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The article below by Nicholas Kollerstrom is a continuation of work reported in 2000 (Kollerstrom and Power, 2000). This article was originally published in Correlation 27(1) 2009 (pp38-46) and is re-printed in this issue with corrections to various problems that occurred during the printing process in Vol 27 (1).

A lunar cycle in mare fertility

by

Nicholas Kollerstrom PhD*

Abstract

An earlier article (Kollerstrom and Power, 2000) presented evidence that the full moon had an effect upon the fertility of thoroughbred mares (as used for breeding of racehorses).Here a further data-set from the same breeding station is here used to complement the original findings. These showed that there were peaks and troughs both in the likelihood of conception ('fertility') of the mares, and in the number of 'coverings' i.e. mating-pair events at the studfarm, at specific parts of the lunar month. The peak occurred around or just after the Full Moon. The data was taken from studbook records over fourteen consecutive years, 1986-1999 all from one single studfarm, in Newmarket UK. In all, 2318 mating-pair events are here examined. The results show that, while there is a dominant three-week rhythm in mare fertility that is endogenous, i.e. the estrus cycle, there is also a monthly, exogenous rhythm relating to the lunar cycle, which is significant for fertility and could be large enough to be of practical relevance. This article puts forward the evidence for this lunar-monthly effect.

Keywords: Thoroughbreds, Mare fertility, conception, moon, lunar month

Introduction

Since the mid 1980s, vets have supervised 'coverings' (the mating of stallion and mare), only during the period of estrus. Mares cycle to their three-week rhythm, and this fertile interval is now reliably detectable (Rossdale, 1993). Thus, one can test whether the Moon

Enquiries about this article should be addressed to: nkastro3@gmail.com

is affecting the fertility of mares, by plotting these mating dates cumulatively against the lunar month. The dates for these events are kept in the yearly 'stud-books' of the breeding-station, and the author has been allowed access to these volumes for a stud farm in Newmarket. Racehorses may be the only creature for whom thorough and reliable mating and conception data is documented, i.e. the present study could not have been done on any other animal.

Modern racehorse breeding is unnaturally stimulated in the early months of each year, by hormone and electric lighting regimes, causing it to start around February-March; it then finishes much earlier than it naturally would, say by June. This compression into a few months of the breeding season (for reasons that need not concern us) means that plotting of the data by lunar-month cycles is quite likely to generate artefacts: a solution to this dilemma, is to carry on accumulating data over the years, and that will yield a data-set in which these artefacts have averaged out. That is why 14 consecutive years of data have here been gathered.

In suggesting that the lunar cycle exerts an 'influence,' one means that a peak can reliably be found in some part of it, and a trough in another, using some relevant parameter. Statistically, the latter is of just as much interest as the former. For plotting the data by lunar month, it is convenient to divide the data according to the sequence of 29 days in that month, however there is an option of in some way using the 360° of the changing Sun-Moon angle, through the lunar month. There are pros and cons to both methods: the former counts 'lunar day numbers,' and by convention this starts at the New Moon; the day of the Full Moon can then vary by several days depending upon the Moon's angular velocity, i.e. Full Moon will arrive soonest after New if perigee (when it has the highest angular velocity) is in the first quarter. The alternative, of plotting the data by Sun-Moon angle, normally involves a fourfold division of the data. On account of the Moon's varying angular velocity, one cannot assume that these four sectors will be equiprobable - unless, perchance, the lunar inequalities are deemed to have averaged out over the 14 years of the survey. A statistical treatment ought therefore to prefer the lunar-day numbers. Each day the Sun-Moon angle changes by 13°, on average.

The model here tested involves periodicities at both the estrus and lunar frequencies, as well as a seasonal peak around March/April. On some years (but not all) a degree of synchronizing in the mares' three-week estrus periods was evident, appearing as rhythmic peaks in covering, and it might be of interest in a separate study to look into this. The present study however is solely concerned to group the data by lunar-month divisions, allowing other factors to average out over the cumulative years of this survey.

Traditions of the lunar cycle being relevant to the breeding of mares, seem not to exist. It is hard to find anything written on the subject beyond Claudius Ptolemy's remark made in Egypt in the 2nd century AD: 'farmers notice the aspects of the Moon, when full, in order to direct the copulation of their herds and flocks .. and there is not an individual who considers these general precautions as impossible or unprofitable.'

Method

Mare 'fertility' is here defined as the percentage of coverings which lead to conception, a figure which averages around forty percent (Usually equine veterinary studies define it as the % of mares which conceive in a season, and that would give a far higher figure, about 90%, as would not here be useful). Each year the 'Statistical Record' is published by the UK's racehorse-breeding firm, having data on thoroughbred mare breeding, and it states whether an issue took place, i.e. a foal was produced, or whether it was barren, or 'no-return.' The latter means there is no record of offspring, probably because the mare went abroad. Thereby, from combining the published and unpublished data-sources, for each mare one has the number of coverings it experienced and whether or not it conceived successfully, in any breeding-season. All of the 'no-return' mares have to be discarded before any such ratio can be computed.

Yearly studbooks give dates of covering, and the published *Return of Mares* and *The General Stud Book* were then used to ascertain whether conception and subsequent livebirth took place (The former groups data by stallion, the latter by mare). The remaining cases for which no outcome was recorded, were sent to the British firm Wetherby's who were kindly able to ascertain a few more of these, thereby limiting the 'no-return' cases to just seven percent of mating-pairs.

All coverings were plotted around the lunar month, with each treated as a yes/no event in which conception did or did not occur. Some mating-pairs had up to six couplings per season, while others (the more successful) had only one. In addition, the dates of only those coverings that led to conception have been plotted, and these comprise the final covering of the season for any successful mating-pair. This latter approach indicates whether there is any portion of the lunar month in which conceptions are more likely to occur. A third approach to the data also used, was that of 'first-mated estrus:' one only scores the coverings, successful and unsuccessful, during the few days of estrus when the first mating of the season is attempted. This assigns a single, limited time-period to each mating-pair in a season, and philosophically one may prefer the idea of plotting this around the lunar month, inasmuch as the probability of conception may be more similar, overall, if one is only scoring the first estrus for each mating-pair.

Using the lunar-day numbers, seven-day intervals (an approximate 'quarter' of the lunar month,) have here been compared, in the data-tables, although in the pilot study co-authored by the present writer (Kollerstrom and Power 2000), five-day intervals were used. An empirical 'Monte Carlo' method was devised, to assess probability.

Results

Each season about 10% of mares are 'barren' i.e. conception fails to happen, so this procedure reduced the total a little. Each mating-pair averaged 2.1 coverings per season. The number of mating-pairs somewhat decreased, by 31%, comparing the first three year's covings with those of the last. Also, at weekends this studfarm averaged 11% less coverings per day than during the rest of the week.

I. Coverings: Mare Estrus in the Lunar month

The stud books of a single horse-breeding station in Newmarket, over the 14 years 1986-99, had altogether 4891 mating events (i.e. coverings) recorded. These events fall within the 4-5 day period of mare estrus. Lunar-day numbers (LDNs) were generated, one for each day of these breeding-seasons. Scored 1-29, these begin on the day after the New Moon. The latter event is defined as the moment in the course of the month when the angle between solar and lunar celestial longitude reaches zero. As the lunar month is 29.5 days, one discards the data immediately before day one and after the 29th day, i.e. this method loses half a day's data each month.

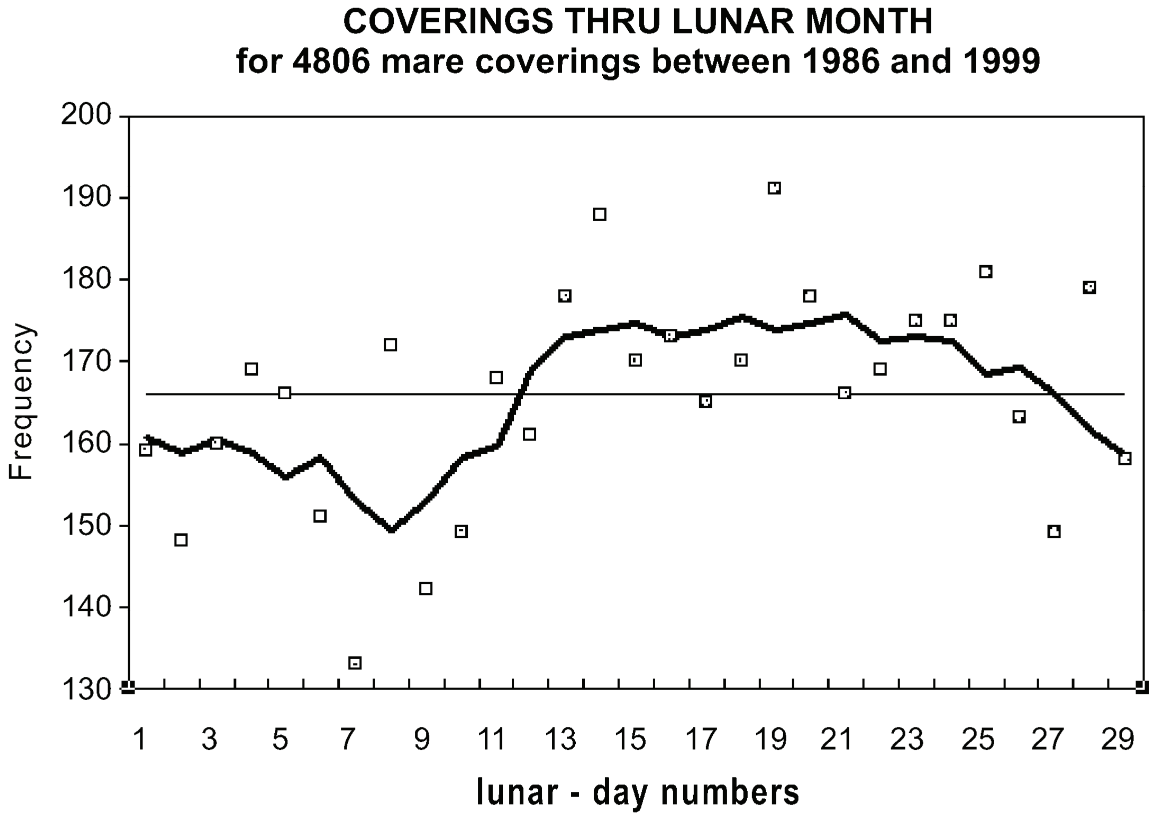

***Figure 1**: Mare coverings thru lunar month 4806 dates of mare-copulation, from one studfarm over 14 consecutive years, are here summed over the 29 lunar-day numbers; with a five-point moving average shown as a continuous line (New Moon = Day 1).*

Figure 1 shows the data plotted in this manner, smoothed with a five-point moving average. The excess of mares coming on heat appears on the day prior to Full Moon and continues for a good week after. Accordingly, the total number of mare-coverings through seven consecutive lunar-day numbers was scored, starting on the day prior to the usual Full-moon number, and likewise for first Quarter and New Moon[1]:

Table 1: Coverings (See Fig. 1) summed over 7 lunar day numbers

Starting at	Coverings	% Excess	χ^2
F.M.-1:	1234 (Expected 1160)	6.4%	5
1st Q.-1:	1076 " "	-7.8%	6

The most significant deviation from chance came from the dip, visible in the graph, over the first lunar quarter. The graph indicates a rather diffuse excess in relation to the event of Full Moon, with no sharp peak, nor any symmetrical New Moon minima a fortnight later. The χ^2 , computed by (observed – expected^2/expected), may serve to indicate significance, however it cannot be converted into an equivalent probability because these deviations were not predicted in advance.

II Total conceptions over the lunar month

Grouping dates on which registered conceptions happened by lunar-day numbers, in a similar manner, i.e. the day on which the successful covering took place, gave Figure 2. While the numbers are smaller than in figure 1, the amplitude of the lunar-month effect appears as larger. An approximately two-day temporal displacement between the axes of this graph should be noted, this being the period between the covering and the ascertaining by vets of the event of conception.

Table 2: Conception (See Fig. 2) summed over 7 lunar day numbers

Starting at	Concepitons	% Excess	χ^2
F.M. -1	520 (expected 450)	15.6%	10.9
1st Q. -1	406 „ „	-9.8%	4.3

Table 2 shows the data grouped similarly to that of the coverings in Table 1. Some 16% more conceptions have appeared from the Full moon period, as compared with a 10% deficit in the First Quarter.

Figure 2 shows a best-fit composite sinewave put through the data, the total number of registered conceptions plotted by lunar-day number on the day of mare-stallion copulation (counting from 1 at the New Moon, reaching Full at or around 14). We may write this equation using just two sinewaves, as:

$$C/C_m = 1 - 0.12cos(360° \times (T-4)/29) + 0.05cos2(360° \times (T-8)/29)$$

Where C is the number of registered conceptions, C_m being the mean value, and T the lunar-day number 1 – 29. The graph compares this sum of two sinewaves with a five-day moving average. That waveform has a 30% differential between its peak on day 16 and its trough on day 7. This suggests a universal statement: that, in all corners of the globe, a thirty percent differential or thereabouts will exist between the number of mare conceptions around the Full Moon, and that nine days earlier in the first quarter of the lunar month. Two waveforms of 12% and 5% amplitude are summed to give this graph, the second of which is a second harmonic, i.e. it goes through two cycles per lunar month.

**Figure 2: Mare Conceptions vs LDNs –
14 years' data 1986-99.**

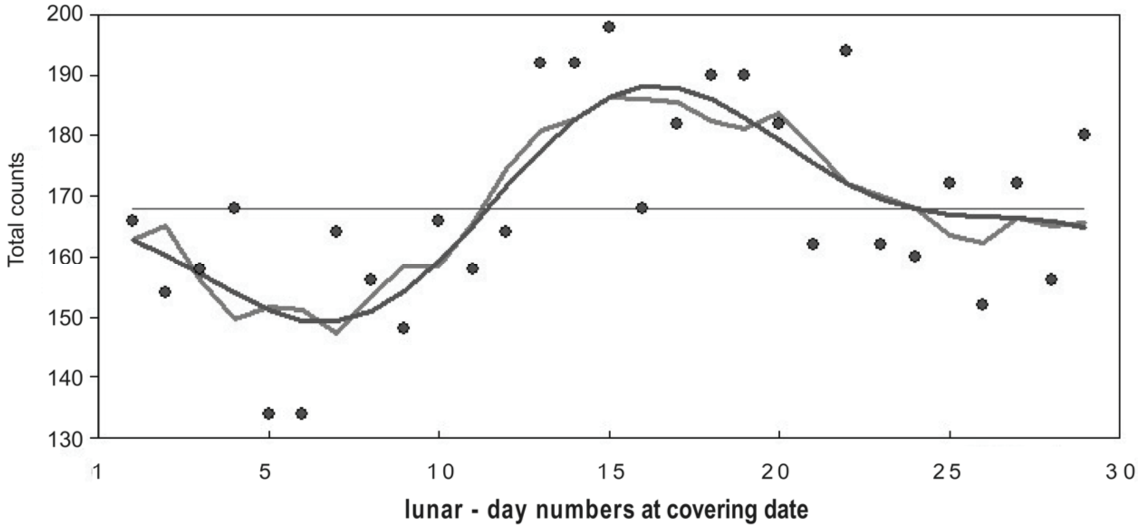

Figure 2: Mare conceptions thru lunar month. The 1865 dates of mating events that led to registered conceptions (excluding those that fell in the half-day per lunar month) are here distributed through the 29 lunar-days (New Moon = Day 1)

III Mare Fertility

We view mare fertility as a ratio, that of the proportion of coverings that were successful. As such it will have a fluctuating, average value that may vary around the lunar month. To indicate any such effect, the data was plotted by Sun-Moon angle (Figure 3) with the latter taken at noon on the day of covering, starting at 0° for the New Moon instant. As before, each covering event was scored as 1 or zero according to whether conception took place. The entire data-set was then sorted by the Sun-Moon angle at each covering date, then large moving averages was put through the data. A 450 point moving average comprised 10% of the total data at each position, spanning about 36° of the Sun-Moon angle circle. The larger the moving average, the more smoothed-out the curve will appear. This method has the advantage of giving a better definition of the event of Full Moon than the previous method, because the 180° Sun-Moon angle is that very moment, whereas using the LDNs one cannot say exactly which of these days fall on the Full Moon.

Figure 3: The Moon and mare fertility: 4557 coverings between 1986-99.

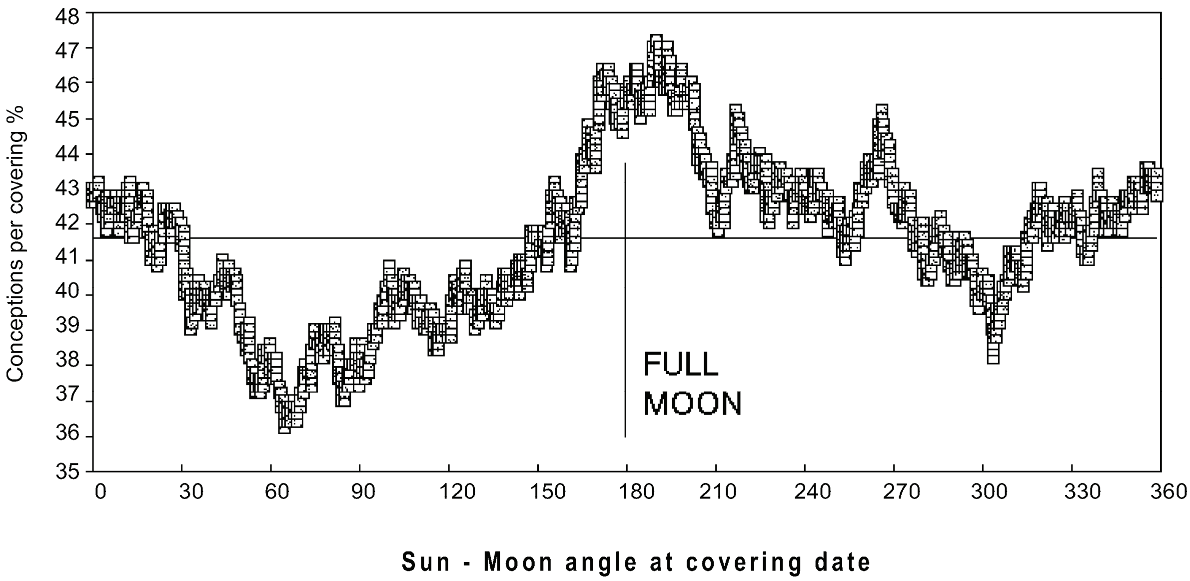

Figure 3: Mare fertility thru lunar month For Sun-Moon angle at noon of covering date (New Moon = 0°), a 450-point moving average is plotted, where each of the 4557 individual values are either 1 or 0, for success or failure. Each point here plotted represents an average fertility value (100 x No. conceptions / No. coverings), spanning about 36 degrees of Sun-Moon angle (i.e., 10% of the data). ***Vertical axis: conceptions per covering%. Horizontal axis: Sun – Moon angle at covering date.***

Figure 3 shows how mare fertility dipped sharply around the First Quarter before peaking at the Full Moon, concordant with the earlier graph. The graph suggests a swing of about 7% in mare fertility, overall, during 7-8 days of the lunar month. The same 'fertility' parameter was also derived using the lunar-day numbers, for comparison, and this gave the following means:

Table 3: Mare Fertility (as in Fig. 3) averaged over 5 lunar day numbers

Starting at	Coverings	Conception	Fertility
F.M. -1	844	369	43.7%
1st Q. -1	740	285	38.5%

Total mean: 41.6%

Thus over a period of about 7 or 8 days in the lunar month, mare fertility as defined climbed by five percentage points, from first to second quarter. Sequences of five lunar-day numbers seem fairly appropriate for this comparison. It may be of interest to compare the manner in which the parameter of fertility as defined varies with mare age: over 3-7 years of mare age averaged 42.4% while that for 8-13 years was 38.8%, and thus decreased by four percent after the peak breeding years.

IV First-Mated Estrus

The director of the Equine Fertility Unit of Newmarket, kindly inspected the present data and made two recommendations: firstly, that old mares should be excluded, as mare fertility drops greatly with age; and secondly, that only the 'first mated estrus' should be used for each mating-pair per season, viz. only the coverings performed during the first estrus period. These two steps of selection give a more homogeneous sample, but involve discarding nearly half of the data (see Appendix levels d and e). This gave:

Table 4: Fertility as per Table 3, for first-mated estrus, mares under 14 years

Starting at	Coverings	Conception	Fertility
F.M. -1	433	220	50.1%
1st Q. -1	416	165	39.7%

Overall mean: 42.7%

A larger swing in mare fertility here appears, of 10% in the course of the lunar month, while the number of conceptions now appears as increasing by one-third, from 1st to 2nd quarter. The numbers may be a little small to have too much weight placed upon them.

A Test of Significance

The chi-square values cited in tables 1 and 2 cannot legitimately be converted into probability values, because these excesses and deficits had not as such been predicted in advance. In the earlier report on 9 years' data 1986-1994, the authors reported an excess of both coverings and conceptions using sets of 5 lunar-day numbers around the Full Moon (starting on the day before), as compared with those around the New, 14 days later. Taking the five years of further data here gathered, 1995-9, there were 579 conceptions; these fell in the 5 LDNs around Full moon 29% more than in those around the New (the totals were 119 and 92, respectively). A 'Monte Carlo' empirical test of the significance of such results was made,[1] and found that this happened 3.8 times out of 100. Thus the prediction as published was confirmed at a 3.8% level of probability. That prediction was, it has here been ascertained, far from optimal.

Table 1 showed how out of all the coverings in the complete data-set, the Full Moon set of 7 lunar-day totals gave 14% more (i.e., 6.4% + 7.8%) than that a week earlier in the lunar month. The 'Monte Carlo' test of this result works as follows. A point is made to fall at random onto a circle divided into 29 ½ parts, or in fact into 59 equal sections, with each of the 'lunar-day numbers' being equivalent to two sections. This was repeated 4891 times (the total of coverings), and the computer summed the total scores falling into two sets of seven consecutive lunar-days. This is then repeated 100,000 times, and the program thereby found that an excess of 14.7% or more, comparing one set with the other, happened by chance about 65 out of 100,000 runs: an empirical probability of such an event occurring of 1 in 1500.

If, instead of coverings one uses the dates of mare conception, there were altogether 1894 in total, and from Table 3 the 7 'lunar days' around the Full Moon scored 28.0% more conceptions than happened in the equivalent period at the First Quarter. That will happen, the Monte Carlo program ascertained, about 17 times per 100,000 cases. Neither of these ratios had been predicted in advance as being in excess, so strictly speaking one is not justified in expressing them as probabilities, albeit they give a guide to the predictions that would be optimal for future testing.

Conclusion

The present replication has supported the claim made in an earlier report, of an excess around the Full Moon period of both frequency of mating events and mare fertility. These two logically distinct factors work in an additive way, to give an increase in the number of conceptions from mares covered in this period of the month. Different ways of presenting the data have been compared: dividing the lunar month by time, as groups of consecutive lunar days, versus dividing by space as Sun-moon angle. Intervals of five lunar-day numbers may be convenient for observing the variation in mare fertility, while seven or even more days seemed more appropriate for totalling the number of coverings or conceptions (the odd numbers having been used, merely as convenient for the moving averages). The equal-time divisions given by the lunar-day numbers were needed for statistical comparison.

A further study should ideally be conducted in a different nation and climate but over the same 14 years, and preferably in the southern hemisphere. The lengthy period here used gave a chance for longer-period lunar inequalities based on the node and apogee-perigee cycles (of 18.6 and 9 years respectively) to even out. No folklore traditions have suggested the deficit in fertility around the first lunar quarter, which was suggested by the graphs in the author's earlier report and has here been confirmed. The science of chronobiology would benefit from elucidation, of how the three-week estrus and four-week lunar month interact during the breeding season, as could be of both practical value and theoretical interest. It is evident that these two cycles cannot remain in synchrony, so there may be a certain logic whereby the first-mated estrus period does optimally demonstrate mare attunement to the lunar month: there could indeed be a case for a replication limiting its data-collection to mares under 14 years and scoring only the first-mated estrus. Or, on the other hand, a further data-set might enable a multivariate approach to mare age, the lunar month and other factors, as would make better prediction of mare fertility feasible.

Sea-tides tides tend to peak a day after the Full Moon on average, and likewise the monthly peak in mare fertility appears as somewhat shifted in this direction, as peaking just after the syzygy. For a general discussion of animal adaptation to the lunar month, see Schad (2002), while Dubrov (1996) also has much pertinent material.

Endnotes

1. The expected values may be computed from the Appendix, level (b): 4086 x multiplying by 7/29 = 1160.

2. Available as a DOS program at www.astro3.mclunar.co.uk.

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Appendix

Level	Data Set	Coverings	Conc^{n}s	Mean Fert^y	Used in
a.	Total (2318 mating-pairs)	4891	1900		
b.	Lose ½ day	4806	1871		Table 1, Fig 1 & 2
c.	Lose no-returns	4643	1865	40.2%	Tables 2
d.	Lose mares over 13 yrs	3711	1543	41.6%	Table 3, Fig 3
e.	Lose 2nd etc. estrus	2587	1105	42.7%	Table 4