

Profiling the reproductive life of the New Zealand Thoroughbred broodmare



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Abstract

The Thoroughbred stud book is New Zealand's largest stud book, however the breeding population has decreased in the past years. In this study the stud book career of 1998/1999 season sired filly foals of three stallions per sire category (Cheap <\$5000, Medium \$5001-\$10.000, Expensive >\$10.000 and Shuttle (both hemispheres) was identified, including racing, breeding and sales records. The same procedure was followed for the dams and granddams of these foals. Proven, expensive, stallions cover most mares per stallion. Foals of expensive and shuttle stallions behave differently in the population than foals of cheap and medium stallions. Foals of expensive sires had a higher commercial value, and breeders seemed to be more intent on reclaiming part of their initial investment. A greater proportion of expensive sired foals was sold on the Premier Yearling Sale, exported, raced and entered the breeding population. The same effect was observed for shuttle sired foals, although there did seem to be a stricter selection for shuttle sired foals to enter the breeding herd. Foals of cheap stallions started breeding at a later age and had a lower parity. The proportion of racing broodmares decreased in older generations. The parity of granddams was lower than the parity of the 1999 foals and dam. However, records seemed to become more unreliable when going back further in time. A smaller proportion expensive sired broodmares raced, indicating a stricter selection on racing performance for cheap and medium sired broodmares.

Cheap sires seemed to disappear from the gene pool over time, with granddams being sired mainly by medium and expensive stallions in an equal measure. Breeders were positively influenced by mare fertility in the decision whether to cover a mare again. This effect was strongest in the dams.

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Introduction

General

The Thoroughbred studbook is New Zealand's largest studbook with approximately 9116 broodmares and 5156 foals bred in 2004. The Thoroughbred studbook is a closed studbook, assisted reproductive technologies, such as artificial insemination and embryo transfer are not permitted within the studbook.^{1,3}

There has been a consistent reduction in the New Zealand Thoroughbred breeding herd since the mid 1980's. The number of active Thoroughbred sires at stud in New Zealand has reduced from 265 sires at stud in the 1989/1990 season to 124 in the 2004/2005 season. While there was a reduction in the total number of mares bred the mean number of mares covered by a stallion per season has increased by approximately one mare per year since 1990.

The percentage of Thoroughbred stallions which is active at stud decreases with each year at stud, after three years only half of the Thoroughbred stallions are still active. A stallion that stays at stud generally covers the largest number of mares in its first five years at stud, after this the number of mares it covered decreases.^{1,3}

Proven sires are usually the most expensive, and the most popular, sires. These proven sires are used to cover all kinds of mares, ranging from very good mares (good performance and pedigree) to poor mares (good pedigree but poor or no performance record). Stallions of a lower quality are usually cheaper, and only get lower quality mares. This effect is called assortative mating. It is much easier to assess the real quality of a popular stallion, who gets a large number of mares of different quality, than to assess the quality of a cheap stallion, who only gets a limited number of low quality mares. This effect is further biased through the fact foals of 'top' stallions get more opportunities, as well racing as breeding, than foals of 'average' stallions.^{7,12}

Shuttle sires are stallions who stand at stud alternately at the Northern and Southern Hemisphere, thus breeding whole year round.¹³ Shuttle sires are generally young promising sires which have just completed their three-year old racing year in the Northern Hemisphere. Shuttle sires can have a large foal crop twice a year, which makes an accurate assessment of the sire possible at a younger age.¹

Short economics and costs of thoroughbred production

The Thoroughbred industry is economically important for New Zealand. More than 18,000 people are involved in the various stages of the production of a Thoroughbred racehorse. Among them are

about 3150 breeders. The New Zealand Thoroughbred industry produces about 4% of the global foal crop and globally is the seventh largest producer of Thoroughbred foals.

Approximately one third of the yearly foal crop is exported, either as yearling or as racehorse. The value of the export market is estimated at \$120 Million in 2004. The gross of the export was to Australia. About 60% of all yearlings sold at the Premier Yearling Sales are exported.^{3,1,12}

Breeding and racing a horse is an unsure business, with relatively high fixed costs and no profit guarantee. The costs to produce a foal include maintenance costs of the mare, mare replacement and insurance costs and stud fee of the sire. A mare traditionally is depreciated over seven years, after which she has a minimal book value.

Additional expenses have to be made in order to let a horse race, such as breaking in and training fees, registration fees, gear hire and track fees. The average cost to train a horse is estimated at \$14,000 to \$20,000 yearly, this is excluding purchase costs.^{3,4}

Reproduction

The emphasis in the Thoroughbred breeding industry lies on breeding the best performing horse. Increasing the reproductive performance of the horse is not the main goal of Thoroughbred breeders, however reviewing the high costs of having a mare at stud there might be some selection on breeding efficiency.

Bosh et al² stated mares which have to be mated multiple times have less chance of getting in foal. Additionally if a mare is expected to produce one foal every year she has to get pregnant within 25 days after foaling or after start mating. If the mare takes longer than 25 days to get pregnant, each subsequent foal will be born later in the year, which will cause the mare to lose a reproductive season later on. Aforesaid means a breeder wants a mare to get in foal again as quickly as possible after foaling in order to maintain reproductive efficiency.

Several authors have written about the relationship between mare age and parity and the quality of the foal. First foals tend to be lighter than subsequent ones, after which an increase in birthweight is observed until the mare is about 11 years old. Foal birthweight decreases again in aged mares. The influence of dam age and parity on performance of the foal on the racecourse is not clear. Wilsher et al did not find a relation between dam age and parity and racing performance of her foals. However, other authors have stated first foals and foals of older dams are less successful on the racecourse. There also seems to be a positive correlation between withers and hip height of yearlings and their racing performance. As a foal with a higher birth weight is more likely to become a bigger yearling a relationship between birthweight, and therefore dam age and parity, and racing

performance seems likely. Live foal rate decreased as age of the mare increased, but no effects of stallion age on live foal rate were reported.^{5,6,9,10,11}

An explanation for the plausible influence of dam age and parity on foal birthweight can be found in the functioning of the placenta. Placenta efficiency is a combination of the surface area of microcotyledons and chorionic volume. In older mares the development of microcotyledons decreases because of degenerative fibrosis of the endometrium. Primiparous mares also show a lower microcotyledon density than young multiparous mares, which suggests the endometrium has to be 'primed' by a first gestation in order to optimally function. The highest microcotyledon density is found in 5-9 year old multiparous mares. Chorionic volume increases with mare age, but this increase is not able to compensate completely for the loss of microcotyledons in older mares.^{8,10,11} Interestingly, the fracture rate of first foals is lower than the fracture rate of subsequent foals and fracture rate decreased with increasing mare age. This might point at an inverse effect of foal birthweight on fracture rate, with lighter born foals developing bones less prone to fracture.¹⁰

This study

We expect to confirm expensive and shuttle sires are popular among breeders and cover a greater number of mares per stallion. Because of the greater initial investment for foals of expensive and shuttle stallions the breeder of the foals will be more intent on reclaiming part of his investment. Therefore we expect foals a greater number of expensive and shuttle sired foals to race and breed compared to foals of medium and cheap stallions. We also expect expensive and shuttle foals to be more commercially interesting, consequently we expect them to be sold Premier Yearling Sale and to be exported more often.

Because foals of expensive sires do not have to prove themselves at the racecourse before they are used for breeding, we expect them to start breeding at an earlier age. Further, we expect to see a difference in parity of the foals sired by an expensive or shuttle stallion, because we expect mares mated to expensive and shuttle stallions to be mainly young mares, who are given the best opportunity to prove themselves at stud, and old mares, who have proven themselves to produce good foals. We also expect dams and granddams of expensive and shuttle foals to have an expensive sire themselves more often.

We do not expect to find differences in the parity, number of racing broodmares or age at start of breeding between generations. We do expect to find evidence breeders use breeding efficiency of a mare as a selection criteria in the decision whether or not to keep her at stud.

Materials and methods

Stallions

Stallions active during the 1998/1999 breeding season were allocated into 4 categories based on service fee of the stallion in the season 1998/1999, using the 'Register of Thoroughbred Stallions of New Zealand 1999'.^{14,15} The categories were: cheap (<\$5000), medium (\$5000-10.000), expensive (>\$10.000) and shuttle sires. Three stallions were at random chosen from each category, with regard to having fathered at least 20 foals in the season 1998/1999.

Foals

All the foals of the selected stallions from the 1998/1999 season were identified, using the online Thoroughbred-industry database¹⁶. General breeding information was recorded, this included total number of foals, mares covered, mares missed and/or slipped, mares exported, number of foals that died and the number of colts and fillies.

Filly foals born in the 1998/1999 season to the selected sires were identified and data pertaining to racing performance (racing yes or no) and breeding performance, namely breeding (yes or no), age at start breeding, number of years covered by a sire, number of positive pregnancy tests (44 day ppt), number of full-term foals, and the relative parity of the foals. Foals that were exported were recorded and excluded.

Age at start breeding was defined as the first season a mare was covered by a stallion. The total number of positive pregnancies were number of foals and number of 'slipped' pregnancies. The number of foals were defined as the number of full term delivered foals, as well as stillbirths and foals that died shortly after birth.

To identify the respective sales history of the foals as yearlings on the Premier Yearling sales it was identified from the from the sales company online database¹⁷ whether the foal was presented for the auction and the sales price of the foal.

Dams and granddams

Subsequently the dams of the 1999 fillies were identified using the same industry database. Records were collected on racing performance (racing yes or no) and breeding performance, namely age of start breeding, number of years covered, number of positive pregnancy tests, number of foals. The parity of the 1999 filly foal was recorded as well. The sire of each dam was listed and put in one of the service fee categories (cheap, medium, expensive and shuttle), using the recorded service fee from sires registers for the year of conception of the Dams where available and expert opinion.

The same procedure was followed with the granddams of the 1999 filly foals. The parity of dam and granddam were listed.

Further

There were no reliable racing and breeding records available for some horses for different reasons, such as being exported at young age, dying at young age, being at stud in a foreign country, or no return without known reason. These horses were excluded from further calculations.

In an attempt to gain insight in the relation between number of coverings and number of foals a ratio was created by dividing the number of years covered by number of foals for each mare.

Statistical Analysis

The data were entered into a Microsoft Excel spreadsheet (Excel 2007). A summary of the data per stallion was made using pivot tables in Excel.

The data were imported into SPSS 17.0. Using SPSS 17.0 a descriptive analysis of the data was made, using a Chi-square test, General Linear Model Univariate or Survival Analysis.

Results

During the 98/99 breeding season there were 146 sires at stud which according to service fee could be categorised as cheap (63%), medium (19%), and expensive (6%), the remainder were shuttle stallions. A total of 6768 mares were covered and produced 4351 live foals. A total of 12 sires were selected across the 4 service fee categories, with 3 sires per category. A summary of the data is presented in **table 1**.

Table 1: Total Thoroughbred sires covering 10 or more mares at stud in the 1998/1999 season according to service fee category

	Cheap (\$0-\$5000)	Medium(\$5001-\$10,000)	Expensive(>\$10,000)	Shuttle (both hemispheres)	Total
Sires in category	92	28	9	17	146
Mean mares covered	34	54	93	76	46
Total mares covered	3117	1518	834	1299	6768
Total live foals	1916	1024	520	891	4351

Cheap sires covered significantly fewer mares than medium, expensive and shuttle stallions ($P=0.006$, $P=0.000$ and $P=0.000$ respectively). However, because there were more cheap sires at stud the total number of mares covered by cheap stallions was greater than the total number of mares covered by expensive and shuttle stallions combined. Expensive stallions covered more mares per stallion than medium stallions ($P=0.003$).

Foals

There was no significant difference in the fraction of dead foals per sire category.

Significantly fewer cheap (0%) sired foals were exported than expensive (31%) and shuttle (26%) sired foals ($P=0.000$ and $P=0.001$ respectively). More expensive and shuttle sired foals were exported than medium (11%) sired foals ($P=0.002$ and $P=0.019$ respectively). (**see figure 1**)

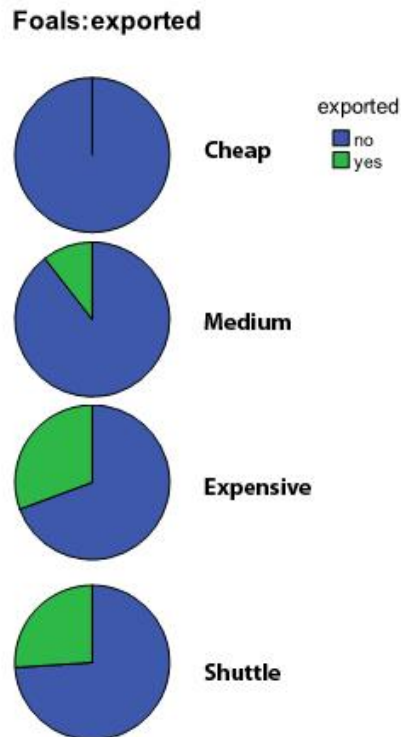


Figure 1: Fraction of exported 1999 born fillies per sire category

More foals of expensive (37%) and shuttle (34%) sires were offered for sale at the Premier Yearling Sale than cheap (0%) sired foals ($P=0.000$ and $P=0.001$ respectively). Significantly fewer medium (1%) sired foals were offered for sale than expensive and shuttle sired foals. (*see figure 2*)
 Of the fillies sold at the Premier Yearling Sale 39% was exported.



Figure 2: Fraction of 1999 born fillies offered for sale at premier Yearling Sale per sire category

There was a significant effect of sire category on whether a foal raced or not. Fewer foals sired by a cheap (50%) sire raced than foals sired by expensive (85%) and shuttle (82%) sires ($P=0.004$ and $P=0.0001$ respectively). More foals sired by expensive and shuttle sires raced than medium (64%) sired foals ($P=0.001$ and $P=0.035$ respectively). There was no difference between cheap and medium sired foals, and there was no difference between foals sired by expensive and shuttle sires. (*see figure 3*)

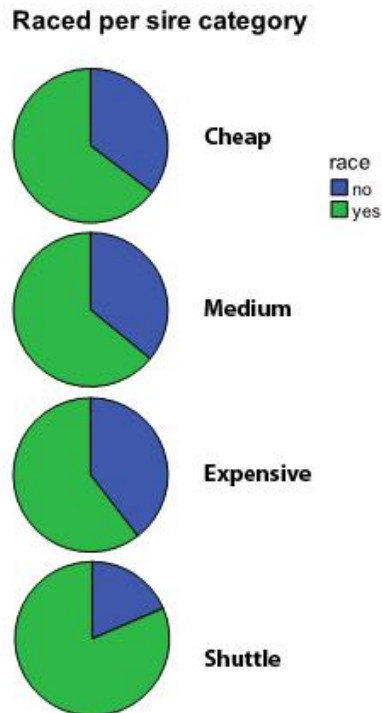


Figure 3: Fraction of racing 1999 born fillies per sire category

More foals of expensive (80%) and shuttle (49%) stallions entered the breeding population compared to foals of cheap (25%) stallions ($P=0.000$ and $P=0.047$ respectively). A greater proportion of foals by expensive stallions entered the breeding herd than foals of medium (43%) and shuttle stallions ($P=0.000$ and $P=0.000$). No significant difference was found between foals of medium stallions and cheap and shuttle stallions. (*see figure 4*)

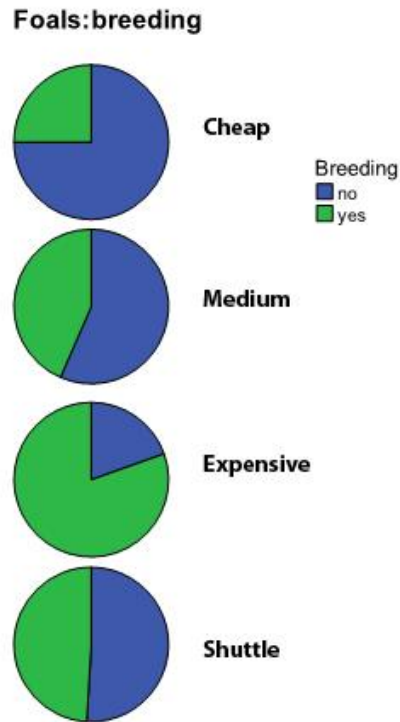


Figure 4: Fraction of breeding 1999 born fillies per sire category

Foals sired by a cheap stallion started breeding at a significantly later age than foals by medium, expensive or shuttle sire ($P=0.004$, $P=0.003$ and $P=0.002$ respectively). (see table 2 and figure 5)

Table 2: Median and 95% confidence interval age of start breeding 1999 fillies per sire category

Sire category	Median Start breeding	95% confidence interval	
		Lower bound	Upper bound
Cheap	8.000	6.868	9.132
Medium	5.000	4.318	5.682
Expensive	6.000	5.733	6.267
Shuttle	6.000	5.507	6.493
Overall	6.000	5.763	6.237

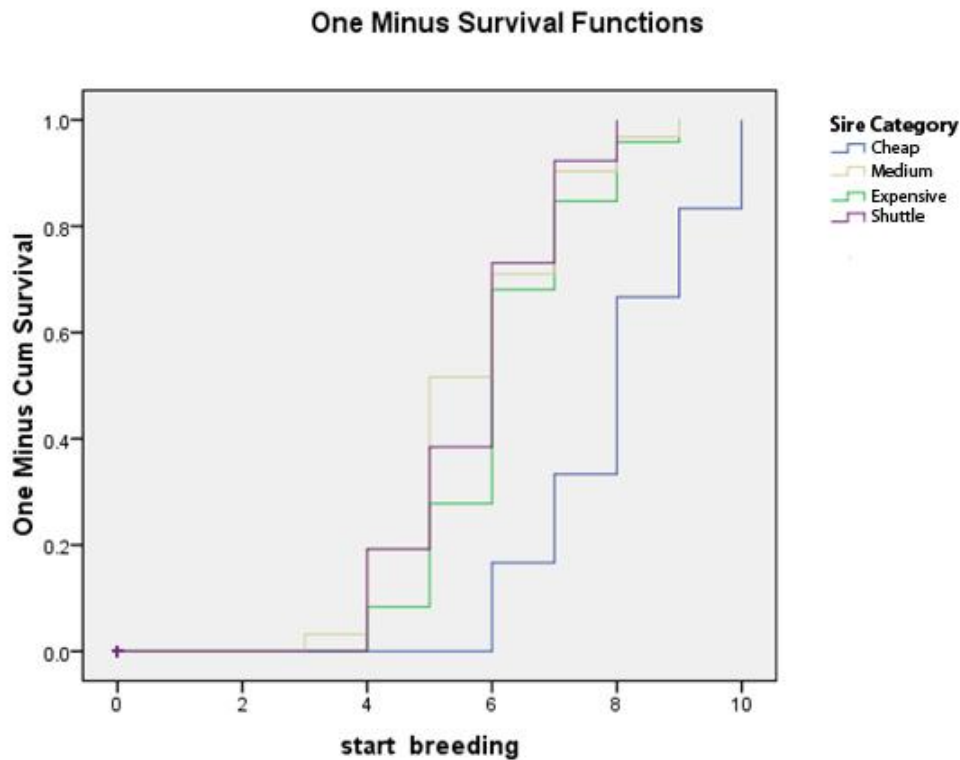


Figure 5: Age of start breeding 1999 born fillies per sire category

Foals sired by a cheap stallion had a significantly lower parity than foals with a medium, expensive and shuttle sire ($P=0.002$, $P=0.000$ and $P=0.000$ respectively). (see table 3 and figure 6)

There were no significant differences in the proportion of foals breeding and racing foals between the sire categories as shown in table 4.

Table 3: : Median and 95% confidence interval of parity 1999 fillies per sire category

Sire category	Median Parity	95% confidence interval	
		Lower bound	Upper bound
Cheap	2.000	1.514	2.486
Medium	3.000	2.341	3.659
Expensive	4.000	3.330	4.670
Shuttle	4.000	3.165	4.835
Overall	3.000	2.594	3.406

One Minus Survival Functions

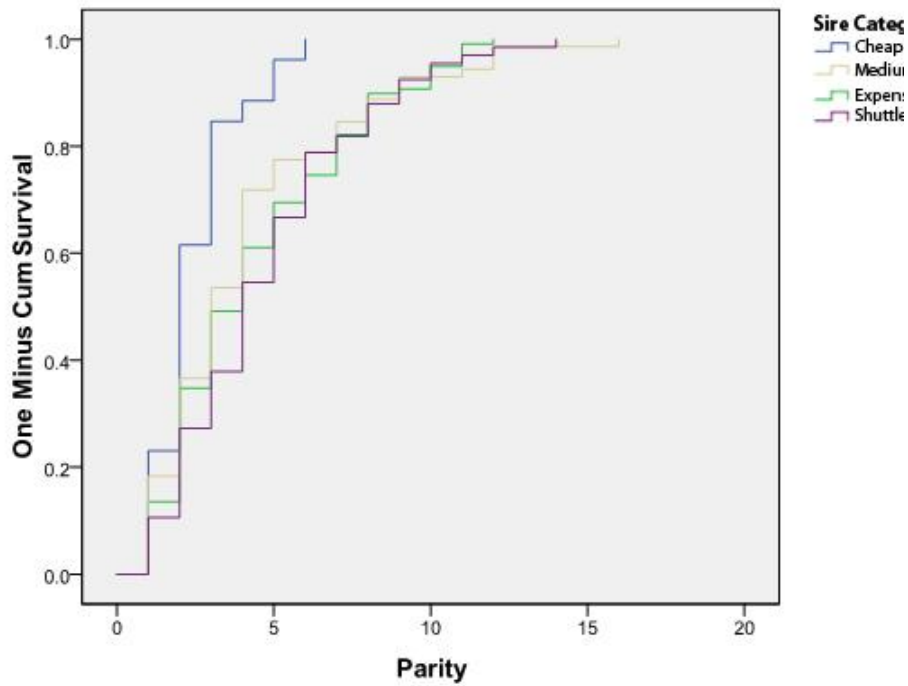


Figure 6: Parity 1999 born fillies per sire category

Table 4: Crosstable 1999 born fillies: breeding versus racing per sire category

Sire Category			Breeding		Total
			Not breeding	Breeding	
Cheap	race	No	10	2	12
		Yes	8	4	12
	Total		18	6	24
Medium	race	No	15	8	23
		Yes	22	22	44
	Total		37	30	67
Expensive	race	No	3	11	14
		Yes	15	67	82
	Total		18	78	96
Shuttle	race	No	4	6	10
		Yes	22	20	42
	Total		26	26	52

Between generations

When making a comparison between generations (foals, dams and granddams) only the records of foals used for breeding were used, unless stated otherwise.

The number of racing broodmares decreased with older generations. There were more breeding foals which raced (81%) than dams (69%) and granddams (45%) ($P=0.009$ and $P=0.0001$ respectively). Significantly more dams than granddams raced ($P=0.0001$). (*see figure 7*)

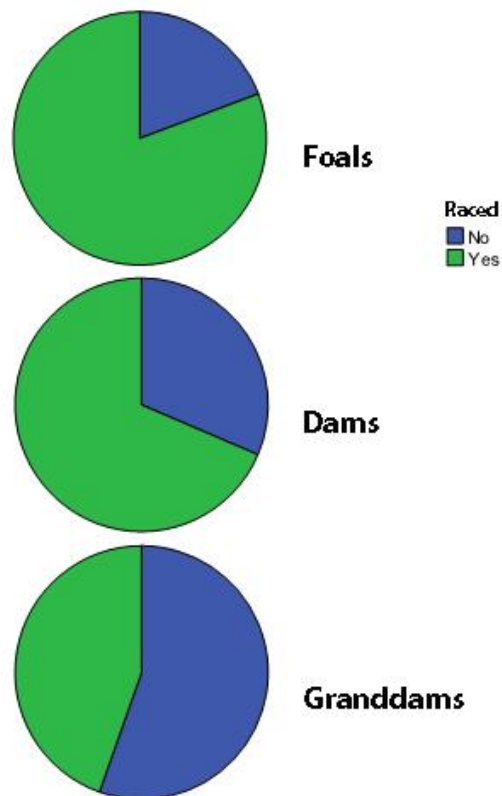


Figure 7: Fraction raced horses per generation

Table 5: Median and 95% confidence interval start breeding all horses per generation

Sire category	Median	95% confidence interval	
		Lower bound	Upper bound
Foals	6.000	5.763	6.237
Dams	6.000	5.816	6.184
Granddams	6.000	5.791	6.209
Overall	6.000	5.880	6.120

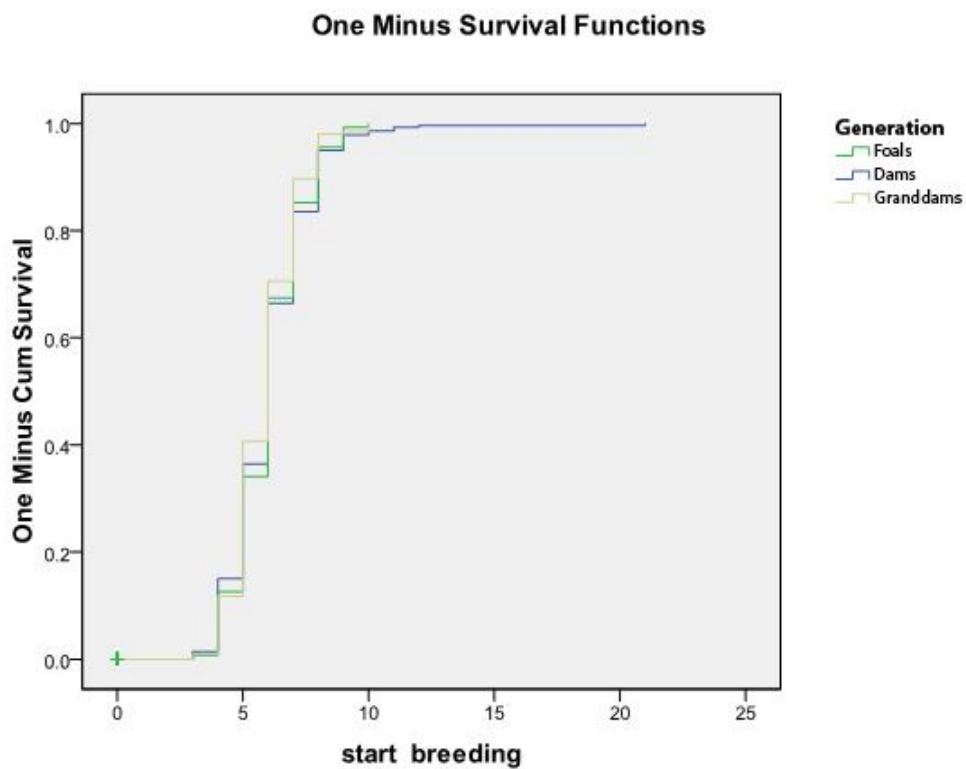


Figure 8: Start breeding all horses per generation

There was no significant effect of generation on the age at the start of breeding, but there seemed to be a trend with granddams starting breeding at an earlier age than dams ($P=0.104$). (*see table 5 and figure 8*)

The parity of granddams was lower than the parity of dams and foals ($P=0.000$ and $P=0.000$). Foals had a higher parity than dams ($P=0.000$). (see table 6 and figure 9)

Table 6: Median and 95% confidence interval parity all breeding horses per generation

Sire category	Median	95% confidence interval	
		Lower bound	Upper bound
Foals	6.000	4.999	7.001
Dams	4.000	3.464	4.536
Granddams	2.000	1.476	2.524
Overall	4.000	3.564	4.436

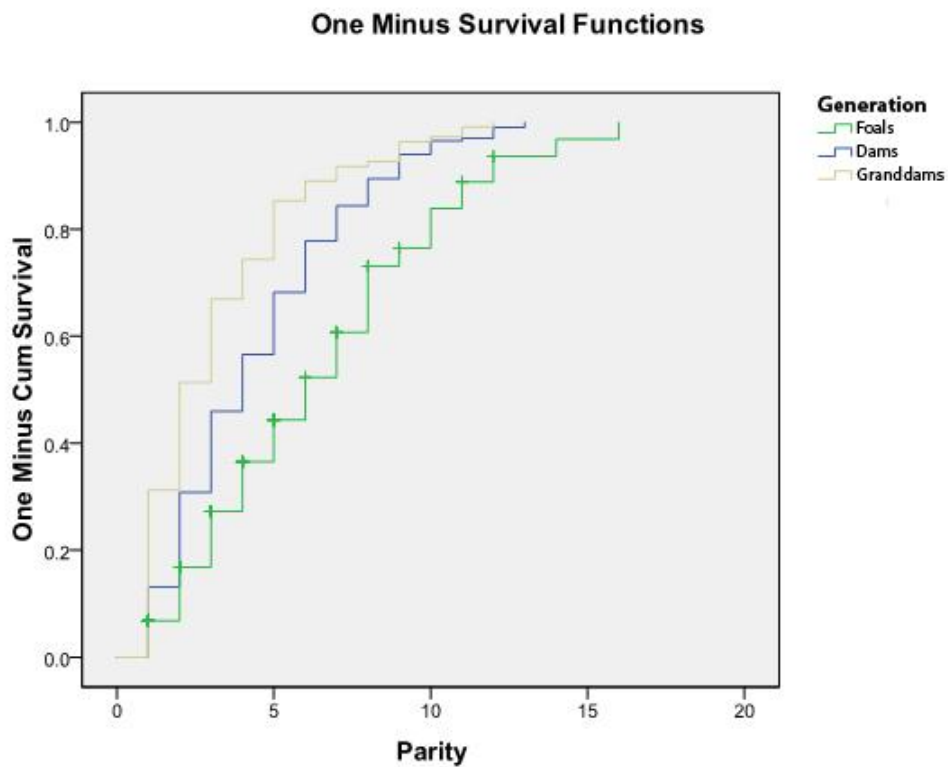


Figure 9: Parity all breeding horses per generation

Broodmares: comparisons between sire categories

When making a comparison between sire categories including foals, dams and granddams only the records of foals used for breeding were used, unless if stated otherwise.

There was no significant effect of sire category on whether a mare raced when looking at all breeding mares. There was a trend for more of the cheap (72%) and shuttle (77%) sired foals to have raced than expensive (58%) sired foals ($P=0.075$ and $P=0.060$ respectively). There was a trend with foals of medium (65%) sires racing more often than foals of expensive stallions ($P=0.112$). (*see figure 10*)

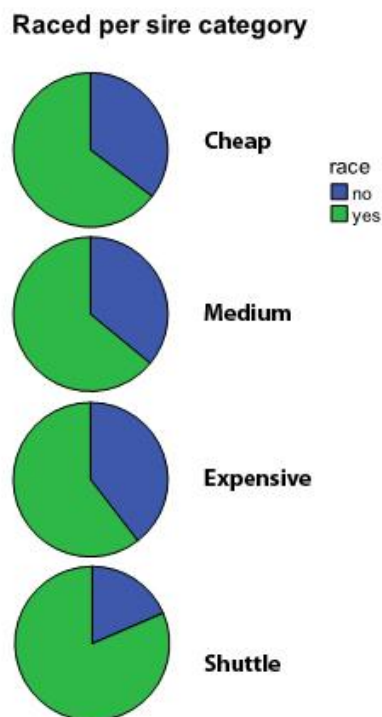


Figure 10: Fraction raced breeding horses per sire category

Note: The sire category shuttle includes only 1999 born fillies

The median age of start breeding was the same for each sire category. (*see table 7*) Mares sired by a cheap stallion started breeding later than mares sired by a medium, expensive or shuttle stallion ($P=0.001$, $P=0.000$ and $P=0.004$ respectively). (*see figure 11*)

Table 7: Median and 95% confidence interval start breeding all horses per sire category

Sire category	Median Start breeding all mares	95% confidence interval	
		Lower bound	Upper bound
Cheap	6.000	5.487	6.513
Medium	6.000	5.812	6.188
Expensive	6.000	5.826	6.174
Shuttle	6.000	5.507	6.493
Overall	6.000	5.880	6.120

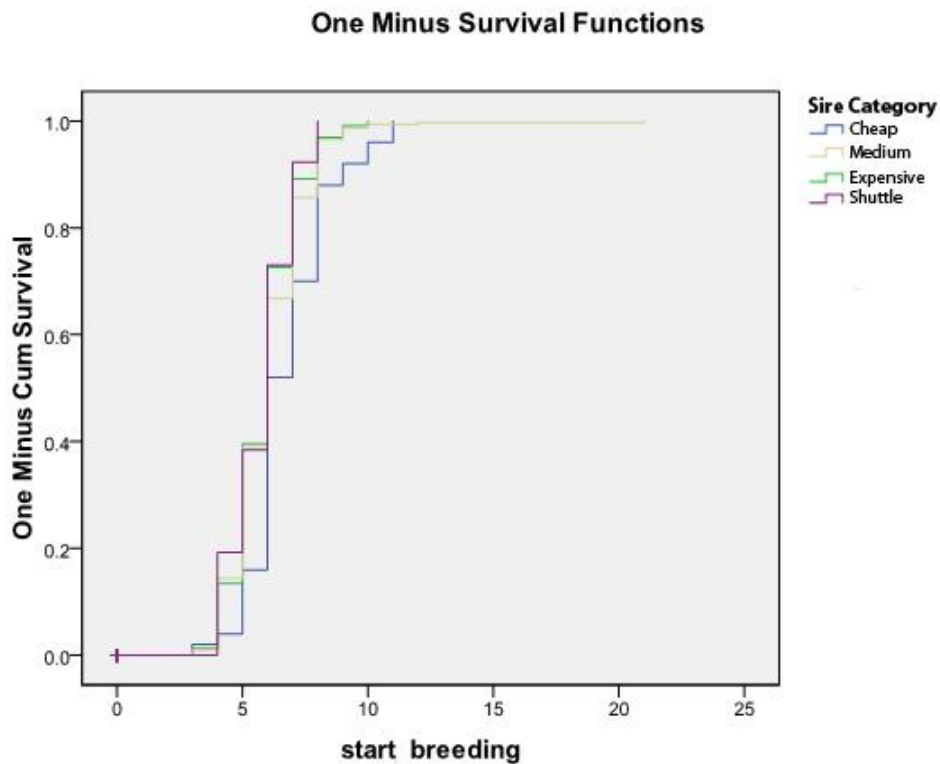


Figure 11: Start breeding all horses per sire category

The sire category did not have a significant influence on parity between mares sired by a cheap, medium or expensive sire. Mares sired by a shuttle stallion had a higher parity than mares sired by a medium stallion ($P=0.032$). The parity of shuttle foals was not significantly higher than the parity of expensive sired foals, but there was a trend ($P=0.069$). (see table 8 and figure 12)

Table 8: Median and 95% confidence interval parity all breeding horses per sire category

Sire category	Median Parity	95% confidence interval	
		Lower bound	Upper bound
Cheap	3.000	1.712	4.288
Medium	3.000	2.470	3.530
Expensive	4.000	3.403	4.597
Shuttle	5.000	3.766	6.234
Overall	3.000	2.625	3.375

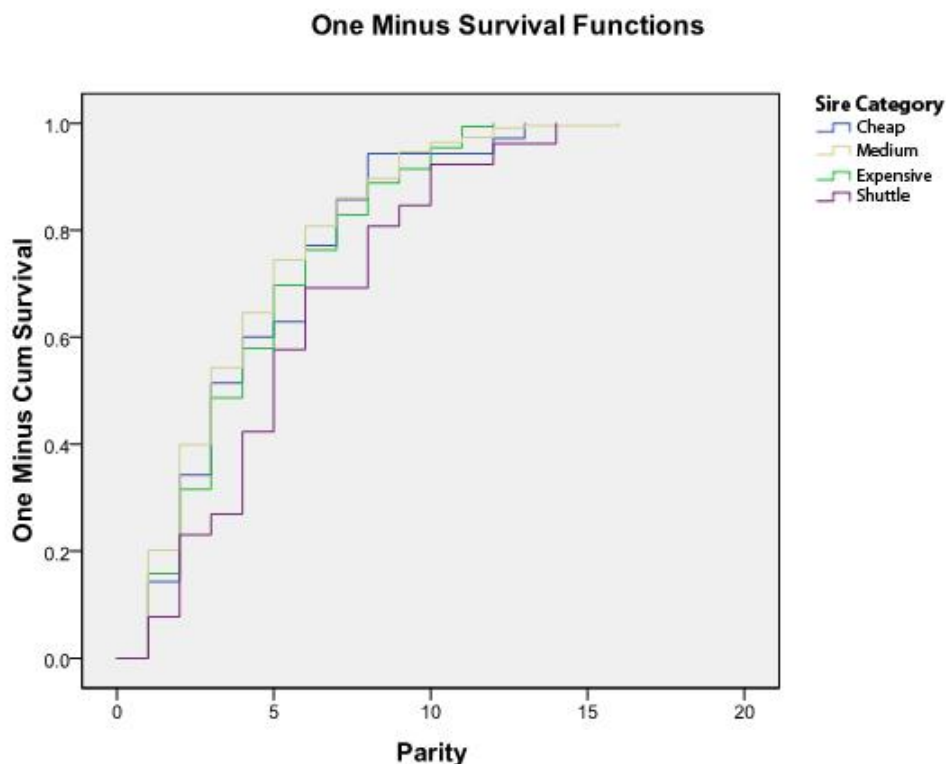


Figure 12: Parity all horses per sire category

There was a significant effect of sire of foal on the ancestry of the dam and granddam.

Dams of medium, expensive and shuttle sired foals were more often sired by expensive or medium sires compared to dams of cheap sired foals (P=0.000, P=0.000 and P=0.003 respectively). **(see table 9 and figure 13)**

Granddams of cheap sired foals were more often sired by a medium prized stallion than granddams of expensive and shuttle sired foals (P=0.013 and P=0.015 respectively). Granddams of medium sired foals had a medium prized sire more often than granddams of expensive sired foals (P=0.015)

The sires of granddams of expensive and shuttle sired foals seemed to be equally distributed among medium and expensive prized. **(see table 10 and figure 14)**

Table 9: Influence of sire category foal's sire on sire category dam's sire

Sire category dam → Sire category foal ↓	Cheap	Medium	Expensive	Total
Cheap	10	12	4	26
Medium	6	41	31	78
Expensive	11	70	57	138
Shuttle	7	54	28	73
Total	34	177	120	315

Table 10: Influence of sire category foal's sire on sire category granddam's sire

Sire category Granddam → Sire category foal ↓	Cheap	Medium	Expensive	Total
Cheap	1	20	5	26
Medium	5	48	25	78
Expensive	3	65	70	138
Shuttle	6	32	35	73
Total	15	165	135	315

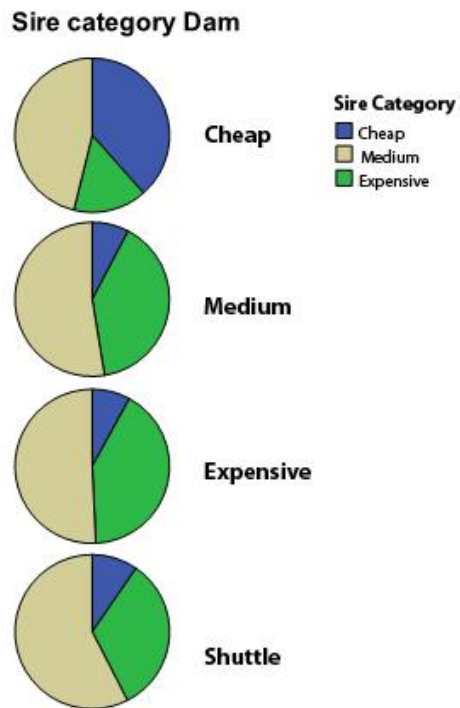


Figure 13: Distribution sire category dams per sire category 1999 born foal

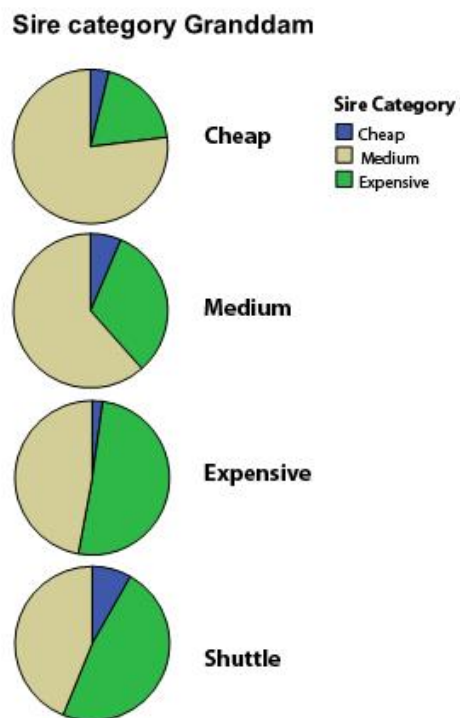


Figure 14: Distribution sire category granddams per sire category 1999 born foal

Breeding efficiency

The highest number of years at stud for the 1999 born foals was 8 years. There did not seem to be a clear effect of the ratio number of foals:number of years covered on the total number of years a mare was at stud. **(see figure 15)**

There was an effect of ratio number of foals:number of years covered on the total number of years a mare was a stud for the dams. Mares with a ratio <0.45 did not receive more than 7 coverings.

There were three mares who were covered between 12 and 15 seasons despite a ratio <0.45. **(see figure 16)**

The effect of ratio number of foals:number of years covered as observed with the dams seemed to occur with the granddams as well. Most granddams had a ratio of >0.4, with the exception a single mare with ratio≈0.2 and of a group of six mares with a ratio of 0.3-0.4 and 12-14 years covered. **(see figure 17)**

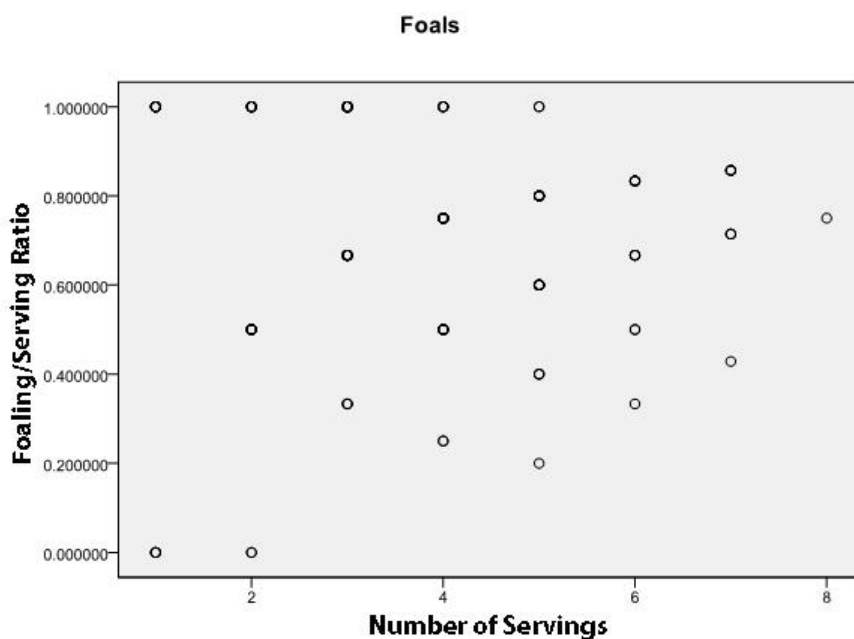


Figure 15: Ratio number of foals:number of years covered versus total number of years covered for the 1999 born fillies

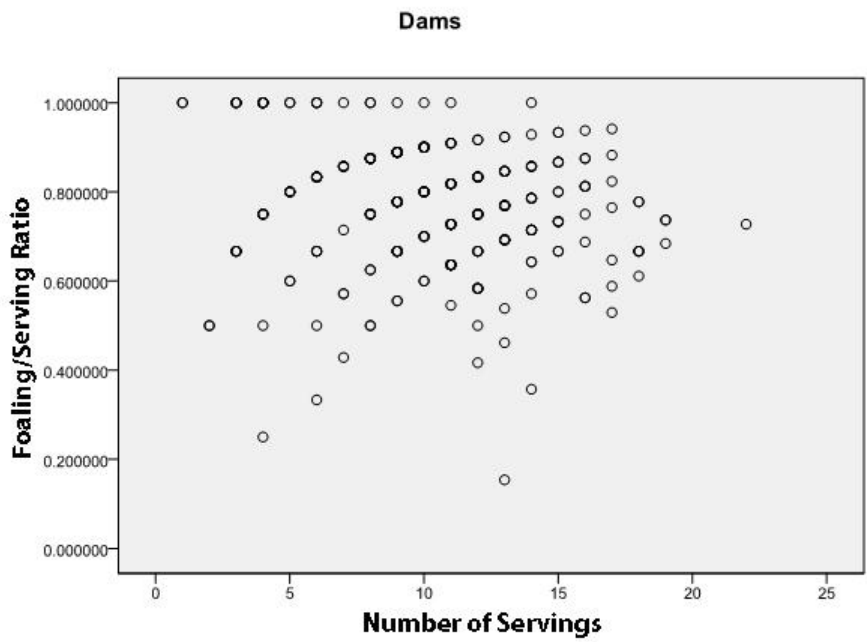


Figure 16: Ratio number of foals:number of years covered versus total number of years covered for the dams

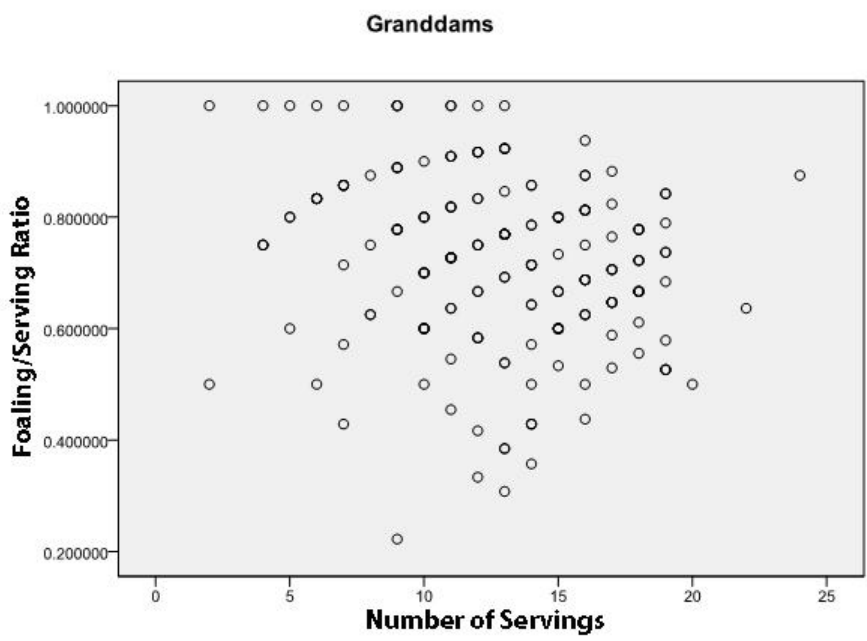


Figure 17: Ratio number of foals:number of years covered versus total number of years covered for the granddams

Discussion

General

Sires with an expensive stud fee covered more mares per stallion, stallions with a cheap stud fee covered the smallest number of mares per stallion. However, there were only a few expensive stallions (9), while there are a lot of cheap stallions (92 who covered more than 10 mares per stallion). It is because of the great number of cheap, and to lesser extent medium, stallions that most broodmares were covered by a cheap stallion, followed by medium and shuttle and concluding with expensive sires.

Foals

The fact that no difference was observed in dead foal rate could mean that there is no difference in attitude of breeders towards the basic and, if necessary, extended care given to a cheap or expensive foal. However, it is probable no effect was found because of the relatively small numbers of foals in the dataset. After all, the influence of a breeder on whether a foals dies or not is limited.

More foals of expensive and shuttle stallions were offered for sale at the Premier Yearling Sale. Likewise, more foals of expensive and shuttle stallions were exported than foals of medium and cheap stallions. This reflects the market value of expensive and shuttle sired foals, only the more valuable foals are offered for sale at the Premier Yearling sale or exported.

The market value of expensive and shuttle sired foals is higher than the market value of medium and cheap sired foals. It is probable that this is influenced by initial investment, that is stud fee, and other factors such as higher expectations regarding racing and breeding performance for foals with better bloodlines.

More foals of expensive and shuttle stallions raced than cheap and medium sired foals. This is an indication breeders are more willing to spend time and money on foals that were more expensive from the beginning, and reflects their higher expectations of these foals. Breeders might be more fixed on trying to reclaim part of their investment when the start investment is bigger. This is also reflected in the fact more expensive and shuttle foals entered the breeding herd.

More expensive sired foals entered the breeding herd than shuttle sired foals. In general expensive sires have a higher stud fee than shuttle sires, therefore breeders might be more intent on reclaiming part of their investment with expensive sired foals.

Foals sired by a cheap stallion started breeding at a later age. This might be an indication breeders wait longer before breeding with a cheap sired foal, so they can more accurately assess whether the

horse will be worth breeding with.

There did not seem to be an influence of whether a filly had raced or not on it entering the breeding population within the sire categories. Between the sire categories some differences could be observed. Most of the expensive foals that raced entered the breeding herd, while only half of the medium and shuttle foals which raced entered the breeding herd. This might be another indication owners of expensive sired foals are more intent on reclaiming part of their investment; the expensive sired fillies are used for breeding, even if their racing performance falls short of expectations, while the medium and shuttle sired foals are actively selected on their racing performance, using only the best racing mares for breeding. In the cheap sired foals the selection seemed to be even stricter, though the numbers were too small to draw a reliable conclusion. Some cheap sired horses are not bred to produce racing horses, but bred for example show jumpers. Jumping horses will be in our records as 'not raced', but their performance in jumping will probably influence the breeder in the decision whether or not to use the mare for breeding. This is a possible explanation for the fact some cheap horses did not race, but did start breeding at a later age.

Foals sired by a cheap stallion had a lower parity than foals of the other categories. The spread in parities was less as well, the highest parity observed in a cheap sired foal was 7. This might be explained by the fact the first foals is often smaller and weaker, possibly breeders do not want to spend a high stud fee on an inferior foal. Another explanation is only broodmares which have proven to produce good foals are kept breeding to produce 7 or more foals. Reasonably, mares who have proven to be good broodmares will be not be bred to a cheap stallion, but to a stallion with a higher stud fee.

Medium foals

Medium prized sires were a real intermediate group in some aspects, such as number of stallions at stud. Medium stallions did not seem to have a consistent trend towards cheap or expensive, their behaviour fluctuated between the different parameters. There was a tendency towards the expensive and shuttle sires with regard to the number of mares covered by a medium stallion. Regarding being sold at the Premier Yearling Sale and export of foals medium sired foals seem to behave more like cheap foals. There is no significant difference in export of cheap and medium sired foals, but medium sired foals were exported significantly less than expensive and shuttle sired foals. It looked like medium sired foals were not as commercially attractive as expensive and shuttle sired foals.

Less medium sired foals raced than expensive and shuttle sired foals, the medium sired foals

behaved more like cheap sired foals in this aspect. However, though the difference between cheap and medium sired foals was not significant, the percentage racing medium sired foals seemed to be in the middle between cheap and expensive and shuttle sired foals.

The fraction of breeding medium foals was different from the expensive sired foals, but there was no significant difference with either cheap or shuttle sired foals. Especially the difference between medium and shuttle sired foals was very small, medium sired foals seemed to enter the breeding herd in the same amount as shuttle sired foals.

Age of start breeding is relatively low for medium sired horses, they behave more like expensive or shuttle here than like cheap. Parity of all 1999 fillies seemed to be intermediate for medium sired foals, but there was more difference between cheap and medium than between medium and expensive and shuttle.

Shuttle foals

Shuttle sired foals behaved like expensive sired foals in all aspects, except for the fraction of fillies that entered the breeding population. This is an indication breeders have equally high expectations of their shuttle sired foals as of expensive sired foals, but are more willing to cull mares that do not live up to those expectations.

Between generations

The number of racing broodmares decreased with older generations. This could be explained by the fact that the total number of mares decreased over the years, the mares that are left are used for racing as well as breeding. Another possible explanation is the increasing use of fertility management tools, such as ultra sound. The better fertility management could increase the chance on pregnancy, thus giving the mare more time to race before breeding, while before a mare could lose valuable years if she was raced first. However, these explanations are contradicted by the finding that age of start breeding is not significantly different between foals and granddams. The difference might also be caused by a decreasing reliability of the records with older generations.

The parity of granddams was lower than the parity of foals and dams. The increasing fertility management in younger generations might increase the chance of a mare of giving birth to a foal, this way increasing the total number of foals per mare and thus parity of a random group of broodmares. Another, not unimportant, factor is the decreasing reliability of foaling records in dams and granddams. Possibly only the mares who contributed to the population, in this case with a broodmare daughter, were recorded in the older records, thus lowering parity for the older mares.

Broodmares: comparisons between sire categories

There was a trend with expensive sired broodmares racing less often than mares sired by not-expensive sires. This could be an indication mares sired by cheap, medium and shuttle stallions are selected on racing performance more than mares sired by expensive stallions. This did not correspond with our finding expensive sired foals raced more often, but did match our hypothesis foals of expensive sires are used for breeding no matter whether and how they performed on the racetrack.

Mares sired by a cheap stallion started breeding at a later age, this matches the findings in the 1999 born fillies. It is probable breeders wait longer before using a cheap sired mare for breeding so they can make a better estimation of the mares capabilities.

Sire category did not seem to influence parity. The parity of shuttle sired mares seemed to be higher, but this could be caused by the lower numbers of shuttle foals, since there were no dams or granddams sired by shuttle sires. The finding there was no effect of sire category on parity of a broodmare did not fit with the lower parity for cheap sired foals. Possibly the lower number of cheap foals could be an explanation for the difference found with the foals, with this difference not being clear anymore when higher numbers of mares are used.

Medium all horses

Mares sired by medium stallions behaved more like mares sired by cheap sires concerning number of racing broodmares. Regarding the age of start breeding medium sired mares behaved more like expensive sired mares than like cheap sired mares.

Further

Dams of medium, expensive and shuttle sired foals more often had an expensive or medium sire themselves, while dams of cheap sired foals were more often sired by cheap or medium sires. This effect was still there with granddams sires, but here there were almost no cheap sired mares left. It seems the cheap sires progeny slowly disappear from the breeding herd, while progeny of expensive and medium stallions become more prominent. With the foals we saw foals of expensive stallions had more chance of becoming a broodmare than foals of a cheap stallion, this seems to be confirmed when looking at the ancestry of dams and granddams. An expensive or medium stallion thus has more chance of being preserved in the gene pool than a cheap stallion. With expensive stallions the effect is caused by a higher fraction of the foals entering the breeding herd. With the medium sired mares a smaller fraction enters the breeding herd, but because there are much more medium sired foals than expensive sired foals their genes are preserved in the population.

Breeding efficiency

No effect of ratio number of foals: number of years covered on the total number of years covered was observed in the 1999 born fillies. It is likely the effect was not yet revealed, the highest number of years covered is 8, while an effect with the dams is observed from 7 years covered. If the 1999 born fillies were followed in the future an effect would be expected.

The effect observed in the dams confirms breeders cull mares with a lower reproductive efficiency. A mare got 7 chances to produce at least 0.45 foals per covering, so about 3-4 foals per 7 years covered. If a mare failed to produce enough foals she was not used for breeding any further. There is the occasional exception, which can be explained by the fact breeders do not only breed to make financial profit, but for emotional and status reasons as well. The decision whether to keep breeding with a mare is not purely rational. Part of the exceptions could also be explained due to the fact the mares did have a positive pregnancy test, but the pregnancy slipped. The fact the mare got pregnant could convince the breeders to give the mare another chance at stud, even if she failed to produce a foal.

The effect as observed in the dams was less clear with the granddams. Most of the mares seemed to have a ratio >0.4 , which seems unlikely. However, this could be caused by the selection of foals and going back to the granddams, after all mares which had a greater number of foals had more chance of producing a broodmare foal and thus ending up in this study. This way granddams with a foaling ratio >0.4 were unintentionally selected. There could also be an influence of less reliable records regarding missed and slipped pregnancies, making the ratio for granddams more positive.

The group of mares with 12-14 years covered despite a ratio <0.4 could be an indication breeders were more willing to keep breeding with a mare, even if she failed to produce 0.4 foals for every year covered. This could be a reflection of a lower fertility rate through less fertility management techniques (e.g. ultrasound) or a sign the breeding of thoroughbreds was less professionalized, with breeders giving an individual mare more chances at stud.

Conclusion

Expensive stallions covered more mares per stallion, but the number of medium and cheap sires was greater, therefore most of the foals born were sired by a cheap or medium stallion. Foals sired by expensive or shuttle stallions had a higher commercial value, they were more often sold at the Premier Yearling sale and/or exported. Breeders of expensive sired foals seemed more intent on reclaiming their investment, which showed in the fact expensive sired foals raced and were used as broodmares more often. Shuttle sired foals tended to behave like expensive sired foals, except when entering the breeding herd, this indicates a stricter selection in broodmares for shuttle sired foals than for expensive sired foals. Foals of cheap stallions started breeding at a later age and had a lower parity. Foals of medium prized sires had less commercial value than expensive or shuttle sired foals, but were selected for breeding in a similar way to shuttle sired foals.

The number of racing broodmares decreased with older generations. The parity of granddams was lower than the parity of dams and foals. Expensive sired broodmares raced less often than cheap and medium sired broodmares, this points at a selection of cheap and medium mares on racing performance before entering the breeding herd.

The percentage of cheap sires decreased in the ancestry of dams and granddams. Eventually the cheap stallions disappear from the breeding population, while medium and expensive stallions stay in the breeding herd. Expensive and medium stallions have more chance of preserving their genes in the thoroughbred gene pool.

Breeders were positively influenced by mare fertility in the decision whether to cover a mare again. This effect was strongest in the dams.

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Appendix I Tables

Table for figure 1: Fraction of exported 1999 born fillies per sire category

Sire category	Not Exported	Exported	Total
Cheap	24	0	24
Medium	68	8	76
Expensive	95	42	137
Shuttle	54	19	73
Total	241	69	310

Table for figure 2: Fraction of 1999 born fillies offered for sale at premier Yearling Sale per sire category

Sire category	Not offered for sale	Offered for sale at PYS	Total
Cheap	26	0	26
Medium	76	1	77
Expensive	87	51	138
Shuttle	48	25	73
Total	237	77	314

Table for figure 3: Fraction of racing 1999 born fillies per sire category

Sire Category	Not Raced	Raced	Total
Cheap	12	12	24
Medium	25	45	70
Expensive	14	83	97
Shuttle	10	44	54

Table for figure 4: Fraction of breeding 1999 born fillies per sire category

Sire Category	Not Bred	Bred	Total
Cheap	18	6	24
Medium	39	30	69
Expensive	19	78	97
Shuttle	27	26	53

Table for figure 7: Fraction raced horses per generation

Generation	Not raced	Raced	Total
Foals	27	113	140
Dams	88	192	280
Granddams	113	91	204
Total	228	396	624

Table for figure 10: Fraction raced breeding horses per sire category

Note: The sire category shuttle includes only 1999 born fillies

Sire category	Not raced	Raced	Total
Cheap	14	36	50
Medium	111	202	313
Expensive	97	133	230
Shuttle	6	20	26
Total	228	391	619