A predictive model for reproductive performance following abortion in thoroughbred mares

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Pregnancy losses include early embryonic death (EED) and later (postimplantation) abortion. Abortions, particularly Equid herpesvirus (EHV-1) abortion epizootics, cause severe economic and production losses. The long-term effects of EHV-1 and other abortions on subsequent reproductive performance in broodmare populations, however, remain undefined. This study described the relationships of EED and abortion with the following reproductive outcomes in thoroughbred systems: breeding efficiency, month of last breeding, subsequent pregnancy and live foal rates. A prospective cohort study in broodmare populations following EHV-1 epizootics on two South African farms was used to develop predictive models of the relative influences and interactions of reproductive variables associated with EHV-1 and other abortion causes on reproductive performance. EED predicted all the reproductive outcomes. Abortion predicted increased effort and month of breeding to establish pregnancy, but not becoming pregnant or foaling. Increasing age predicted decreased reproductive efficiency, and pregnancy and foaling probabilities. Mare reproductive status predicted breeding efficiency and the last month of breeding, but not establishing pregnancy. The last month of breeding predicted efficiency, pregnancy and foaling. Interestingly, breeding in the first month of the season was associated with an improved probability of pregnancy among barren mares.

Introduction

Various aspects of reproductive performance have been reported in thoroughbred breeding systems. Reproductive variables include pregnancy rates (PR) per oestrous cycle or season (cumulative) and live foal rate (FR) (Brück and others 1993, Morris and Allen 2002, Schulman and others 2003, Hemberg and others 2004, Allen and others 2007, Bosh and others 2009). Pregnancy losses include early embryonic death (EED) following confirmed pregnancy within six weeks of conception and later (postimplantation) loss or abortion. Mare age and reproductive status category are associated with reproductive performance, including pregnancy loss (which rises with age and barren status), and must be considered to understand reproductive outcomes in thoroughbred populations (Bain 1969, Morris and Allen 2002, Hemberg and others, [b11]2004, Allen and others 2007, Yang and Cho 2007).

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Abortion causes are subdivided into infectious or non-infectious origin (Acland 1987, Jonker 2004, Laugier and others 2011) with Equid herpesvirus (EHV-1) as the most important viral cause of infectious abortion (Allen and Bryans 1986, Smith 1997, Gilkerson and others 1999, Gerst and others 2003, Smith and others 2003, Slater and others 2006, Brown and others 2007, Lunn and others 2009, Laugier and others 2011). Following abortion, EHV-1 virus rapidly clears from the genital tract, and future breeding capacity is unimpaired unless uterine damage has occurred from dystocia (Smith 1997).

This study aimed to describe the relationship between abortions and other reproductive variables with subsequent key outcomes in thoroughbred pregnancy, including associated reproductive efficiency, and successful foaling. This study also aimed to enhance understanding of poorly supported assumptions regarding effects of EHV-1 and other abortion causes on reproductive performance.

Materials and methods

Design

A retrospective analysis of reproductive events affecting pregnant broodmares during unrelated abortion epizootics from confirmed EHV-1 infection during 2007 (farm 1) and 2009 (farm 2), respectively, was conducted on two thoroughbred stud farms in geographically separated areas of South Africa (Schulman and others, in submission). This prospective cohort study was undertaken in the same broodmare populations to assess the association of EHV-1 and other causes of abortion with subsequent reproductive performance.

Background

Farm 1

Farm 1 is located in the Western Cape Province of South Africa. Nine of 30 (30 per cent) pregnant resident broodmares aborted between May and September 2007. All abortions were confirmed as caused by EHV-1 through submission of fetal tissue and membranes for histopathology. One mare died following abortion, the remaining 21 foaled normally. During the subsequent breeding season (September 1, 2007–January 31, 2008) all resident broodmares (n=45) were bred including 21 that foaled, eight surviving EHV-1 abortion mares (allocated as barren mares), and an additional 16 (four foaling, six maiden and six barren) mares.

Farm 2

Farm 2, in KwaZulu-Natal Province, experienced an EHV-1 abortion epizootic between May and September 2009. Eighteen (5.7 per cent) EHV-1 abortions occurred amongst the resident pregnant mare population (n=316). EHV-1 was confirmed by submission in all cases of fetal tissue and membrane samples using both qPCR assay and histopathology (Smith and others 1992, Gerst and others 2003). Forty-three (13.6 per cent) abortions were recorded during 2009, including 25 from other causes. A cause was diagnosed in 10 (40.0 per cent) of the non-EHV abortions; six (24.0 per cent) were associated with ascendant placentitis. During the subsequent breeding season (September 1, 2009–January 31, 2010), 375 resident broodmares were bred, including 18 EHV-1 abortion mares and 21 non-EHV abortion mares, all reallocated as barren mares.

Resident broodmare populations

Resident broodmares on both farms were divided into the following populations:

1. Non-abortion mares (foaling normally in the same season or not previously bred)
2. Abortion mares (aborting in the preceding season from any cause)
3. EHV-1 abortion mares (aborting from EHV-1 in the preceding season)
4. Non-EHV abortion mares (aborting from non-EHV-related causes in the preceding season).

Mares were grouped into three age categories associated with thoroughbred breeding systems: young (less than six years), middle-aged (7–11 years), and old (>12 years) mares.

Mares were further grouped by reproductive status: foaling (successful foaling in the current season); maiden (never previously bred); and barren (bred at least once previously but did not foal successfully in the current season, including the abortion mares).

Data

Sources of data were the two farms' broodmare and foaling records maintained by each respective farm's manager and veterinarian. The observation period commenced in the postepizootic breeding (covering) season (September 1–January 31) and ended with the associated foaling season from approximately August 1, one year later.

The variables selected for describing reproductive performance were: (1) number of oestrous cycles per pregnancy or PR per cycle (by transrectal ultrasound at 14–16 days postovulation); (2) number of breeding attempts per pregnancy (from mare records); (3) incidence of EED observed <40 days postovulation (by transrectal ultrasound subsequent to initial positive diagnosis); (4) cumulative pregnancy rate (PR cumulative) at the end of the breeding season by transrectal ultrasound and palpation; and (5) successful (live) foaling (FR) in the subsequent foaling season.

The number of breedings was usually equivalent to the number of oestrous cycles. A maximum of two oestrus periods per month were available with an interovulatory interval of 21–22 days (Aurich 2011). The farms commenced breeding in September (month 1), continuing in October (month 2) with most breeding attempts in November (month 3) and declining through December (month 4), with a negligible number of mares being bred in January (month 5). The month of last breeding was an indirect indication of the month pregnancy was established. Early diagnosed pregnancy loss resulted in the mare being rebred during a subsequent oestrus.

Data analysis

Statistical models were created for four defined outcomes to explain the relative influence and interactions of the different reproductive variables in the different broodmare populations in the subsequent breeding seasons. The data from both farms were pooled for analysis because 'farm' was neither a confounder nor effect modifier when examining main and interaction effects. Statistical significance was defined as P<0.05

Four outcomes were defined for these models:

1. Pregnant at end of breeding season, analysed with logistic regression, evaluated separately for all mares and only barren mares
2. Successful foaling in the subsequent season, analysed with logistic regression
3. Number of breeding attempts to establish pregnancy between September 1 and January 31, analysed as contingency table data using either an exact Kruskal-Wallis test for singly ordered data (EED, aborting mares, EHV and non-EHV-induced abortion, mare status) or an exact Jonckheere-Terpstra test for doubly ordered data (age categories, month of last breeding), and as continuous data (age) using linear regression and Pearson correlation
4. Month of last breeding attempt between September 1 and January 31, analysed as singly ordered contingency table data (mare status, aborting mares) using an exact Kruskal-Wallis test.

Predictor variables evaluated by logistic regression analysis were:

1. Age
2. Mare reproductive status (barren, maiden or foaling)
3. EED incident
4. Number of breeding attempts
5. Month of last breeding
6. Abortion due to any cause
7. Abortion due to EHV-1
8. Abortion due to non-EHV causes.

Results of logistic regression analyses are presented as odds ratios (OR), 95 per cent confidence intervals (95% CI), and P values testing the null hypothesis that the OR=1. For continuous variables, the assumption of linearity in the log odds was verified in the analyses. Variables with significant ORs were then included in a multivariable logistic regression model, followed by using likelihood ratio tests to remove variables not significantly improving model fit.

Two logistic regression models were developed to predict probabilities of establishing pregnancy in the interval September 1–31 January 31 and for successful foaling in the associated season. Multivariable models were applied to hypothetical characteristic Thoroughbred broodmares typical of the internationally expected demographic to illustrate the relative influence and interactions of the selected reproductive variables on the probabilities of two key outcomes.

Results

Reproductive performance of the different resident broodmare populations during the breeding seasons subsequent to the EHV-1 epizootics is summarised in Table 1 (farm 1) and Table 2 (farm 2). On farm 1, although EHV-1 abortion mares required more cycles to become pregnant, all became pregnant compared with 89.2 per cent of non-abortion mares. Twelve (26.7 per cent) mares (including two EHV-1

TABLE 1: Reproductive performance of the resident broodmare populations on farm 1 between September 1, 2007 and January 31, 2008

	Mare populations		
Reproductive performance	All mares (n=45)	Non-abortion mares (n=37)	EHV-1 abortion mares (n=8)
Per cycle pregnancy rate (mean, range)	1.4 (1–5)	1.2 (1–4)	1.8 (1–5)
Early embryonic deaths (%)	6 (13.3)	5 (13.5)	1 (12.5)
Cumulative pregnancies (%)	41 (91.1)*	33 (89.2)	8 (100)
Not pregnant (January 31, 2008) (%)	4 (8.9)	4 (10.8)	0 (0)
Live foals (foaled in 2008) (%)	27 (60.0)	22 (59.4)	5 (62.5)

*Two pregnant mares subsequently died
EHV-1 Equid herpesvirus

TABLE 2: Reproductive performance of the resident broodmare populations on farm 2 between September 1, 2009 and January 31, 2010

	Mare populations			
Reproductive performance	All mares (n=368)	All abortion mares (n=43)	EHV-1 abortion mares (n=18)	Non-EHV abortion mares (n=25)
Per cycle pregnancy rate (mean, range)	1.7 (1–6)	1.9 (1–4)	1.9 (1–4)	1.8 (1–4)
Early embryonic deaths (%)	31 (8.4)	4 (9.3)	2 (11.1)	2 (8.0)
Cumulative pregnancies (%)	319 (86.7)*	36 (83.7)	16 (88.9)	20 (80.0)
Not pregnant (January 31, 2010) (%)	49 (13.3)	7 (16.3)	2 (11.1)	5 (20.0)
Live foals (foaled in 2010) (%)	279 (75.8)	34 (79.1)	16 (88.9)	18 (72.0)

*Five pregnant mares subsequently died
EHV-1 Equid herpesvirus

abortion mares) subsequently aborted. The submission of samples for diagnostic screening universally failed to show EHV-1 or any other potentially epizootic-associated cause. The associated FR was similar in all mare populations, and also to that reported in the previous, EHV-1 epizootic-associated season. On farm 2, a similar PR per cycle and EED incidence was seen in all broodmares, PR cumulative and FR in the abortion populations was similar, but higher than that for the overall broodmare population.

The number of breeding attempts required to establish pregnancy

Age had a significant association with the number of breeding attempts, whether regarded as continuous (r=0.12, P=0.016) or as ordinal categories (P=0.040) (Table 3). Findings showed 68.5 per cent young mares were bred once, compared with 60.6 per cent middle-aged and 55.5 per cent old mares, respectively. The trend with multiple breeding attempts was similar across all three age categories, two breeding attempts for 23.3 per cent, 26.7 per cent and 26.4 per cent of young, middle-aged and old mares, respectively. Mare status had a significant association with the number of breedings (P<0.0001), with 73.3 per cent maidens requiring a single breeding, compared with 63.8 per cent foaling and 46.2 per cent barren mares. A similar percentage (27.9 per cent and 25.3 per cent) of foaling and barren mares required a second attempt to establish pregnancy. EED had a significant association with the number of breedings (P<0.0001), associated with 46.0 per cent second, and 21.6 per cent third breeding attempts, with only three (8.1 per cent) and one (2.7 per cent) incidents of EED associated with a fourth and fifth breeding, respectively. There was a significant association between the number of breedings and the last month of breeding a mare (P<0.0001). A single breeding and its association with pregnancy showed a monotonic decline with each successive month. From the first to the fourth month, 71 (85.5 per cent), 67 (64.4 per cent), 76 (57.1 per cent), and 33 (37.9 per cent) of mares, respectively, became pregnant by a single breeding. The association with multiple (less than two) breedings and establishment of pregnancy showed that two breedings were required in only 12 (14.5 per cent) of the mares bred in the first month. In the second, third and fourth months, a similar proportion of mares: 31 (29.8), 36 (27.1 per cent), and 26 (29.9 per cent), respectively, required two breedings. Similarly, a third breeding was recorded from the second to the fourth month in five (4.8 per cent), 18 (13.5 per cent), and 12 (13.8 per cent) mares, respectively.

A mare having aborted due to any cause was associated with the number of breedings (P=0.021). A single breeding was sufficient in 62.4 per cent of non-abortion mares, whereas, less than half (46.8 per cent) the number of abortion mares became pregnant from only one breeding. The requirement for a second breeding (25.4 per cent and 29.8 per cent) was, however, similar between the two mare populations.

The month of the last breeding attempt in the interval September 1–January 31

A significant relationship was seen with mare status (P<0.0001) (Table 3). In the first month, September, 46.2 per cent barren, 26.7 per cent maiden and 9.7 per cent foaling mares were bred for a last time. In the second month, October, a similar proportion of barren (23.1 per cent) and foaling (24.4 per cent) mares and 33.3 per cent maidens were bred one last time. The largest proportion of mares was bred in the third month, November, with 16.5 per cent barren, 25.0 per cent maiden and 39.9 per cent foaling mares. In December, a similar proportion of the barren and maiden (14.3 per cent and 15.0 per cent, respectively) and 25.2 per cent of foaling mares were bred for the last time. A negligible proportion of mares were January. Abortion due to all causes (P=0.0001), EHV-1 abortion (P=0.0014) and non-EHV-1 abortion (P=0.0023) were all associated with the last month of breeding. Approximately half (48.9 per cent) the number of abortion mares were bred for the last time in the first month, with a monotonic decline from this point (23.4 per cent, 17.0 per cent and 10.6 per cent) from October to December. A significant association was seen with EED (P<0.0001). A low incidence of EED of only one (2.8 per cent) and three (8.3 per cent) was recorded from mares bred in the first and second months, respectively. A high EED incidence (47.2 per cent and 41.7 per cent) was seen in the third and fourth months, respectively. A significant association was also seen with the number of breedings required (P<0.0001), as described above.

TABLE 3: A summary of outcomes-based analyses of reproductive performance of pregnant broodmares resident on both farms

Outcome	Variable							
	Age	Status	Early embryonic death	Number of breedings	Month of last breeding	Abortion (all causes)	Abortion (EHV-1)	Abortion (non-EHV)
Cumulative pregnancy rate	P=0.0005	P=0.77* P=0.24†	P<0.0001	P<0.0001	P<0.0001	P=0.31	P=0.75	P=0.51
Cumulative pregnancy rate: barren mares	–	–	–	–	–	P=0.38	P=0.43	P=0.28
Foaling rate	P<0.0001	P=0.055†	P<0.0001	P<0.0001	P<0.0001	P=0.19	P=0.49	P=0.44
Number of breedings	P=0.016‡ P=0.040§	P<0.0001	P<0.0001	–	P<0.0001	P=0.021	P=0.086	P=0.16
Month of last breeding	P=0.19‡ P=0.28§	P<0.0001	P<0.0001	P<0.0001	–	P<0.0001	P=0.0014	P=0.0023

*Comparing foaling with barren mares
†Comparing maiden with barren mares
‡Data as continuous
§data as ordinal categories
EHV-1 Equid herpesvirus

TABLE 4: Univariate logistic regression models of potential determinants for establishing pregnancy in two populations of resident broodmares Q8

Determinants	Pregnant (n)	Not pregnant (n)	Odds ratio	95% confidence interval	P value
4.1 Age (years)			0.90	0.84 to 0.95	0.0005
4.2 Early embryonic death			0.073	0.030 to 0.16	<0.0001
4.3 Number of breeding attempts			0.39	0.28 to 0.53	<0.0001
4.4 Monthly trend of last cover			0.24	0.15 to 0.38	<0.0001
4.5 Month of last cover					
September	81	2	1		
October	103	1	2.53	0.13 to 151.5	0.83
November	119	14	0.21	0.023 to 0.96	0.042
December	56	31	0.045	0.0051 to 0.19	<0.0001
4.6 Abortion (any cause)					
No	316	46	1		
Yes	44	3	2.13	0.64 to 11.17	0.31

Pregnancy at the end of the breeding season

Univariate analyses of potential determinants of pregnancy at the end of the breeding season are shown in Tables 3 and 4. Significant variables include age, history of EED, number of breeding attempts and month of last cover. Multivariable analysis of the significant predictors showed a significant main effect of age (P=0.0042), and significant interactions between EED and number of breedings (P=0.0023), and between number of breeding attempts and month of last breeding (P=0.014). For each additional year of age, the odds of establishing pregnancy declined approximately 10 per cent (OR=0.89, 95 per cent CI 0.82 to 0.96). The predictive probability of establishing pregnancy with consideration of the interactions between the significant predictors is shown by the logistic regression model in Table 5. Three hypothetical broodmares, representative of the demographic in thoroughbred systems are included. These include a five-year-old maiden and a 15-year-old barren mare that are bred commencing in the first month, September, continuing until the end of the season. In addition a 10-year-old mare that foaled in the middle of the second month and was subsequently bred, commencing in November and continuing until January 31 was included.

Foaling successfully in subsequent season

Univariate analyses of potential determinants of pregnancy at the end of the subsequent breeding season are shown in Tables 3 and 6. Significant variables include age, history of EED, number of breeding attempts, and month of last cover. Multivariable analysis included significant interactions between the potential determinants (results not shown). The predictive probability of foaling in a mare with consideration of the interactions between the significant predictors is shown by the logistic regression model in Table 7. Hypothetical broodmares, representative of the demographic in thoroughbred systems, are included in this model. These include a five-year-old maiden mare, a 10-year-old foaling or barren mare, and a 15-year-old foaling or barren mare.

Discussion

The reproductive efficiency, EED rates and PR cumulative were similar in all populations. The PR per cycle in the various broodmare populations was similar to previous reports for thoroughbred mares of all ages (Hemberg and others 2004, Allen and others 2007). After establishing pregnancy, horses' abortion rates were similar to those during the previous, epizootic-associated season on both farms. The FR on farm 1, although similar to an earlier report in South African Thoroughbreds (Schulman and others 2003), was appreciably lower than that on farm 2, which in turn was similar to reported ranges for other populations of a similar age distribution (Hemberg and others 2004, Allen and others 2007). In the breeding season following the epizootic, a better foaling outcome (in particular, on farm 2) was observed for mares with a recent abortion history than with non-abortion mare populations.

These observations are difficult to explain, but imply an advantageous relationship between a history of abortion and subsequent reproductive performance. The influence of epizootic-associated versus endemic (from sporadic causes) abortion on reproductive outcomes in a particular season is also unclear from these data.

Results indicate that solely focusing and reporting on the crude relationships between predictors and subsequent reproductive performance, can lead to misleading conclusions, because such effects are

TABLE 5: The predictive probability of establishing a pregnancy between September 1 and January 31 in three hypothetical broodmares according to number of breedings and the month of last breeding and either with or without an incident of early embryonic death in the logistic regression model

	No early embryonic death incident Number of breedings					Early embryonic death incident Number of breedings			
Month of last breeding	1	2	3	4	5	2	3	4	5
5.1 A five-year-old maiden mare									
1	0.99	1.00	–	–	–	0.98	–	–	–
2	0.99	0.99	1.00	1.00	–	0.92	0.99	–	–
3	0.98	0.97	0.96	0.95	0.95	0.70	0.88	0.96	–
4	0.95	0.87	0.71	0.47	0.24	0.33	0.40	0.49	0.04
5	0.90	0.59	–	–	–	0.10	–	–	–
5.2 A 10-year-old mare foaling in the middle of the second month									
3	0.99	0.99	–	–	–	0.97	–	–	–
4	0.98	0.99	0.99	0.99	–	0.86	0.98	–	–
5	0.96	0.95	0.94	0.94	0.91	0.57	0.80	0.93	–
5.3 A 15-year-old barren mare									
1	0.98	1.00	–	–	–	0.94	–	–	–
2	0.96	0.98	0.91	0.99	–	0.77	0.96	–	–
3	0.92	0.91	0.89	0.87	0.84	0.42	0.69	0.87	–
4	0.85	0.68	0.43	0.21	0.09	0.13	0.17	0.22	0.28
5	0.74	0.31	–	–	–	0.03	–	–	–

TABLE 6: Univariate logistic regression models of potential determinants of successful foaling in two populations of resident broodmares in a subsequent season

Determinants	Foaled (n)	Did not foal (n)	Odds ratio	95% confidence interval	P value
6.1 Age (years)					
			0.89	0.85 to 0.94	<0.0001
6.2 Early embryonic death					
			0.092	0.038 to 0.21	<0.0001
6.3 Number of breeding attempts					
			0.54	0.41 to 0.70	<0.0001
6.4 Monthly trend of last cover					
			0.38	0.28 to 0.50	<0.0001
6.5 Month of last cover					
September	74	8	1		
October	92	9	1.10	0.35 to 3.40	1.00
November	100	31	0.35	0.13 to 0.84	0.015
December	47	38	0.089	0.033 to 0.21	<0.0001
6.6 Abortion (any cause)					
No	266	89	1		
Yes	39	7	2.13	0.64 to 11.17	0.31
6.7 Mare status					
Barren	65	25	1		
Foaling	188	63	1.15	0.64 to 2.03	0.71
Maiden	52	8	2.49	0.98 to 6.92	0.055

heterogeneous and consistent with modification by other factors, as evidenced in the multivariate model. The development of a predictive model for reproductive outcomes with inclusion of effect modifiers, such as age and mare reproductive status, was used to enhance understanding of the association and relative influence of the various variables at key points in the thoroughbred reproduction process.

Increased age reduced the probability of a successful outcome in establishing pregnancy and foaling. Age also strongly predicted of the number of breedings: approximately one-third less than six years required a second attempt. The trend with multiple breeding attempts was conspicuously similar across all three age categories.

Mare status showed no predictive association with the establishing pregnancy, although barren mares have been reported in association with reduced fertility (Hemberg and others 2004, Allen and others 2007, Yang and Cho 2007). Foaling status conferred an age-dependent predictive advantage on successful foaling compared with maiden and barren statuses. As age increased, the advantage conferred by foaling status, however, declined. Status was predictive of the number of breedings, with a single breeding sufficient in the majority of maidens (73.3 per cent) compared with foaling mares (63.8 per cent) and less than half the barren mares (46.2 per cent). A similar percentage of foaling and barren mares required a second attempt to establish pregnancy. Mare status was predictive of her last month of breeding, as maidens and barrens were 'available' from the onset of the season in most cases, unlike the foaling mares foaling until December in some cases. Approximately half the barrens became pregnant in the modal first month. This may, perhaps, mitigate some of the effects of the reported inherent subfertility of barren mares, providing a potentially increased number of cycles available to rebreed them. Maidens showed a wider distribution by month of last breeding, as the modal month for becoming pregnant occurred in the second month. This may imply that in these populations, barrens are better prepared by management than maidens to resume cyclic activity, or perhaps a barren versus maiden status confers fewer disadvantages at the onset of the breeding season. November, with the most breedings, resulted in pregnancy in nearly 40 per cent of the foaling mares. A considerable number of mares in all categories were still being bred in December.

The number of breedings predicted establishment of pregnancy and foaling and was significantly associated with age and status, last month of breeding, and EED More maidens became pregnant with a single breeding than foaling or barren mares. Interestingly, a similar percentage of foaling and barren mares required a second attempt to establish pregnancy. There was an enhanced probability of establishing pregnancy early in the season, as breeding in September was surprisingly strongly predictive that a single breeding would result in pregnancy. The relative efficiency of breeding effort and implied result (ie, pregnancy) monotonically declined. The 85.5 per cent of mares

TABLE 7: The predicted probability of successful foaling in hypothetical broodmares of different ages and status categories according to the month of their last breeding, and with or without an incident of early embryonic death in the previous season in the logistic regression model

Month of last breeding	No early embryonic death incident		Early embryonic death incident	
7.1 A five-year-old maiden mare				
1	0.98		0.84	
2	0.94		0.65	
3	0.86		0.40	
4	0.69		0.20	
5	0.44		0.08	
	Barren	**Foaling**	**Barren**	**Foaling**
7.2 A 10-year-old barren or foaling mare				
1	0.91	0.97	0.54	0.8
2	0.79	0.93	0.30	0.59
3	0.58	0.82	0.14	0.34
4	0.33	0.62	0.05	0.16
5	0.15	0.38	0.02	0.06
7.3 A 15-year-old barren or foaling mare				
1	0.91	0.94	0.53	0.64
2	0.78	0.85	0.29	0.39
3	0.57	0.67	0.13	0.19
4	0.32	0.42	0.05	0.08
5	0.15	0.21	0.02	0.03

becoming pregnant at the expected onset of physiological cyclicity in September contrasts with 37.9 per cent in December, coincident with the physiologically optimal peak in ovulation rates. This may imply that any potential physiological advantage of a relatively late breeding is overcome by other negatively associated factors related to breeding at a later stage. The number of breeding attempts significantly predicted FR, with each additional breeding halving the probability of foaling. Month of last breeding was also a significant predictor, with a monotonic decline in the probability of successful foaling between September and December.

EED was strongly predictive of multiple breeding attempts and pregnancy. Of interest and difficult to explain is EED associated with reducing the probability of foaling by almost 90 per cent. In the predictive model of an incident of EED in a relatively young mare, the probabilities of her becoming pregnant and foaling are reduced compared with a substantially older mare with no EED. The sudden and marked increase in EED in the third and fourth months coincided with commencing breeding the majority of the foaling mares. Many are bred within a short interval postfoaling, reportedly associated with the highest EED (Yang and Cho 2007).

Abortion from any cause (EHV-1 or non-EHV-1 causes) did not predict subsequent pregnancy or foaling. Abortion was predictive of the number of breedings to establish pregnancy: slightly fewer than half the abortion mares which became pregnant from a single breeding, compared with nearly two-thirds of non-abortion mares. An abortion history, including EHV-1, predicted the last month of breeding: approximately half these mares became pregnant due to breeding in the first month, with a monotonic decline through December.

In conclusion, development of a predictive model for important outcomes enhanced understanding of complex interactions and relative influences of various reproductive variables. Outcomes, such as pregnancy associated with the customary predictor variables by bivariate analysis, appeared to be either unaffected, or confusingly enhanced in mares subsequent to abortion. Abortion was not predictive of becoming pregnant or foaling, in contrast with previous reports (Bain 1969, Hemberg and others 2004), but was associated with increased effort to establish pregnancy and last month of breeding. Increased age, supporting previous reports, was predictive of increased breeding efforts and decreased the probabilities of establishing pregnancy (Allen and others 2007, Yang and Cho 2007) and foaling (Hemberg and others 2004, Allen and others 2007). Reproductive status was not predictive of establishing pregnancy, contrasting with Allen and others (2007) and Hemberg and others (2004), but being predictive of the number of breedings, and the last month of breeding was similar to other reports (Hemberg and others 2004, Allen and others 2007). The increased probability of foaling success in foaling mares declined with age. In all mares, EED was strongly predictive of all outcomes: breeding attempts, the last month of breeding, pregnancy and foaling. The last month of breeding was predictive of the effort and success of establishing pregnancy (in contrast with Hemberg and others 2004) and foaling. Interestingly, the combination of barren status and breeding in the first month of the season improved the probability of establishing pregnancy, as was seen in approximately half the number of the abortion mares.

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