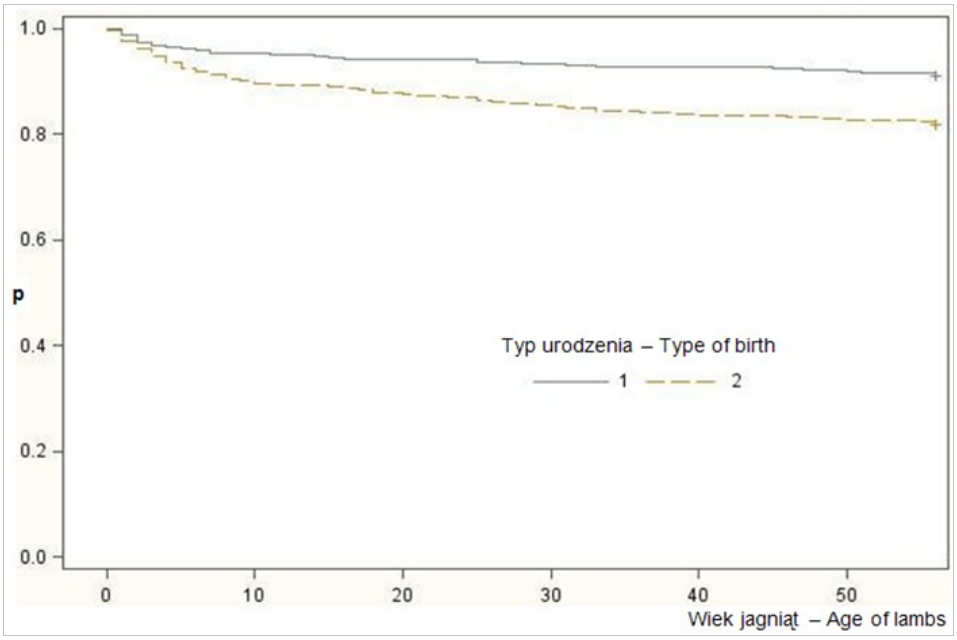


Fig. 1. Survival curves in respect of type of birth
Rys. 1. Krzywe przeżycia w zależności od typu urodzenia

The calculated hazard indices have been confirmed by the analysis of quartiles. In the case of a single birth type, 25% of mortalities took place within the first three days of life, and a half of them occurred within 8 days. In a group of multiple lambs, the values of both quartiles were lower by one day. These results are convergent with those of Szymanowska [19]. The mortality until the third day of life was lower in multiple (29.7% mortalities) than in single lambs (26.2%) [19]. In addition, the author concluded that the concentration of mortalities was higher in ewe lambs (29.0) than in ram lambs (27.8). In neither of these cases were the differences supported statistically. In the author's own research, in relation to the lambs born in four years (1999-2001, 2003), the first two days of life proved the most critical, i.e. 25% mortalities (Table 1). In one case the first quartile fell on the third (2004), and in one on the fifth (2002) day. The median values were characterized by high variability depending on respective years, i.e. 4.5-14 days.

The survival curves related to the type and year of birth, and determined with the Kaplan-Meier method can be found in Figures 1 and 2. The Wilcoxon test that was carried out proved that the survival curves related to individual levels of the type and year of lamb's birth differed statistically ($P<0.0001$), which was at the same time a confirmation of the Wald test results (Table 2). It is curious that the possibility of survival in single-birth lambs until the age of 56 days was 0.915, whereas the probability of a multiple-birth lamb surviving the same period was 0.825. In Figure 1 the curve denoting multiples is clearly lower than the one depicting the possibility of a single lamb surviving. Two groups of curves

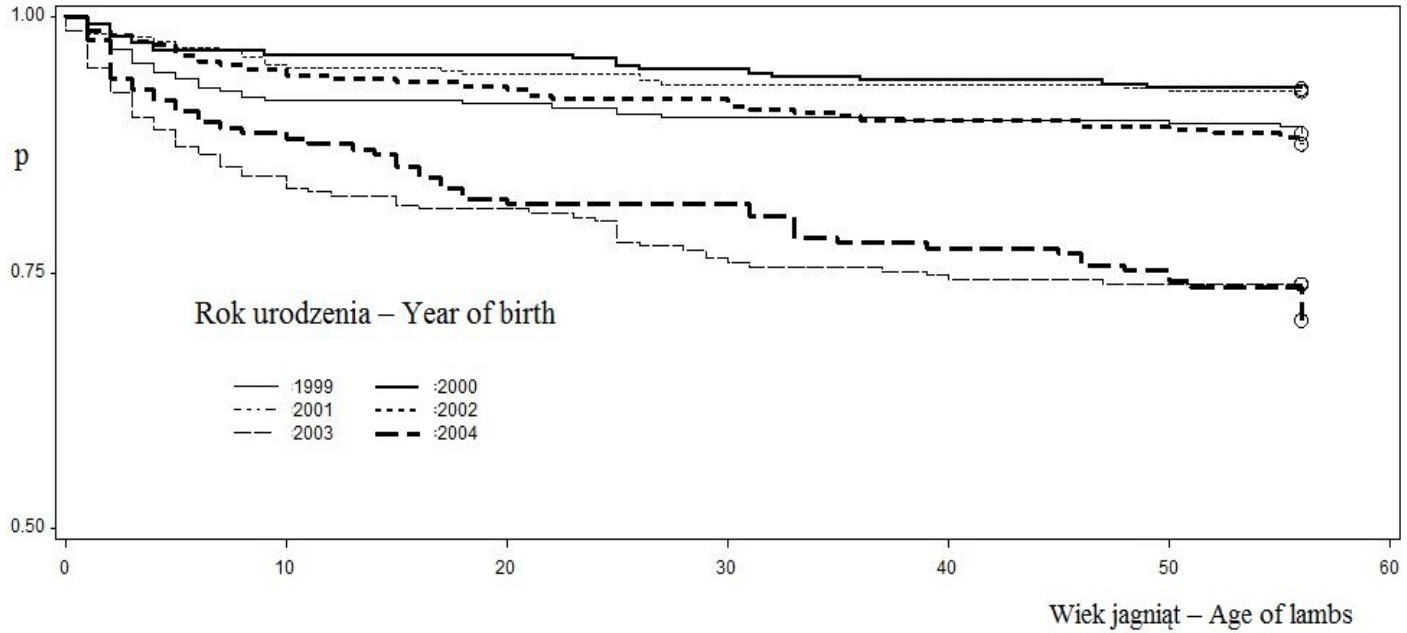


Fig. 2. Survival curves in respect of year of birth
Rys. 2. Krzywe przeżycia w zależności od roku urodzenia

can be observed in the figure related to the year of birth (Fig. 2). The first group represents lambs born in the years 1999-2002. The second group, situated below the first one, denotes lambs born in the years 2003 and 2004. The survival probability of lambs born in individual years was as follows: 1999 – 0.887, 2000 – 0.931, 2001 – 0.928, 2002 – 0.877, 2003 – 0.740 and 2004 – 0.704.

Southey et al. [17] outlined survival curves utilizing the Kaplan and Meier method as regards the data on the survival of lambs until the age of 50 days, and obtained the results similar to those in the author's own research. One of the conclusions they arrived at was that the probability of survival of a lamb until day 10 of its life was 0.9, whereas with respect to day 50 it was 0.85.

The conclusion of the research conducted is that the period requiring special attention on the breeder's part as regards newly born lambs is the first 7 days. This care should be directed especially at lambs born in large litters, as these are more likely to collapse before they reach 56 days of age, and mortalities in them are recorded at a younger age. The results suggest that the Cox's proportional hazard model and the Kaplan and Meier method can be used to provide the statistical analysis of lamb mortality.

**REFERENCES**


1. BINNS S.H., COX I.J., RIZVI S., GREEN L.E., 2002 – Risk factors for lamb mortality on UK sheep farms. ***Preventive Veterinary Medicine*** 52, 287-303.
2. CASELLAS J., CAJA G., SUCH X., PIEDRAFITA J., 2007 – Survival analysis from birth to slaughter of Ripollesa lambs under semi-intensive management. ***Journal of Animal Science*** 85, 512-517.
3. GAMA L.T., DICKERSON G.E., YOUNG L.D., LEYMASTER K.A., 1991 – Effects of bred, heterosis, age of dam, litter size, and birth weight on lamb mortality. ***Journal of Animal Science*** 69, 2727-2743.
4. HATCHER S., ATKINS K. D., SAFARI E., 2010. Lamb survival in Australian Merino Sheep: A genetic analysis. ***Journal of Animal Science*** 88, 3198 - 3205.
5. Hodowla owiec i kóz w Polsce w 2009. 2010, PZO Warszawa.
6. KRZESKI P., 2000 – Model przeżycia dla polskiej populacji chorych z pierwotną marskością wątroby. Zastosowanie metod statystycznych w badaniach naukowych. Wyd. StatSoft Polska, Kraków, http://www.statsoft.pl, dostęp 2010.
7. MAXA J., SHARIFI A.R., PEDERSEN J., GAULY M., SIMIANER H., NORBERG E., 2009. Genetic parameters and factors influencing survival to twenty-four hours after birth in Danish meat sheep breeds. ***Journal of Animal Science*** 87, 1888-1895.
8. MILERSKI M., 2006 – Analysis of lamb mortality in Sumava, Suffolk, Charollais, Romney, Merinolandschaft and Romanov sheep in the Czech Republic. Book of Abstracts of the 57th Annual Meeting of the EAAP. Antyla, Turcja, 215.
9. MOCZKO J.A., 2003 – Analiza czasów przeżycia w badaniach medycznych. ***Neuroskop*** 1(5), 121-126.
10. NASH M.L., HUNGERFORD L.L., NASH TG, ZINN GM., 1996 – Risk factors for perinatal and postnatal mortality in lambs. ***Veterinary Record*** 139(3), 64-67.
11. NIŻNIKOWSKI R., OPRZĄDEK A., POPIELARCZYK D., STRZELEC E., GROBEREK J., 2005 – Wielkość miotu i wskaźniki odchowu jagniąt u owiec rasy merynos polski utrzymy-

wanych w stadach należących do spółek agencji nieruchomości rolnych. ***Roczniki Naukowe Zootechniki*****,** Suplement 21, 19-22.
12. PETERSSON C.J., DANELL Ö., 1985 – Factors influencing lambs survival in four Swedish sheep breeds. ***Acta Agriculturae Scandinavica*** 35, 217-232.
13. PIWCZYŃSKI D., 2007 – Statystyczna analiza śmiertelności jagniąt za pomocą regresji logistycznej. ***Roczniki Naukowe Polskiego Towarzystwa Zootechnicznego*** 3(1), 19-26.
14. PIWCZYŃSKI D., 2009 – Doskonalenie cech użytkowych merynosa polskiego. ***Rozprawy Uniwersytetu Technologiczno-Przyrodniczego w Bydgoszczy***, nr 135, 1-122.
15. SAS Institute Inc. 2008. SAS/STAT User's guide, Version 9.2, Cary, NC, SAS Institute Inc.
16. SMITH T., SMITH B., 2000 – Survival analysis and application of Cox's proportional hazards modeling using SAS. ***Statistics Data Analysis and Data Mining,*** Paper 244, 26.
17. SOUTHEY B.R., RODRIGUEZ-ZAS S.L., LEYMASTER K.A., 2001 – Survival analysis of lamb mortality in a terminal sire composite population. ***Journal of Animal Science*** 79, 2298-2306.
18. STANISZ A., 2002 – Analiza przeżycia. ***Medycyna Praktyczna*** 2002/03, 1-6. http://www.mp.pl (dostęp 2010).
19. SZYMANOWSKA A., 1998 – Straty jagniąt w okresie odchowu w zależności od niektórych czynników genetycznych. ***Annales Universitatis Mariae Curie-Skłodowska***, Lublin, sek. EE, XVI, 22, 161-166.
20. WARREN J.T., MYSTERUD I., 1995 – Mortality of domestic sheep in free-ranging flocks in Southeastern Norway. ***Journal of Animal Science*** 73, 1012-1018.

Dariusz Piwczyński, Sławomir Mroczkowski, Beata Sitkowska

## Analiza czasu przeżycia jagniąt za pomocą metody proporcjonalnego hazardu Cox'a i metody Kaplana-Meiera

S t r e s z c z e n i e

Badania przeprowadzono na 1633 jagniętach rasy merynos polski utrzymywanych w dwóch stadach z rejonu Pomorza i Kujaw. Analizowano dane dotyczące terminu upadku jagniąt do wieku 56 dni. W celu wskazania czynników istotnie wpływających na śmiertelność zwierząt zastosowano model proporcjonalnego hazardu Cox'a. Metodą selekcji wstecznej wskazano zmienne istotnie związane ze śmiertelnością jagniąt, tj. typ i rok urodzenia jagnięcia. Ponadto, dla wyłonionych zmiennych wyznaczono krzywe przeżycia metodą Kaplana-Meiera. Obliczona średnia arytmetyczna wskazuje, że przeciętny czas upadku przypadał na 14.-15. dzień życia. Stwierdzono, że około 25% upadków miało miejsce do 3. dnia życia. Krytycznym momentem odchowu jagniąt były dalsze 4 dni ich życia. Łącznie w pierwszym tygodniu życia zarejestrowano 50% padnięć. Na koncentrację upadków w pierwszym tygodniu życia wskazuje również kształt krzywych przeżycia wyznaczonych metodą Kaplan-Meiera. Wyznaczone krzywe przeżycia świadczą również o słabszej przeżywalności jagniąt z urodzeń mnogich niż pojedynczych. Prawdopodobieństwo przeżycia do wieku 56 dni jagnięcia pochodzącego z urodzeń pojedynczych wyniosło 0,915, podczas gdy szansa na przeżycie jagnięcia urodzonego jako bliźnię kształtowała się na poziomie 0,825.

**SŁOWA KLUCZOWE: analiza przeżycia / hazard / Kaplan-Meier / jagnięta / merynos polski**