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Choice of scan-sampling intervals—An example with quantifying neighbours in dairy cows

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ABSTRACT

To date, only a few studies using scan-sampling intervals to record neighbours in groups of animals explain how the interval length was chosen. In this study, we investigated the effects of different scan-sampling intervals, behavioural context, and the definition of neighbours on the accuracy of data as compared to a quasi-continuous observation. The data was collected from dairy cows kept in cubicle housing systems. Dairy herds of 22–43 cows on 6 farms were observed once a minute with an automatic tracking system for 6 days, and both the nearest neighbour and all neighbours within a defined distance of each cow were recorded with references to the activity, feeding and lying area and stored in neighbourship matrices. In the analysis, we used data collected at intervals of 2, 3, 4, ..., 30 min, and correlated this simulated data with the data based on the 1-min interval using a specialised correlation coefficient for matrices τ_{Kr}. This correlation coefficient was then used as the response variable in mixed-effects models. We found that the size of the correlation coefficients generally decreased as interval length increased. This decrease was less pronounced for all neighbours than for the nearest neighbour. Moreover, the decrease was greatest with data from the activity area and lowest with data from the lying area. We concluded that, even with the relatively slow dairy cows in a barn environment, neighbour recordings should be conducted at short scan-sampling intervals in order to achieve a minimum correlation of $\tau_{Kr} = 0.8$ with the quasi-continuous data. Intervals of every 2, 8 and 17 min are recommended for observation of neighbours in dairy cows for the activity, feeding and lying areas, respectively, and species that move faster may well require even shorter sampling intervals.

1. Introduction

Descriptions of the social relationships of group-living animals are often based on observing the proximity or distance between pairs of animals (e.g. Syme et al., 1975; Le Pendu et al., 1995; Sigurjónsdóttir et al., 2003; deVries et al., 2004; Swain and Bishop-Hurley, 2007). In order to quantify such socio-spatial patterns, neighbours within a group are commonly identified at regular intervals (e.g. Sato et al., 1993; Christensen et al., 2002; Durrell et al., 2004; Hoerl Leone et al., 2007). Usually, scans are used as the sampling rule and instantaneous sampling as the recording rule (Martin and Batson, 1993); for brevity's sake, we will henceforth refer to this combination as scan sampling. To date, only a few studies have discussed the relative accuracy of different scan-sampling intervals (e.g. Dunbar, 1976; Leger, 1977; Simpson and Simpson, 1977; Tyler, 1979; Damerose and Hopkins, 2002). A majority of these studies focused on whether a scan-sampling approach could be used instead of continuous sampling

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(e.g. to allow for other behavioural observations in parallel) by comparing data based on instantaneous sampling and continuous sampling. Given an interval length of between 15 and 120 s, these studies found instantaneous sampling to be an adequate method for sampling various behaviours. Such short intervals are rarely used, however, and could pose serious practical problems for the observation of social relationships in large groups of animals.

Studies on social relationships have used different strategies like e.g. sampling social behaviour (e.g. Calhim et al., 2006), sampling the group locations in a social context (e.g. Durrell et al., 2004), sampling distances between animals (e.g. deVries et al., 2004), but mostly methods of neighbour sampling were used (e.g. Sibbald et al., 2006, Sato et al., 1993). Scan-sampling intervals chosen for the latter ranged from 20 s to 30 min, but it has not been indicated how interval length had been determined. Most probably the scan-sampling interval had been chosen by the authors for practical reasons, and thus depended on the structure of the animal's environment, the number of animals to be sampled, or the necessity of conducting additional observations in parallel.

There are two types of neighbour sampling which are frequently used: (1) those in which all neighbours of a focal animal (within a defined distance) were considered to be neighbours (e.g. Gros-Louis, 2004; Lazaro-Perea et al., 2004), and (2) those in which only data on the nearest neighbour of a focus animal (within a defined distance) were collected (e.g. Christensen et al., 2002; Archie et al., 2006). Rarely an explanation was found how the definition of "neighbour" was arrived at. Only few studies collected neighbour data specific for the behavioural context (foraging: Hollén and Manser, 2006; Gros-Louis, 2004).

Here, we provide an example well based on data that illustrates how neighbour definition, i.e. all neighbours versus the nearest neighbour of a focal animal within a defined distance, and the functional context influences the accuracy of neighbour data. At the same time, we show how quickly information on neighbours deteriorates if data is sampled at increasing sampling intervals.

We were interested in the social structures of dairy cows since changes in these structures might serve as a subtle tool for assessing changes in animal welfare. We observed herds of dairy cows in loose housing systems on six farms. To investigate the context-specificity of the choice of neighbours, the barns were divided into functional areas for data evaluation: (1) the feeding area along the feed rack, (2) the lying area with the lying cubicles, and (3) the remaining activity area.

Our study was conducted with a radar-based automatic tracking system (local position measurement, LPM) which allowed the use of 1-min scan-sampling intervals regardless of the number of animals in the herds (22–43). We collected data on the positions of all cows in the six herds at 1-min intervals continuously for six days. Using the spatial aspect of this data, information on the neighbours of each individual summed over the complete six-day period was gathered for each of the functional areas (feeding, lying and activity area) as well as for all areas combined. For each area and all areas combined, two neighbourhood matrices were constructed, taking into account either all neighbouring cows (within a defined distance) or the nearest neighbour only. Furthermore, additional matrices were calculated simulating data recordings with increasing scan-sampling interval lengths, enabling us to show how neighbour information changes with longer scan-sampling interval lengths.

2. Animals, materials and methods

2.1. Animals, housing and management

The study was conducted on six Swiss working farms (labelled A to F; Table 1). The housing system on all farms was a loose system in which cows were able to move about freely and were provided with lying cubicles. All cows wore a tracking transponder around their necks (Gygax et al., 2007). The transponder was fixed at the cows' necks a few hours before the experiment started. Cows had all been used to wearing neck bands and no changes in behaviour due to the transponder had been observed (Gygax et al., 2007). Barns were divided into three functional areas: a feeding area (transponder at the neck within 1 m of the feed rack), a lying area (all lying cubicles) and an activity area (the remaining area where cows could move about freely). Some farms had an additional exercise yard (3/6), or used a pasture (4/6) for part of the day (Table 1), but these areas were not considered in the present study. Farm F had a feed rack divided into three different sections. On all farms, lying cubicles (≥1 cubicle per cow) were divided into 3–5 rows. Cows on all farms had ad libitum access to water. All cows were milked twice daily. The herd composition on 4 farms was stable from at least 3 days before the start of the experiment onwards. On farm F, herd composition did not change from one day before the start of the experiment onwards. At this time, two animals were removed from the herd and were replaced by three others. The newly introduced animals were, however, familiar with the rest of the herd and had been outside the herd for the dry period (max. 42 days). On farm A, one cow was removed after 5 days for management reasons. Consequently, data on this animal were excluded from all analyses.

2.2. Data acquisition: tracking system

Data was automatically collected with a local position measurement system (LPM®; http://www.lpm-world.com; ABATEC electronics systems, Regau, Austria), which recorded the animals' positions in the barns in two dimensions to an accuracy of about 20 cm (Gygax et al., 2007). After setting up the position measurement system, we confirmed its accuracy in each barn by walking pre-defined patterns and visualising the tracked path.

The system consisted of antennas (8–11 per farm depending on the size of the barn) mounted on the walls and pointed towards the centre of the barn. Each cow wore an animal transponder that transmitted a signal to the antennas at regular intervals. The antennas relayed the exact time of reception of the transponder signal to a central computing unit that calculated the 2D position. In principle, the system is capable of recording data at a frequency of 300 position estimates/s. In our set-up, each animal transponder switched between a 10-s transmission interval and a dormant period of 50 s. Since the system required a minimum of 2 s at the beginning of each transmission period to transmit the coordinates with maximum precision, data transmitted in the first 3 s were omitted. With the data of the following 7 s, a mean position was calculated. We thus recorded a position estimate of each cow every minute. Because transponders were locally activated by switching their batteries on, the 10 s activation interval could not be synchronised among cows. Given the average travel speed of cows in a barn and the duration of our observation, this temporal variance among the position estimates of different cows was not considered relevant. We had two reasons to sample data only once a minute: firstly, to reduce the amount of stored data, and secondly, to further increase the accuracy of the position estimates by averaging them over the 7-s period of valid data transmission. We assume that the 1-min interval data was nearly equal to data from a continuous recording approach because cows in barns move relatively slowly. This notion is supported by Leger (1977), Simpson and Simpson (1977), Tyler (1979) and Damerose and Hopkins (2002), who found strong correlations between scans at 1-min intervals and continuous recording in different situations and species.

Table 1
Information on the farms and herds studied and the amount of data collected

	Farms					
	A	B	C	D	E	F
Herd size	22	24	24	29	30	43
No. of dyads	231	276	276	406	435	903
Breeds	Brown Swiss	Brown Swiss	Brown Swiss & Holstein-Friesian	Brown Swiss & Holstein-Friesian	Brown Swiss	Brown Swiss
Exercise yard	None	None	Temporary	Permanent	None	Permanent
Use of pasture	Until 17 h	Until 17 h	None	Mornings	Mornings	None
Material of feeding rack	Metal	Metal	Metal	Metal	Wood	Metal
Floor surface in the activity area	Rubber coated	Slatted concrete	Mastic asphalt	Solid concrete	Slatted concrete	Mastic asphalt
Proportion of available data						
Percentage of recorded data per animal [median, min.–max. in %][a]	94 (67–99)	57 (36–67)	89 (67–97)	85 (67–100)	94 (83–100)	64 (0–74)
Proportion of time [%] spent in[b]						
Activity area, median (quartiles)	14 (12–20)	20 (17–22)	11 (09–12)	08 (06–11)	20 (17–24)	19 (18–22)
Feeding area, median (quartiles)	35 (31–36)	26 (24–30)	29 (27–33)	30 (24–32)	29 (25–32)	39 (36–43)
Lying area, median (quartiles)	53 (44–56)	53 (51–56)	58 (54–63)	62 (59–67)	51 (46–55)	40 (35–44)

[a] Median and range of the proportion of available location estimates per cow and week relative to the total number of measurement intervals in the barn.
[b] Median and range across cows of the proportion of intervals spent in the different functional areas.

Taking failures of the position measurement system (0–1 day/farm) and time on pasture (6 h/day on farms that used pasture) into account, recordings during about 85% (median per farm; Table 1) of the observation time within the barn were realised per animal. In addition, most interruptions were short, with the median of the disruption time being between 1 and 3 min for all individual cows. Thus, whenever data was collected this occurred at almost the intended 1-min sampling interval. We assume that missing location estimates were at random because disruption times were mostly very short and because there is no indication that area use is correlated with the amount of missing data (Table 1).

Batteries in the transponders usually lasted the complete observation period of 6 days but were exchanged during the morning feeding at the feed rack if necessary.

2.3. Experimental design

Data was collected 24 h a day for 6 days. From the spatial aspect of the data, we were able to calculate information on the neighbours summed over the complete observation period of each individual cow with reference to the functional areas (feeding, lying and activity areas) using self-authored software (written in R: http://www.r-project.org, R Development Core Team, 2006). For each area, two types of neighbour matrices were constructed, taking into account either all neighbouring cows within a distance of 1.8 m in the feeding and 2 m in the lying and activity areas, or only the nearest neighbour within these defined distances. Using these criteria, we restricted data collection to neighbours at a short distance from the cows. Critical distances varied slightly between functional areas, as we wished to restrict the neighbour definition to encompass cows at adjacent feeding places in the feeding area, and cows in adjacent lying cubicles in the lying area. In general, animals were only considered to be neighbours if not separated by a visual or physical barrier in the activity area, if in the same functional area and if on the same side of opposite cubicle rows. This information was filled into neighbour matrices presenting the percentage of scans in which the cows in the rows had the cows in the columns as one of their neighbours or their nearest neighbour, divided by the number of scan-sampling intervals in which the positions of both cows were recorded. One matrix was created for each of the three functional areas, as was one combining data from all the areas. In the analysis, we simulated recordings at intervals of 2, 3, 4, ..., 30 min (29 intervals in total) by omitting the intervening observations of the complete data set. Owing to computational limitations, this simulation had to be reduced to intervals at 2-min steps from 1 to 11 min (1, 3, 5, ..., 11 min) and intervals at 5-min steps from 15 to 30 min (15, 20, 25, 30 min) for the largest herd. For all these simulated data sets, the neighbour matrices for all neighbours as well as for the nearest neighbour were calculated specific to the functional areas.

For purposes of evaluation, we calculated matrix correlation coefficients τ_{Kr} (Hemelrijk, 1990) between the matrices with the simulated intervals and the matrix using all data (1-min intervals). We also calculated the correlation between the matrix of all neighbours and the matrix of the nearest neighbour for each scan-sampling interval. This procedure was carried out separately for the three functional areas and over all areas in total.

2.4. Statistical analysis

The matrix correlation coefficients were used as response variables in two linear mixed-effects models (Pinheiro and Bates, 2000) using R 2.3.1 (R Development Core Team, 2006). So as to reflect the experimental design, farms and situation (combination of functional area and type of neighbourhood) nested within farms were included as random effects to account for dependency in our data set.

A first model used the correlation coefficients between the original data set and those from the simulated longer scan-sampling intervals as response variable. Scan-sampling interval (continuous), functional area (factor with levels activity area/feeding area/lying area/total), number of neighbours (factor with levels all neighbours/nearest neighbour), and all possible interactions were included as explanatory variables.

The second model used the correlation coefficients of the two types of neighbour matrices as the response variable and scan-sampling interval (as above), functional area (as above), and their interaction as explanatory variables.

To allow for an a priori unrestricted smooth shape of the regression model, natural splines were used for the effect of scan-sampling interval (Venables and Ripley, 2002). The number of knots in the splines necessary to represent the pattern was found by continuously increasing this number as long as the increase resulted in a statistically significant improvement of the model. In the first model, 5 knots (df = 7) were necessary. In the second model, 1 knot (df = 3) was sufficient.

It was found that (1) including an interaction between scan-sampling interval and the random effects, and (2) including a term accounting for heteroscedasticity between the functional areas, significantly improved the model, and these parts were therefore included. Assumptions of the models were checked using graphical analysis of residuals. The fixed effects and their interactions were reduced using a step-wise backwards procedure until all terms remaining in the model reached a significance level of less than 5%.

3. Results

Although the size of the correlation coefficient τ_{Kr} decreased with increasing sampling-interval length, the

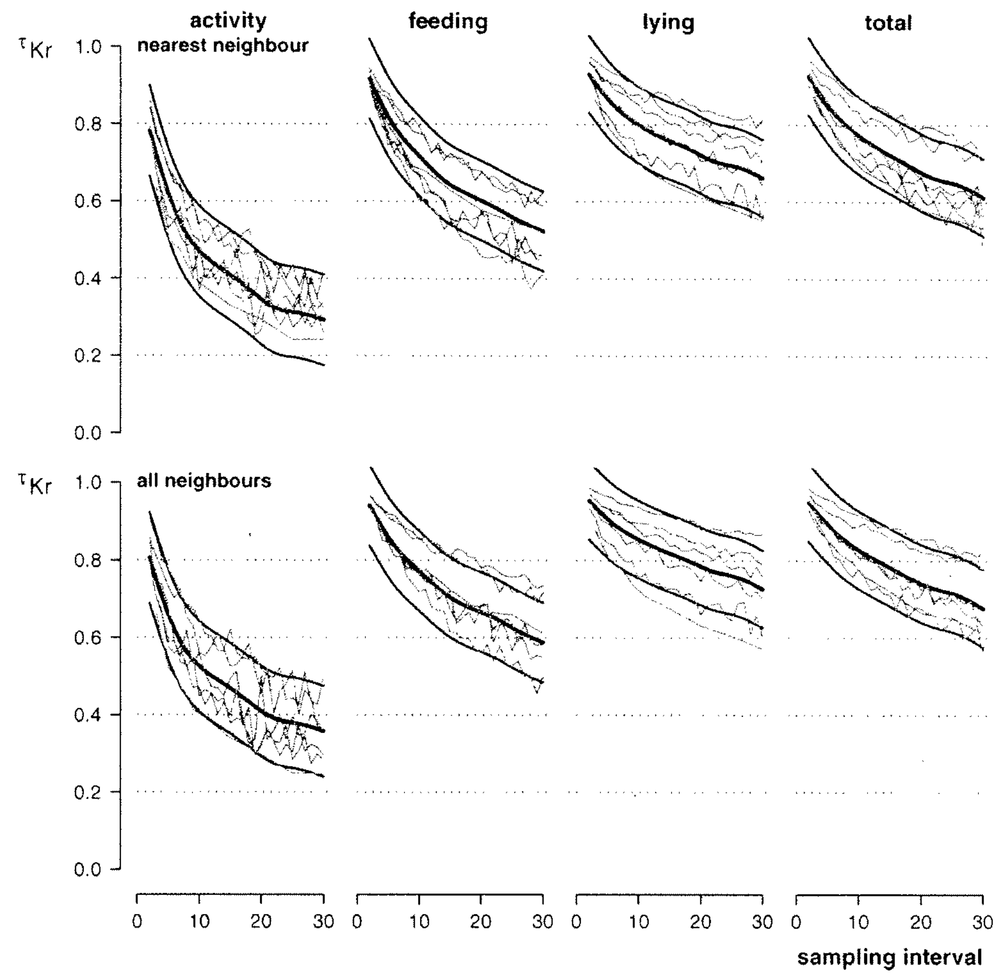

Fig. 1. Matrix correlation coefficients τ_{Kr} between nearest neighbours (top) and all neighbours (bottom); social matrices based on data collected at 1-min sampling intervals, and analogous matrices based on data simulating increased sampling-interval lengths. Grey lines: data of the individual farms ($n = 6$); thick black line: model estimate; thin black lines: 95% confidence intervals.

decrease depended on the functional areas (interaction between interval and areas: $F_{21,1149} = 21.295$, $p < 0.001$; Fig. 1). The decrease was most pronounced in the activity area, followed by the feeding area, and was smallest in the lying area. The decrease observed in the correlations over all areas was between that found in data from the feeding and lying areas. In addition, the decrease in the size of the correlation coefficients was less pronounced for all neighbours than for the nearest neighbour (interaction between interval and number of neighbours: $F_{7,1149} = 6.397$, $p < 0.001$, Fig. 1). Assuming that a correlation coefficient of $\tau_{Kr} = 0.8$ should be reached for adequate data accuracy, interval lengths must be between 1 and 17 min, depending on the functional area and the neighbour definition (Table 2).

Regarding the choice of neighbour definition, the change in the τ_{Kr} values between the social matrices of nearest neighbours and all neighbours depended on the scan-sampling interval length and the functional area (interaction intervals and areas: $F_{9,604} = 8.00$, $p < 0.001$, Fig. 2). In the activity area, the τ_{Kr} was nearly constant at 0.8. In the feeding and lying areas and over all areas, there was a decrease in the correlation coefficient with increasing sampling-interval length, with a difference in the absolute level of the coefficients.

Using the data of the 1-min scan-sampling intervals, neither the matrices based on nearest neighbour nor those based on all neighbours correlated well between different functional areas (Table 3). The matrices for the entire barn (over all areas combined) correlated increasingly well with the data from the activity, feeding and lying areas (Table 3).

Table 2
Scan-sampling interval lengths (and 95% CI) in minutes for the different functional areas (activity, feeding, lying and total over all areas) reaching a correlation coefficient of $\tau_{Kr} = 0.8$ with data gathered once a minute

Functional areas	"Neighbour" definitions	
	Nearest neighbour	All neighbours
Activity area	1 (1–2)	2 (1–4)
Feeding area	6 (2–11)	8 (3–16)
Lying area	10 (3–24)	17 (5–30)
Total over all areas	8 (3–17)	13 (4–27)

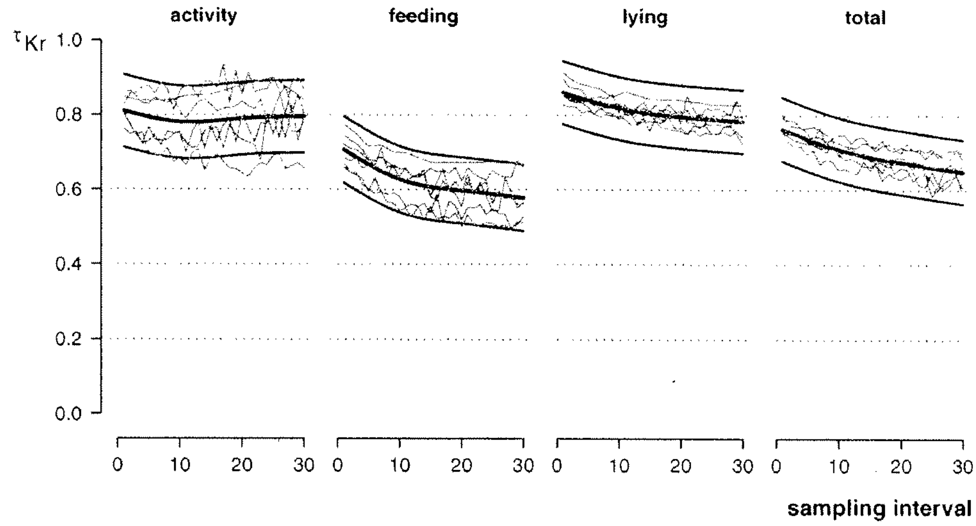

Fig. 2. Matrix correlation coefficients τ_{Kr} between nearest neighbours and all neighbours; social matrices based on data with different sampling-interval lengths. Grey lines: data of the individual farms ($n = 6$); thick black line: model estimate; thin black lines: 95% confidence intervals.

Table 3
Median τ_{Kr} correlation coefficients (and range across farms) for the neighbour matrices in the different functional areas using the "nearest neighbour" (above the diagonal) and "all neighbours" (below the diagonal) definitions

	Activity area	Feeding area	Lying area	All areas
Activity area	–	0.10 (−0.01–0.17)	0.04 (−0.01–0.23)	0.17 (0.11–0.29)
Feeding area	0.08 (−0.02–0.19)	–	0.01 (−0.03–0.07)	0.36 (0.27–0.52)
Lying area	0.03 (0.00–0.21)	0.02 (−0.05–0.09)	–	0.67 (0.54–0.75)
All areas	0.16 (0.08–0.23)	0.44 (0.32–0.61)	0.61 (0.43–0.68)	–

4. Discussion

In this study, we used data on the positions of cows in barns to evaluate the effects of the scan-sampling interval length, the choice of neighbour definition, and the functional context on the accuracy of neighbour data. With regard to the effect of the sampling-interval length, it was found that the τ_{Kr} correlation coefficients of a social matrix based on data collected at 1-min intervals and social matrices based on increasingly longer sampling intervals decreased significantly with increasing interval length.

The decrease in the correlation coefficient with increasing sampling-interval length was specific to the functional areas within the barn and to the neighbour definition. Cows spent varying proportions of time in the different functional areas (activity area 10–20%, feeding area 30–40%, lying area 40–60%; Table 1) which are typical for this housing system (Krohn et al., 1992, Munksgaard et al., 2005). Cows not only spent an increasing amount of time in the activity, feeding and lying areas, but at the same time also spent longer periods in one position without moving while continuously feeding at one feeding place and lying in a specific lying cubicle. In contrast, animals usually move about in the activity area. The more pronounced decrease of the τ_{Kr} in the activity area can hence be explained by more-rapidly changing neighbours owing to shorter times without change of location. Consequently, a smaller scan-sampling interval of 1–2 min was necessary in the activity area, as compared to the feeding or lying areas, where intervals of 6–8 min and 10–17 min, respectively, were sufficient to attain the same accuracy of data (a τ_{Kr} of 0.8; Table 2). The curve over all functional areas combined (total) can be considered as an average between the functional areas, weighted by the length of stay in these areas (based on the increasing correlation of the total over all areas in relation to the activity, feeding and lying areas, as seen in Table 3). Surprisingly, the 95% CI in Fig. 1 were very similar for the different functional areas even though a term adjusting for different variance was included in the model and though it would be plausible that neighbours are more difficult to estimate in the areas where cows spent less time due to the reduced amount of accruing data (Table 1). The functional areas defined in our study correspond to the behavioural context, i.e. cows mostly exhibited lying, feeding and standing/walking behaviour in the lying, feeding and activity areas, respectively. As we show in Table 3 and as has previously been observed (Reinhardt and Reinhardt, 1981; Wasilewski, 2003), the behavioural context influences the choice of neighbours in cows and potentially in other animals, and must therefore be taken into account when recording and analysing neighbour data.

We also found differences in the sharpness of decrease of the τ_{Kr} correlation coefficients with regard to the choice of neighbour definition (nearest neighbour versus all neighbours). The decrease was slightly sharper if only one neighbour as opposed to all neighbours was recorded.

If all neighbours at a defined distance from a focal animal are considered, the social pattern around this animal changes more slowly, since if an additional animal enters the critical distance and thus becomes a new neighbour, other existing neighbours may remain. By contrast, when only the nearest neighbour is considered, the social pattern around the focal animal changes completely every time another animal in the vicinity reaches a distance closer to the focal animal than the former nearest neighbour. Consequently, the pattern in the social matrix of neighbour recordings is more stable when all neighbours are recorded. In our example with dairy cows, there was no a priori restriction in the number of potential neighbours, and it would be difficult to characterise the significance of different neighbours based solely on small differences in distance, and thus support the importance of the one nearest neighbour.

We also correlated social matrices of nearest-neighbour data with matrices of all-neighbours data for the different scan-sampling intervals (Fig. 2). The correlation coefficients were generally lowest in the feeding area. There, the animals were usually close to the two animals occupying the adjacent feeding spaces. It is likely that nearest neighbours changed rather quickly in this situation, given that, in a constant feeding place, even small neck movements of the focal cow or of the potential neighbours on both sides could change the distance between their necks (where the transponder was worn), resulting in a change in nearest neighbour. Taking into account both neighbours in the adjacent feeding places on either side produced more reliable data than merely recording the one that happened to be closer at the time of recording. The same holds true for the lying area structured by adjacent lying cubicles, although the effect is less extreme, since cows remain lying in the same location for longer periods of time. Consequently, the method involving the recording of all neighbours, or – in the case of the feeding and lying areas – focusing on the two nearest neighbours, was more suitable for recording neighbours in the feeding and lying areas. In contrast to this observation, the all neighbours definition seems to be mainly used in basic research (e.g. Michelena et al., 2004), whereas the method of nearest neighbour is used in basic as well as in applied research (e.g. Durrell et al., 2004).

Based on our observations, it would seem advisable to work with short scan-sampling intervals (Table 2) in order to achieve an accurate picture of neighbours and to record all neighbours, at least in those functional areas where the presence of two (or more) neighbours readily occurs owing to the environmental structure in question (feeding spaces, lying cubicles). It can be assumed that the intervals found for dairy cows (Table 2) are also sufficient for species with a similar behaviour, e.g. a similar pattern of movement. Intervals must be shorter for faster-moving animals, and may be longer for slower species. In addition, it may not be advisable to collect neighbour data in a non-specific context, as choice of neighbours may change according to context (Table 3).

It would appear that a sampling interval of no more than a few minutes' length is necessary in order to achieve a reasonable level of accuracy for proximity data. Given such a short interval, it may be difficult for one observer to scan a complete group if the animals are widely scattered, or if a group is large. By deploying several observers and using video equipment, photographs or an automatic tracking system, it may be possible to collect data at short intervals as needed. The automatic recording system used in the current study was able to scan large groups of cows in a fairly spacious housing system, which allowed us to collect data on the animals' neighbour relationships at short intervals without investing excessive effort or time.

Where it is not possible to record data with the recommended short scan-sampling intervals, using longer intervals over extended periods of time is a potential way of collecting data of similar accuracy. In this regard, we are unable to provide data based on the present study. If this approach is to be followed, we need to be sure that the neighbour relationships are stable enough to remain constant over the period of observation.

We conclude that the accuracy of neighbour data depended on the neighbour definition, the functional area and the length of the sampling interval. For dairy cows kept in cubicle housing systems, our data show that, in order to achieve correlation coefficients of at least $\tau_{Kr} = 0.8$ with a social matrix based on near-continuous data, it is advisable to record data of all neighbours every 2, 8 and 17 min for the activity, feeding and lying areas, respectively. Consequently, for the observation of neighbours in other species, sampling interval length needs to be evaluated and chosen with care.

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