Evaluation of crude annual parturition rate estimates in a small-holder African ruminant farming system

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(Received 25 September 2008; Accepted 14 May 2009; First published online 3 June 2009)

Many parameters have been proposed for evaluating livestock reproduction performances in tropical farming systems. In tropical free-ranged and small-holder systems, where reproduction cycles cannot be individually observed without expensive field surveys, one of these parameters is the average number of parturitions \( h \) expected by reproductive female, if the female spends the whole year in the herd. A frequent approach for estimating \( h \) is to use the ratio \( h_c = \frac{m}{T} \), so-called ‘crude annual parturition rate’, where \( m \) is the observed number of parturitions and \( T \) is the total time of presence of the reproductive females in the herd during the year. The bias encountered when \( h \) is estimated by \( h_c \) was evaluated in this paper. Six methods of estimation were used, where \( T \) was the exact observed time of presence \( (h_{c1}) \) or approximated by monthly, quarterly, half-yearly and yearly averages or final size of the reproductive herd size \( (h_{c2} \text{ to } h_{c6}) \). Data came from long-term follow-up of cattle and small-ruminant herds (with data recorded at animal level) in extensive agro-pastoral systems in Senegal. In general, \( h \) was correctly estimated by \( h_{c1} \). Nevertheless \( h_{c1} \) was sensitive to competing risks (e.g. deaths, sales and slaughtering of reproductive females) and was seriously biased when intensive withdrawals of females occurred before or during the parturition peak. Reliability of crude rates progressively decreased from \( h_{c2} \) to \( h_{c6} \), corresponding to the degradation of information used for approximating \( T \). This decrease was much lower for cattle (for which all methods had acceptable reliability) than for small ruminants. Among the compared methods, the lower reliability was observed for \( h_{c6} \) that we do not recommend for small ruminants. Methods \( h_{c5} \) and \( h_{c6} \) are currently used in rapid cross-sectional retrospective surveys based on the recall of the farmers on the demographic events which occurred in the herd over the last past 12 months. The study has showed that such surveys and estimates \( h_{c5} \) and \( h_{c6} \) can generate seriously biased results. More globally, annual parturition rates can be highly variable depending on the 12-month periods considered. Annual parturition rates estimated on short-term data, even with precise herd follow-up surveys, must be considered cautiously.

Keywords: parturition rate, bias, tropical ruminant livestock, small-holder farming systems, Senegal

Implications

In African small-holder free-ranged farming systems, reproduction is a key component for improving livestock productivity. Reliable estimates of parturition rates are needed to orientate decision makers and research. Naive, crude rates can be misleading. Annual parturition rates can be highly variable depending on the 12-month periods considered. Rates estimated on short-term data, even with gold standard field survey methods, must be considered cautiously.

Introduction

Many parameters have been proposed for evaluating reproduction performances of ruminants in tropical farming systems. In intensive farming conditions or experimental stations, reproduction is controlled and continuous observations of the reproductive status of females (e.g. anestrous, oestrus, service and gestation periods) are available. This enables to calculate detailed parameters such as the percentage of mated or inseminated females that become pregnant or the average number of services per conception (Mukasa-Mugerwa, 1989). In free and extensively ranged systems (even in Northern countries, e.g. Marzin and Liénard (1984)), reproduction is generally uncontrolled. Males and females are reared together and births occur throughout the
year, although seasonal peaks are generally observed. Mating and reproductive cycles cannot be individually monitored without cumbersome protocols and cruder reproduction parameters must be used.

One of these parameters is the number of parturitions, say \( h \), encountered in average by a reproductive female, if this female spends the whole year in the herd. In such a parameter, for simplification, females are classified as reproductive when they are older than a given age (which can depend on farming systems). A frequent estimate of \( h \) is the ratio \( h_c = m/T \), so-called 'crude annual parturition rate' (e.g. ILCA, 1990; Lhoste et al., 1993), where \( m \) is the observed number of parturitions during the year in the herd and \( T \) the corresponding total time of presence of the reproductive females. This estimate is simple to calculate but suffers from several difficulties. It is only valid if instantaneous hazard rates (i.e. probabilities of occurrence in a very short period of time) of parturition and of its competing events (such as mortality or other exits from the herd) are constant with time. In that situation, \( m \) follows a Poisson distribution and \( h_c \) is the maximum likelihood estimator of \( h \) (Kalbfleisch and Prentice, 1980; Laird and Olivier, 1981; Agresti, 1990). In other cases, \( h_c \) is biased and represents an apparent parturition rate. For instance, when parturitions and females’ sales or slaughtering are seasonal, \( h_c \) can vary without biological meaning, depending on whether the main parturition season is sooner or later than sales or slaughtering periods (this point is discussed later). An additional source of bias in \( h_c \) comes from the calculation of \( T \). Accurate \( T \) estimates can only be obtained from longitudinal herd follow-up data on cattle and small ruminants. A frequent estimate of \( h_c \) was calculated by comparison to a gold-standard, calculated on long-term longitudinal herds’ follow-up data on cattle and small ruminants.

### Material and methods

#### Data sets

Data used for bias calculation were collected during two past research programs (PPR: *Pathologie et productivité des petits ruminants* and ABT: *Alimentation du bétail tropical*) jointly implemented by ISRA (Senegalese Institute of Agricultural Researches) and CIRAD (French Agricultural Research Centre for International Development). Herds were selected in traditional villages sampled from northern to southern Senegal. Two sites, N’Diagne and Kolda, were considered in the article (Table 1), representing different rainfall patterns. N’Diagne is located in northern Senegal (16.10W; 15.38N) and is classified in the Sahelian eco-climatic type with an average annual rainfall of 300 mm. Kolda is located in Upper-Casamance in southern Senegal (14.94W; 12.88N) and is classified in the Sudano-Guinean eco-climatic type with an average annual rainfall of 1.110 mm.

In each site, herds have been monitored by field enumerators using the same protocol (Fauge`re and Faugére, 1986; Faugére et al., 1991). At the first farm visit, all the animals present in the herds have been recorded and identified with ear-tags. Herds have been subsequently visited every 15 days. At each visit, exact dates of all parturitions, exits (natural deaths, slaughtering, sales, gifts, loans and withdrawals) and entries (purchases, gifts and loans) occurred since last visit have been recorded. Data have been stored in a relational database especially designed for herd follow-ups (with animal identification) in tropical extensive farming systems (Juanés and Lancelot, 1999). Recorded information have already been analyzed in other contexts (Fauge`re et al., 1990a and 1990b; Clément et al., 1997; Lesnoff, 1999; Lancelot et al., 2000; Ickowicz and Mbaye, 2001; Ezanno et al., 2003).

Five data sets have been used in the article (Table 1): cattle (one), goats (two) and sheep (two). Study periods were 1994–97 for cattle (Kolda) and 1985–95 for small ruminants (N’Diagne and Kolda).

### Table 1 Data sets used to estimate the relative bias in annual parturition rates

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>Monitoring period</th>
<th>Number of herds</th>
<th>Number of females</th>
</tr>
</thead>
<tbody>
<tr>
<td>N’Diagne</td>
<td>Goats</td>
<td>1985–95</td>
<td>49</td>
<td>972</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>1985–95</td>
<td>144</td>
<td>2557</td>
</tr>
<tr>
<td>Kolda</td>
<td>Goats</td>
<td>1985–95</td>
<td>92</td>
<td>993</td>
</tr>
<tr>
<td></td>
<td>Sheep</td>
<td>1985–95</td>
<td>102</td>
<td>1004</td>
</tr>
<tr>
<td></td>
<td>Cattle</td>
<td>1994–97</td>
<td>12</td>
<td>509</td>
</tr>
</tbody>
</table>

*Period considered in the article.
*Average number of herds or females (all ages) present per month in the follow-up survey (averaged over the study period).
Annual parturition rate

Gold standard estimate. When estimating $h$ over a 12-month period, one approach to eliminate bias due to variable competing risks (Prentice and Kalbfleisch, 1978) is to calculate hazard rates over successive short sub-periods of times (e.g. day, week, fortnight or month) and then to sum the sub-period rates over the whole period. Calculating rates for each sub-period independently and then summing sub-period rates enables to represent more accurately the expected average number of parturition by reproductive female spending whole year in the herd. This approach is close to the one used in the non-parametric Kaplan–Meier survival model when instantaneous hazard death rates are calculated at each time of death or censoring and then summed to get the cumulative hazard rate (Collett, 2003).

Time was decomposed into monthly intervals. Finer decomposition can improve the estimate. Nevertheless, improvement was negligible on our data sets (results not detailed here). Shorter sub-periods also had the drawback to generate larger databases, especially for long-term follow-up (e.g. a weekly decomposition of the demographic data of sheep in N’Diagne generated a database of size higher than 80 Mo).

For a given 12-month period, the annual parturition rate estimate used as reference was defined as the sum of the monthly rates:

$$h_{ref} = \sum_{j=1}^{12} h_{c,j},$$

where $j$ is the index of the month in the 12-month period, $h_{c,j} = m_j/T_j$, $T_j$ is the time of presence of the reproductive females (defined as females older than a given exact age) in the herd in month $j$, $m_j$ is the number of parturitions in month $j$.

Crude estimate and approximations. For the 12-month period, the crude estimate (without approximation) of the annual parturition rate was calculated by $h_{cr} = m/T$, where $T$ is the time of presence of the reproductive females in the herd in the period ($T = \sum_{j=1}^{12} T_j$) and $m$ the number of parturitions ($m = \sum_{j=1}^{12} m_j$). Five approximations of the crude estimate ($h_{cr}$ to $h_{cr}$) were calculated by $m/T_{approx}$, where $T_{approx}$ represents estimates of average reproductive herd size. Denoting $t$ the time (in month) within the 12-month period ($t = 0$ and $t = 12$ correspond to beginning and end of the year, respectively) and $n_t$ the number of reproductive females present at time $t$ in the herd, $T_{approx}$ was calculated as:

- $T_{approx, 2} = \sum_{t=0}^{12} n_t/13$ (monthly average),
- $T_{approx, 3} = \sum_{t=0,3,6,9,12} n_t/5$ (quarterly average),
- $T_{approx, 4} = \sum_{t=0,6,12} n_t/3$ (half-yearly average),
- $T_{approx, 5} = \sum_{t=0,12} n_t/2$ (yearly average),
- $T_{approx, 6} = n_{12}$ (end of the 12-month period).

Bias calculation

To take into account for seasonal patterns, successive 12-month periods have been built (within study periods) by shifting the annual observation period of one month each time: 36 successive 12-month periods have been built for the period 1994–97 and 120 for the period 1985–95. For each 12-month period, bias has been evaluated as follows. We calculated the reference rate $h_{ref}$ and then the crude rate $h_{cr}$ and its approximations ($h_{cr}$ to $h_{cr}$). The relative bias (in percentage) was calculated as $100 \times (1 - (h_{approx}/h_{ref}))$ for $i = 1$ to 6. A positive relative bias means an overestimation of $h_{ref}$. Distributions (location and variability) of $h_{ref}$ and of the bias of $h_{cr}$ to $h_{cr}$ were summarized with descriptive statistics and graphical analyses.

Results

Time series of $h_{ref}$ for each site and species in the study periods are provided in Figure 1. Cattle $h_{ref}$ in Kolda ranged from 0.33 to 0.54/year with an average of 0.43/year (Table 2). For small ruminants, $h_{ref}$ was in average lower in N’Diagne than in Kolda (Table 2), but with higher dispersion (for instance, for goats, average $h_{ref}$ were 0.84 and 1.25/year in N’Diagne and Kolda, respectively, while corresponding ranges were 0.66 and 0.33/year).

Average bias of $h_{cr}$ to $h_{cr}$ was low for all sites and species (Table 2); depending on the site and the estimation method, average bias varied from −0.5% to 0.7% for cattle, from −2.7% to 1.8% for goats and from −3.0% to 0.5% for sheep. Bias dispersion was sensitive to the site, the species and the estimation method. This dispersion was lower for cattle than for small ruminants (Figures 2 and 3): in absolute value, minimum and maximum biases for cattle were 1.9% ($h_{cr}$) and 6.9% ($h_{cr}$), while biases higher than 10% were frequent for small ruminants, particularly with $h_{cr}$. Highest bias dispersion has been observed in N’Diagne for sheep. In absolute values, maximum biases were 19.6%, 19.2%, 17.2%, 18.2%, 24.6% and 64.5% with $h_{cr}$ to $h_{cr}$ respectively.

For small ruminants, bias dispersion has increased from $h_{cr}$ to $h_{cr}$ (Figure 3). For instance, in N’Diagne, bias standard deviation (s.d.) increased from 2.3 ($h_{cr}$) to 8.8 ($h_{cr}$) for goats and from 3.5 to 13.8 for sheep. This pattern was less obvious for cattle: bias s.d. has increased from 1.6 ($h_{cr}$) to 2.8 ($h_{cr}$) (Figure 2).

Time series of biases over the study periods has shown complex patterns depending on the estimation method and the period, mixing seasonal and irregular fluctuations. Series of sheep in N’Diagne are presented in Figure 4 as an example. Besides fluctuations, Figure 4 has confirmed the increasing amplitude of the bias dispersion from $h_{cr}$ to $h_{cr}$. It has also showed that even the less variable estimate $h_{cr}$ can be affected by large drops.

Discussion

An important feature observed in the study was the high variability of the successive 12-month parturition rates $h_{ref}$ (the same result was noted by Marzin and Liénard (1984) in a French extensive farming system). For instance, for sheep in
N'Diagne, $h_{ref}$ has dropped from 1.15 to 0.87/year only by shifting the 12-month period three months later. This variability was mostly due to the marked seasonality of parturitions in the observed systems (particularly in N'Diagne) and to the location of the parturition peaks which can shift of one or two months according to the year. For instance, in N'Diagne, highest observed values of $h_{ref}$ corresponded to 12-month periods including a parturition peak and, by chance, a part of the start of the following peak. Such phenomena make it difficult to get a representative estimate of the annual parturition rate when data are only recorded over one or two years. Longer data are needed to eliminate the effect of the successive 12-month rates variability.

In general, $h_{ref}$ has been correctly estimated by $h_{c1}$. In absolute value, bias was lower than 11% in all sites and species, except for sheep in N’Diagne (19.6%, corresponding to the negative drop observed in Figure 4). Rate $h_{c1}$ is simpler to calculate and to analyze with inferential statistical methods ($h_{ref}$ needs within-year decomposition and involves more parameters). Nevertheless, one drawback of $h_{c1}$ is its potential sensitivity to competing risks, such as mortality and other exits from the herd (sales, slaughtering,
gifts and loans) of reproductive females. For instance, in farming systems with marked seasonal parturitions, large withdrawals of females before parturition peak will artificially decrease the number \( m \) of parturitions observed in herds, and subsequently \( h_{c1} \). An example of this effect was the drop that has been observed for sheep in N'Diagne (Figure 4). It was due to massive exits of ewes within a short period of time (Lesnoff, 1999). In such situations, \( h_{c1} \) represents an apparent annual parturition rate, without biological meaning, rather than the average parturition rate of a reproductive female spending all the year in the herd. The same drawback applies to approximate crude rates (Figure 4). Therefore, when using crude rates \( h_c \), we recommend to also calculate \( h_{ref} \) (if data have been collected in a herd follow-up survey), and to check that discrepancies between these estimates remain at an acceptable level, and that no events such as in Figure 4 has occurred.

In this study, reliability of the crude rate has progressively decreased from \( h_{c2} \) to \( h_{c6} \), corresponding to the degradation of information used for approximating \( T \). This decrease was much lower for cattle (for which all methods had an acceptable reliability) than for small ruminants, in relation with a higher precocity of goats and sheep and a faster turnover of these animals in herds. Among compared estimates, the lower reliability has been observed for \( h_{c6} \); bias reached 26.0% for goats and 64.5% for sheep. Therefore, we do not recommend using this estimate, especially for small ruminants. Reliability of \( h_{c2} \) and \( h_{c3} \) was acceptable, with the same reservation as for \( h_{c1} \) regarding the sensitivity to competing risks.

![Box-and-whisker plots of the relative bias (%) of the estimated annual parturition rates \( h_{c1} \) to \( h_{c6} \) compared to the reference value \( h_{ref} \) for cattle in Kolda site.](image)

**Figure 2** Box-and-whisker plots of the relative bias (%) of the estimated annual parturition rates \( h_{c1} \) to \( h_{c6} \) compared to the reference value \( h_{ref} \) for cattle in Kolda site. For a box, the closed point located in the box represents the median and the two ‘hinges’ are the first and third quartile. The ‘whiskers’ extend out from the box to the most extreme data, which is \(<1.5 \times \text{IQR}\) away from the box (IQR: inter-quartile range). Eventual outliers are represented by open circles.

![Box-and-whisker plots of the relative bias (%) of the estimated annual parturition rates \( h_{c1} \) to \( h_{c6} \) compared to the reference value \( h_{ref} \) for small ruminants in N'Diagne and Kolda sites (see Figure 2 for details on box-and-whisker plots).](image)

**Figure 3** Box-and-whisker plots of the relative bias (%) of the estimated annual parturition rates \( h_{c1} \) to \( h_{c6} \) compared to the reference value \( h_{ref} \) for small ruminants in N'Diagne and Kolda sites (see Figure 2 for details on box-and-whisker plots).
Rates \( h_{c5} \) and \( h_{c6} \) can be used in rapid cross-sectional 1-year retrospective surveys based on interview of farmers and their recall of the demographic events that occurred in the herd over the last past 12 months (ILCA, 1990; Lesnoff et al., 2008). These surveys are quicker and less expensive than herd follow-up – especially in large areas or in nomadic systems – and can be implemented after unpredictable crises (such as droughts or disease outbreaks) to estimate their impacts. Nevertheless, the study has shown that \( h_{c5} \) and \( h_{c6} \) only provide very approximate results. Calculation bias may also be worsened by farmers’ recall errors during retrospective interviews. Results of retrospective surveys and \( h_{c5} \) and \( h_{c6} \) estimates should be considered with caution. When possible, other surveys methods and estimates should be preferred.

Finally, the observed variability between the estimates and between the successive 12-month periods have shown that comparisons of parturition rates, for instance, during a literature review or when analyzing field data for testing impacts of innovations, should use estimates calculated with the same method and on the same 12-month periods. In the first case, however, the frequent lack of methodological details reported in the articles on small-holder tropical livestock farming systems remains a constraint.

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