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Assessing the risk to Père David's deer and its red deer hybrids from Malignant Catarrhal Fever.

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Abstract. *Père David's deer are a rare and threatened species of Cervidae, and their conservation is important. A proportional hazards model is used to quantify the relative risk from Malignant Catarrhal Fever to pure bred animals and various hybrids with red deer. The apparent susceptibility of the Père David's deer to Malignant Catarrh Fever is confirmed thereby facilitating decisions concerning the management of the pure-bred animals and hybrids.*

KEY WORDS: Père David's deer; Malignant catarrhal fever; Proportional hazards model; Relative risk.

1 Introduction

Père David's deer (*Elaphurus davidianus*) evolved in the south of China and are thought to have become extinct in the wild over 2000 years ago. The sole remaining animals were kept as a herd, until the late 1800s, in the Imperial Hunting Park near Beijing when a small number were transported to Europe. At the turn of the century the European held deer and their offspring were gathered together by the Duke of Bedford in a park at Woburn Abbey in England. All the remaining deer in China subsequently died in war, floods and famines. Today the world population of these deer numbers around 1500 and all have descended from the Woburn herd (Wemmer, 1983).

Père David's (PD) deer are members of the Cervidae family as are red deer (*Cervus elaphus*). However, they are larger and long day breeders (i.e. breed in summer) as distinct from red deer which are short day breeders (Fennessy and Mackintosh, 1992). In 1985 a group of PD deer were imported to New Zealand (NZ) and established at the Invermay Agricultural Centre. The intention was to maintain a breeding herd in order to help conserve the species and to provide male deer for hybridising with red deer. The hybrids potentially had more desirable carcass characteristics than red deer while breeding earlier in the season. The initial group was followed by two further groups of deer which were imported in 1985 and 1986. However, soon after their arrival serious losses occurred due to the viral disease, Malignant Catarrhal Fever (MCF).

MCF is caused by a herpes virus carried asymptomatically by sheep (Reid, 1991). In European cattle and red deer it is associated with low morbidity but high mortality. However some species of deer, namely PD, sika, rusa and white-tailed deer as well as buffalo and Indonesian cattle appear very susceptible. For example, some outbreaks have resulted in up to 50% mortality (Hoffmann, et al. 1984, Mackintosh, 1991). The hybridisation of PD deer with red deer, using artificial breeding and natural mating, has resulted in the generation of a few F1 hybrids and several backcross quarter bred PD hybrids. The relative susceptibility of these deer to MCF is the subject of this paper.

2 General details

Three cohorts of PD deer were transported from Woburn to Invermay including periods in quaratine in both England and New Zealand. The first of 24 arrived on 1 April 1985, the second of 8 arrived on 30 November 1985 and the third of 5 arrived on 24 October 1986. Monthly records of their mortality and attributed cause of death were kept till September 1991 when only four of the animals remained alive.

In November of 1987, 1988 and 1989, 4, 5 and 6 calves, respectively were born and they are included in the study as 3 separate NZ born cohorts.

In all, 13 F1 hybrids were born during the period from 1988 till 1991. Monthly records of their mortality and attributed cause of death were kept till December 1995 when only 2 animals remained alive.

The quarter bred PD deer were born in November each year from 1989 till 1994. In that period 235 progeny were weaned. Monthly records of their mortality and attributed cause of death were kept till December 1995. The F1 sire GW899 sired all the 1991 born cohort but died at mating the following March. His replacement, GW903, was used till 1994 but in 1993 and 1994 his activities were supplemented by the F1 sire GW018 who mated about half the red hinds used in the breeding programme.

Ten years of records for red deer at Invermay from herds maintained at about 1000 animals were used to obtain an estimate of the hazard posed by MCF to pure bred red deer kept in what amounted to typical farm conditions at Invermay.

3 Model selection

A proportional hazard model was selected as a suitable model for the survival time of the different hybrids of PD deer. In accordance with convention, the effects of covariates on the hazard are assumed to be multiplicative. This assumption leads to the model

$$h_i(t) = \exp(\beta^T x_i)h_0(t)$$

where $\beta^T x_i$ is a linear predictor for the i^{th} hybrid class describes by the covariate x_i such that $\ln[h_i(t)/h_0(t)] = \beta^T x_i$ and the proportional hazard with respect to the reference class is $h_i(t)/h_0(t) = \exp(\beta^T x_i)$. This is a particular case of regression models considered by Cox (1972).

Let T_i be a random variable representing the time till death attributable to MCF of an animal in the i^{th} hybrid class, with $F_i(t) = Pr(T_i \leq t)$ the probability of dying from the disease by time t.

The hazard function $h_i(t)$ is the instantaneous risk from MCF for an animal in the i^{th} hybrid class and $h_i(t)dt$ is the probability of death from the disease in the interval $(t, t+dt)$, given it has survived till time t. It can be shown that

$$1 - F_i(t) = \exp[-\int_0^t h_i(u)du]$$

The conditional probability of a death in the i^{th} hybrid class during the time interval $[t_{j-1}, t_j]$ attributable to MCF, given survival till time t_{j-1} is

$$\begin{aligned} p_{ij} &= [F_i(t_j) - F_i(t_{j-1})] \,/\, [1 - F_i(t_{j-1})] \\ &= 1 - \exp[-\int_{t_{j-1}}^{t_j} h_i(t)dt] \end{aligned}$$

Substitution for $h_i(t)$ gives

$$p_{ij} = 1 - \exp[-\exp(\beta^T x_i) \int_{t_{j-1}}^{t_j} h_0(t)dt]$$

and so by applying the complementary log - log transformation we get

$$\ln[-\ln(1 - p_{ij})] = \beta^T x_i + \gamma_j$$

where γ_j is $\ln[\int_{t_{j-1}}^{t_j} h_0(t)dt]$. Without time dependent covariates, the model implies the ratio of hazards is a constant which is independent of time.

The model is one of a class of generalised linear models of Nelder and Wedderburn (1972) and so maximum likelihood estimates of the parameters are available through many computer packages.

4 Results

Instead of estimating all the 128 γ_j's, one for each month from April 1985 till December 1995, year and month effects were estimated as main effects as were deviations from these main effects for particular years and months. This was considered desirable as a parsimonious model with few parameters was being sought in order to use the asymptotic distribution of the parameter estimates and the likelihood-ratio statistic. McCullagh and Nelder (1989) suggest limiting the number of parameters to be estimated to a small fraction of the number of observations, particularly if some of the binomial denominators are small, which in this case they were.

With the objective of obtaining a parsimonious model the importance of a term in the fitted model was assessed by considering the difference between the scaled deviance (dispersion parameter with a value of 1) of that model and the model excluding the term. This process was facilitated by the following accumulated analysis of deviance table, which presents the change in scaled deviance resulting from adding the term after the inclusion in the model of the terms which precede it.

Change	df	Deviance	Mean Deviance
+ Species	3	88.3	29.5
+ Month	11	28.7	2.61
+ Year	10	12.4	1.24
+ Month · Year	107	113.2	1.06
Residual	601	175.3	0.29

On the basis of the mean deviance reported above, the Month.Year terms were eliminated from the model. As would be expected, changing the order of fitting Month and Year did not change the interpretation of the analysis of deviance table and so Year was then eliminated, leaving only Species and Month in the final parsimonious model.

The proportional hazard with respect to the imported PD deer were estimated as follows. The confidence range assumes a dispersion parameter with a value of 1.

Species	Proportional Hazard	95% Confidence range
NZ born PD	0.70	0.33 to 1.46
F1	0.53	0.25 to 1.09
1/4 bred PD	0.08	0.05 to 0.15

The proportional hazard to the 1/4 bred animals is significantly less than to the NZ born PD or F1 animals.

The months of July and October were estimated to be 4.31 and 4.50 times as hazardous as January (95% confidence ranges were respectively, 1.24 to 14.96 and 1.28 to 15.79).

The long run proportional hazard to farmed red deer from MCF based on 5 deaths per thousand animals per year and the proportion of imported PD animals dying per month as predicted by the parsimonious model, is 0.013 with an approximate 95% confidence range 0.010 to 0.019. This is significantly less than the hazard posed to the 1/4 bred animals.

5 Discussion

The increasing hazard posed by MCF for an increasing PD component is consistent with the PD deer being exposed to a new hazard. There are no sheep in the region of China where PD deer evolved whereas it is believed that red deer have evolved in areas where there has been sufficient exposure to sheep for them to have developed some resistance to MCF. Conservation of PD deer in NZ would therefore appear to require a sheep free environment. In fact it has been suggested (Reid, H. W., *pers. comm.*) that harbouring MCF is a strategy which has allowed sheep to successfully compete with deer where they co-exist.

The periods of the year when deer are likely to be subject to the most stress are during winter when body energy reserves are at their lowest especially in males and in spring prior to calving in females. These periods are consistent with the periods of increased hazard from MCF identified in this paper. This also fits the pattern seen with red deer and cattle in NZ with the highest mortality in winter/spring and lowest in summer/autumn. Unfortunately, the power of the comparison between genders within months precluded informative modelling of this effect.

Parameter estimates for the NZ born PD deer and the F1 animals are consistent with two intriguing possibilities although the large confidence intervals do not permit strong inference. The usual strategy for dealing with this difficulty, which involves generating more NZ born PD or F1 deer and so make more precise comparisons, is not available to us. Consequently, we attempt to make the following suggestions where in more usual circumstances we would be more circumspect.

The best estimate of the proportional hazard to the NZ born PD with respect to the imported PD suggests that the death of around half of the imported deer in the first year resulted in selection against the more susceptible of the animals and has resulted in more resistant progeny. That is, it seems possible that the NZ born animals, which are progeny from the imported animals which survived long enough to reproduce, are overall less susceptible to MCF than the imported reference group. This would be consistent with the converse of the suggestion by Reid, (1991) that in many parts of the world deer have been adapted by selection to coexist with sheep.

Another explanation of the higher mortality rate in the imported animals may have been the stresses of transport from England to NZ, their accommodating to the 6 month shift in seasons and that their adaptation to a new environment made them more susceptible to challenge by the MCF virus than the NZ born counterparts.

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