

Hazard rates for clustered populations of David's deer (*Elaphurus davidianus* Milne-Edwards, 1866)

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The objective of the study was to assess the mortality risk of David's deer associated with climatic conditions by the use of hazard function within clustered populations and according to place of birth. Additionally, the inbreeding level was examined within each cluster. Records were considered of 1192 individuals born in 56 zoological gardens in the years 1947-2000. Censored data (animals which were alive on December 31, 2000) were also included in the analysis. Average lifetime and percentage of dead individuals per zoo were used to determine two-dimensional Euclidean distances. The hazard rates were estimated within derived clusters of zoological gardens. The analysis was performed within sex groups for the following two data sets: all individuals (1), and animals dead in the first year of life (2). In the case of the latter, only three clusters were included. In general, the sizes of clusters appeared different (from two to eighteen zoos). From a geographical perspective these groups are heterogeneous. Generally, the shapes of hazard curves are similar with a clear increasing trend. The differences between groups reflect mainly an inconsistency of time points. The first peak of mortality appears at an early stage of life. The results clearly show the differences in mortality between males and females in all groups (for both sets – 1 and 2). Geographical region showed no significant effect on the survival of David's deer. It is concluded that life span is determined more by the inbreeding level and zoo management conditions than by the climatic zone.

KEY WORDS: deer / Euclidean distance / life span / survival analysis / zoological gardens

Gradual degradation of environment is a threat for many animal species in natural habitats [Guthmann *et al.* 1997, Farfan *et al.* 2004]. Sometimes long-term pressure leads to total extinction of some species. Over the last decades, the main places for protection of endangered animal populations have been zoological gardens. On the other hand, keeping animals under different climatic conditions often leads to genotype by environment interactions, which may considerably affect fitness and especially survival traits.

One of the species extincted in natural environment and then restored by reintroduction is David's deer (*Elaphurus davidianus*, Milne-Edwards 1866). Tang [2001] reported that the current David's deer population has been derived from 18 animals kept in Park Abbey (Great Britain). In 1922 the species became completely extinct in its natural habitat, *i.e.* North-East China. The owner of Park Abbey, possessed 18 individuals brought to England. At the moment, David's deers are kept mainly in a number of zoological gardens around the world.

This report is a continuation of a study by Molińska-Glura *et al.* [2004] who observed that the life span of the David's deer females was longer than that of males. However, the hazard function showed similar values for individuals of both sexes in the 6th, 10th, 15th, 17th and 18th year of life. In that earlier analysis birth places were not considered. The study conducted by Sternicki *et al.* [2003] indicated low heritability of life span in this population, so environmental effects should be considered as determined by the backgrounds of longevity. Hazard functions have been widely applied for livestock population [Sewalem *et al.* 2005, Vukasinovic *et al.* 2001].

The objective of the present study was to assess the risk of mortality in David's deer world's population associated with climatic conditions using hazard function. Additionally, the inbreeding level was examined within each cluster.

Material and methods

Animals

Data for the present study were extracted from the International Species Information System (ISIS), January 2001 edition, and consisted of records of 1192 animals from 56 zoological gardens, born in the years 1947-2000. Censored data (animals which were alive on December 31, 2000) were also included in the analysis.

Table 1. Description of data sets

Animals	Number of individuals	Mean age	Standard deviation
Total	1192	5.5 years	5.9
males	512	4.7 years	5.4
females	680	6.5 years	5.4
Dead in the 1st year of life	338	57.7 days	106.5
males	190	50.0 days	97.0
females	148	68.0 days	116.0

A brief numerical description of the data sets is presented in Table 1. The animals recorded were classified according to zoological gardens where they were born. Zoos with less than two animals were omitted from the analysis. Hence, 29 recorded individuals were rejected from the analyses.

Cluster analysis

The term cluster analysis, introduced by Tryon [1939] encompasses a number of different algorithms and methods for grouping objects of similar kind into respective categories. In this study, cluster analysis is an exploratory data analysis tool which aims at sorting different zoological gardens into groups in such a way that the degree of association between two of them is maximum if they belong to the same group, and minimum otherwise [Romesburg 2004]. In fact, cluster analysis is not so much a typical statistical test as a “collection” of different algorithms that “put objects into clusters according to well defined similarity rules” [Romesburg 2004].

The joining or tree clustering method uses the distances (or similarities) between zoos when forming the clusters. Similarities are a set of rules that serve as criteria for grouping or separating items. These distances can be based on a single dimension or multiple dimensions, with each dimension representing a rule or condition for grouping the zoos. The most straightforward way of computing distances between zoological gardens in a two-dimensional space is to compute Euclidean distances. This is probably the most commonly chosen type of distance. It is simply the geometric distance in a two-dimensional space. In this study, the average life span and percentage of dead individuals per zoo were used to determine two-dimensional Euclidean distances.

Survival analysis

Random variable X is the individual's age (expressed in days or years), whereas n_x^* is the expected number of individuals which survived from birth denoted as point (n_0) to the current age x . The distribution of survival times was divided into intervals. For each interval it is possible to determine the number of individuals which entered the interval alive, and those which died within this interval (d_x). The analyses were corrected for information on individuals for which only the birth date was available, and $u_x = n_x^* + r_x$. Such cases are called *truncated*, as the information on them is incomplete, although to some extent it contributes to the overall picture of the whole population [Elandt-Johnson and Johnson 1999]. Their number will be calculated according to the formula:

$$r_x = \frac{1}{2}(n_x^* - n_{x+t} - d_x)$$

Functions used in the construction of mortality functions are also defined at a given age interval, defined by two different values x and $x + t$. For example μ_x is such a function, as presented by the formula:

$$\mu_x = P\{x < X \leq x+t \mid X > x\} = -\frac{1}{n_x} \frac{dn_x}{dx}$$

This value may be interpreted as a conditional probability of death in the interval $(x, x+t)$ attributed to an individual which reached the precise age of x [Crowder 2001]. In the further analysis this value will be called the hazard rate, calculated as the number of individuals which died within periods in a given interval divided by the mean number of animals surviving within a given interval. The hazard rates were estimated within derived clusters of zoological gardens.

The analyses were performed within sex groups for the following two data sets: all individuals (set 1) and animals dead in the first year of life (set 2). In the case of yearlings only three clusters (III, V, VI) were included, since for the other ones the number of observations was too small.

Inbreeding level

Inbreeding coefficients of animals were extracted from the ISIS. In the case of coefficients lower than 0.001, the animals were considered as non-inbred.

Results and discussion

The estimated Euclidean distances between zoological gardens are presented in Figure 1, whereas the results of cluster analysis are given in Table 2. Six groups of zoos were formed. In general, the sizes of clusters are different (from two to 18

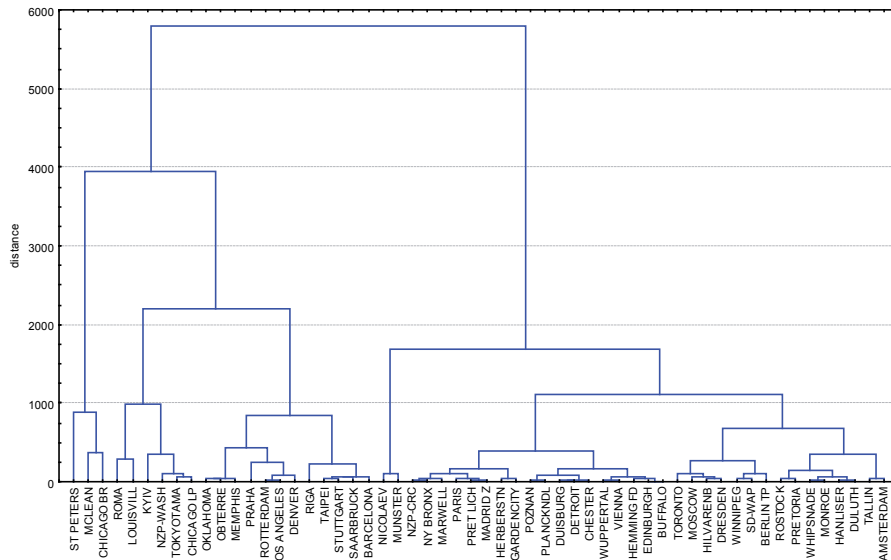


Figure 1. Euclidean distances between zoological gardens studied.

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Table 2. Results of cluster analysis – zoo groups

I	II	III	IV	V	VI
CHICAGO BR	CHICAGO LP	BARCELONA	MUNSTER	BUFFALO	AMSTERDAM
MCLEAN	KYIV	DENVER	NIKOLAEV	CHESTER	BERLIN
ST PETERS	LOUISVILL	LOSANGELES		DETROIT	DRESDEN
	NZP-WASH	MEMPHIS		DUISBURG	DULUTH
	ROMA	OBTERRE		EDINBURGH	HANLISER
	TOKYOTAMA	OKLAHOMA		GARDENCTY	HILVARENB
		PRAHA		HEMMINGFD	MONROE
		RIGA		HERBERSTN	MOSCOW
		ROTTERDAM		MADRID	PRETORIA
		SAARBRUCK		MARWELL	ROSTOCK
		STUTTGART		NY BRONX	SD-WAP
		TAIPEI		NZP-CRC	TALLIN
				PARIS	TORONTO
				PLANCKNDL	WHIPNADE
				POZNAN	WINNIPEG
				PRET LICH	
				VIENNA	
				WUPPERTAL	

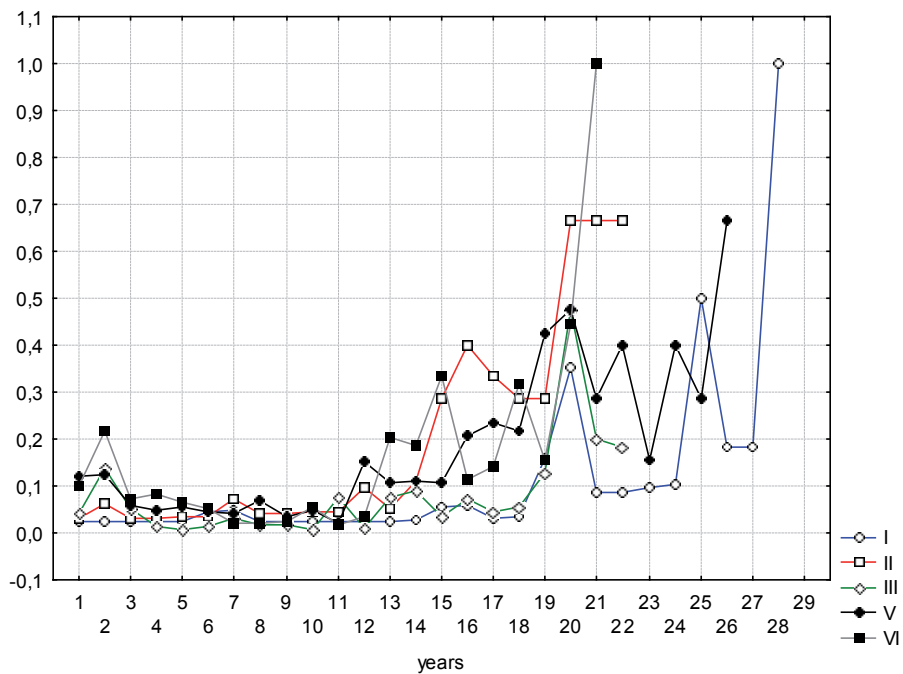


Figure 2. Hazard functions for all females from clustered zoos.

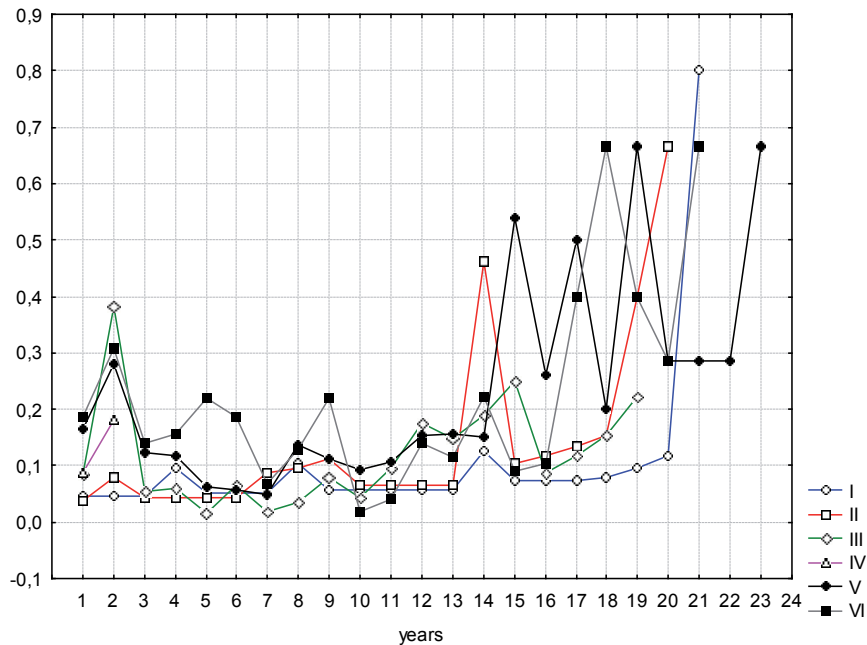


Figure 3. Hazard functions for all males from clustered zoos.

units). It should be noted that from the geographical perspective these groups are heterogeneous. This indicates that the impact of climatic zones is negligible for the longevity and mortality in David's deer population kept in zoological gardens. The differences in hazard rates for males and females within groups are presented in Figures 2 and 3, respectively. Generally, the shapes of curves are similar with a clear increasing trend. The differences between groups mainly reflect an inconsistency of time points. The first peak of mortality appears at the early stage of life. Therefore a separate analysis was carried out for this group. Considerable increase in mortality within the three largest clusters was recorded in the second year of life, and after year 13 of life with multiple fluctuations. For older animals differences between the groups have been noted. Despite the fact that some of the effects result from inconsistency of time points, in the first group including three zoological gardens (Chicago, McLean and Sankt Petersburg) stabilization (low mortality) should be stressed. In this group, a rapid increase in mortality rate was recorded only for the oldest individuals (aged over 20 and 27 years for males and females, respectively).

Hazard functions derived for individuals of both sexes which survived less than one year are shown in Figures 4 and 5. It should be recalled that groups I, II and IV had low frequency and were, therefore, excluded from analysis. Larger differentiation of the shape of the curve was observed in the analysis pertaining to all individuals. For males and females in groups V and VI the hazard functions were congruent. Mortality rate was high in the first days of life, then it stabilized and increased later in life.

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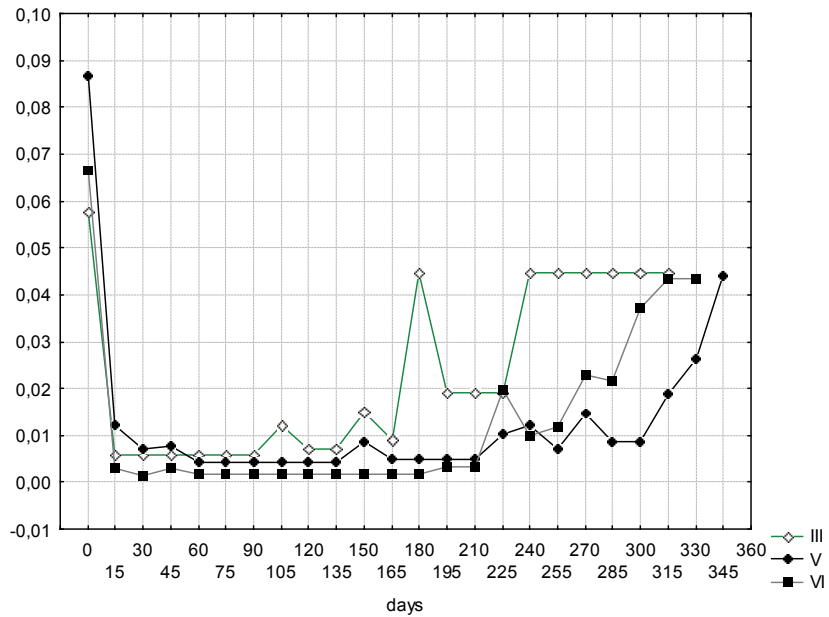


Figure 4. Hazard functions for females dead in the first year of life from clustered zoos.

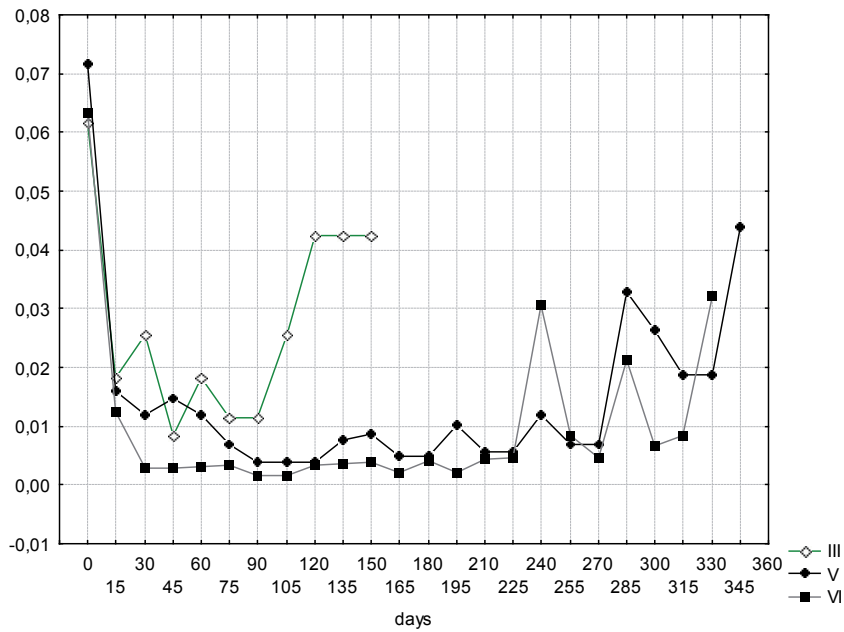


Figure 5. Hazard functions for males dead in the first year of life from clustered zoos.

The results show clearly the differences in mortality between males and females in all the groups (for all individuals and for individuals that survived less than one year). Generally the females lived longer and were characterized by a lower mortality rate in most of the analysed periods. Mean inbreeding level of the population studied was low (2.42%). However, this might have to do with the availability of pedigree information. Inbreeding coefficients as well as number of individuals and number of inbred individuals are shown in Table 3. Considerable differences between clusters have been found. In the first group, null average inbreeding level was observed, whereas for the sixth cluster the average inbreeding coefficient ranged from 0.03 (all males) to 0.054 (females < 1 year). It suggests that life span is determined more by inbreeding level and zoo management conditions than by the climatic zone.

Table 3. Mean inbreeding coefficients (F), number of animals (n) and number of inbred animals (n_F) across clusters of zoological gardens

Data set	Cluster						
	I	II	III	IV	V	VI	
All females	F	0.00	0.007	0.012		0.028	0.037
	n	22	17	97		269	262
	n_F	0	1	6		36	44
All males	F	0.00	0.00	0.008	0.042	0.023	0.030
	n	11	13	61	6	216	200
	n_F	0	0	2	1	28	27
Females (<1 year)	F			0.025		0.017	0.054
	n			15		58	70
	n_F			2		4	18
Males (<1 year)	F			0.011		0.017	0.048
	n			23		58	81
	n_F			1		4	17

The present study confirmed the complexity of background of animal mortality. The heritability of life span is relatively low [Sternicki *et al.* 2005]. Although the trait is difficult to model statistically (distribution of longevity differs from normality, and in consequence, heritability can be underestimated), it corresponds with results obtained both for livestock [Diaz *et al.* 2002, Forabosco *et al.* 2002] and wild animal populations [Grzech *et al.* 2005, Kruuk *et al.* 2000]. However, longevity, especially during the neonatal period, can be strongly affected by specific genetic factors (e.g. lethal mutations) and pregnancy effects. Riley *et al.* [2004] reported that vigour at birth and preweaning mortality of Brahman calves are influenced by age of dam, calving difficulties, neonatal behaviour, maternal care, temperament, *etc.* On the other hand, length of life depends on environmental conditions, for instance feeding or climate. Some authors [Josey *et al.* 1993, Wittum *et al.* 1993] reported that calf mortality increased due to exposure to cold. Mukasa-Mugerva *et al.* [2000] found a reduction of lamb survival in the rainy season of a tropical environment.

The zoo impact (recognized in this study) can be considered as a number of different effects including climatic, management and genetic ones. As already mentioned, the geographical composition of these clusters indicates negligible effects of climate on life span. Hence, differences in hazard rates among these groups mainly resulted from some management effects and rate of inbreeding. Mean inbreeding coefficients varied across clusters belonging to different geographical zones. Although hazard function is widely applied in demographic studies of animal populations [see e.g. Luder 1993], direct comparison of our results with reports by other authors seems to be difficult. Of course, shapes of hazard rates obtained in the present study correspond with other reports for a number of wild animal species. However, published reports are not performed within clusters according to our criteria. On the other hand, Szablewski [2003] found a similar inbreeding level and its effects on life span in some animal populations rebuilt from a small number of founders.

In the first period, both for groups of males and females, the shapes of hazard curves were shown to be convergent. By contrast, these hazard functions are different for the older animals in six groups. Similar conclusions were drawn in an earlier study by Molińska-Glura *et al.* [2004]. Variability of hazard functions has also been reported. Vukasinovic *et al.* [2001] estimated that it is approximately constant in the first four lactations and increases gradually after that point, as older cows are at higher risk of dying or culling for involuntary reasons.

This study includes a relatively long time of observation (53 years). So, some differentiations of hazard shapes can be determined by time. Nguti *et al.* [2003] on the basis of survival analysis in lambs concluded that when an analysis of the cause of death was done by year, some variations in the ranking of causes of mortality were observed across years, particularly in the post-weaning period, and this resulted in a significant interaction between the year and mortality causes.

It seems that this can be considered as one of the main reasons of variation of hazard functions for David's deer groups (under the age of one). The shapes of hazard functions are different for males and females. However, it is well known, that the highest mortality is observed in the first days of life. This corroborates the results obtained by Szablewski [2003]. Furthermore, these hazard functions are characterized by small values. However, for individuals aged one hundred days (and more) the shapes of hazard functions vary.

Finally, this paper has shown that the demographical tendencies in David's deer population kept in zoological gardens do not depend on their geographical location. A moderate inbreeding impact on the survival of David's deer is suggested. Zoo management effects can also be considered in a further study to determine this trait. Differences in survival between sexes were found to the advantage of females. However, it should be remembered that the recorded animals were only born in slightly more than the last 50 years, therefore the above mentioned factors may be modified by time. What is the future of David's deer population? The obtained results and current status of the population seem to show a non-negative perspective.

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Funkcje hazardu dla grup skupień populacji jelenia Dawida (*Elaphurus davidianus*)

Streszczenie

Celem badań było określenie ryzyka śmiertelności związanego z warunkami klimatycznymi w populacji jelenia Dawida, z wykorzystaniem funkcji hazardu wyznaczonej w ramach grup ogrodów zoologicznych. Ponadto dokonano oceny inbredu dla poszczególnych skupień. Analizą objęto 1192 osobniki urodzone w latach 1947-2000 z 56 ogrodów zoologicznych. Do badań włączono także osobniki żyjące. Średnią długość życia i procent padnięć w poszczególnych ogrodach zoologicznych wykorzystano do wyznaczenia dwuwymiarowej odległości euklidesowej. Funkcje hazardu wyznaczono w obrębie grup skupień poszczególnych ogrodów zoologicznych. Badania przeprowadzono w obrębie grup płci dla następujących dwóch zestawów danych: wszystkie osobniki (zestaw 1) i osobniki padłe w pierwszym roku życia (zestaw 2). Wyodrębniono tylko trzy grupy osobników, których długość życia nie przekraczała jednego roku. Wielkość grup skupień była różna (od dwóch do osiemnastu osobników). W grupach tych stwierdzono zróżnicowanie geograficzne analizowanych ogrodów. Generalnie, kształty krzywych hazardu były podobne, z wyraźnie rosnącym trendem. Różnice między grupami ujawniały się głównie w rozbieżności punktów czasowych – pierwszy szczyt śmiertelności pojawiał się w pierwszym okresie życia. Wykazano różnice w śmiertelności między samcami a samicami we wszystkich grupach (dla wszystkich osobników i dla osobników, które żyły mniej niż rok). Stwierdzono, że rejon geograficzny nie ma wpływu na przeżywalność jeleni badanego gatunku. Chociaż poziom inbredu okazał się stosunkowo niski (2,42%), to jednak zaobserwowane różnice w jego wielkości między poszczególnymi skupieniami potwierdzają jego wpływ na długość życia.

