

Supplementary Material 3. Additional distribution maps.

Here we present additional distribution maps to support our main findings. Following the methods described in Section 2.4.4.1 of the main paper (adapted for temperature), we show space-use intensity distribution maps across the entire study, for periods of low and high bunching, and for each time period (Section 3.1). Temperature distribution maps are also provided, summarising patterns by month, time period, and across the entire study (Section 3.2).

3.1. Space use

Space-use intensity distributions were determined for the 10 % of time periods with the lowest of each of the following metrics: mean individual CR, mean individual FR, mean ICD, and mean NND, corresponding to the highest levels of bunching for each metric separately ($n = 79$ time periods per metric). A combined space-use distribution was then determined using the union of all time periods identified as the lowest 10 % across any of the four bunching metrics ($n = 203$ time periods). Similarly, a combined space-use distribution was determined for the 10 % of time periods with the highest values for each metric ($n = 79$ per metric), representing periods of low bunching. These aggregated space-use distributions were then compared to each other, and against the aggregated space-use distribution determined across the entire study period, to assess whether the animals were distributed differently across the barn during high and low bunching events. Similarly, space-use distributions were generated for each time period during high (10 % data corresponding to lowest values for each bunching metric combined; $n = 38, 39, 38, 37$ and 33 days for P1 to P5 respectively) and low bunching (10 % data corresponding to highest values for each bunching metric combined; $n = 36, 36, 35, 34$ and 35 days for P1 to P5 respectively).

To compare space-use distributions between low and high bunching periods, we use the Bhattacharya coefficient (BC) which provides a quantitative measure to assess the level of similarity between two-dimensional matrices:

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$$BC = \sum \sqrt{P_x \times Q_x}$$

where P_x and Q_x are the (normalized) distributions being compared. The resulting BC ranges from 0 to 1, where 1 indicates complete overlap between the 2 distributions, and 0 indicates complete dissimilarity.

The BC gives only a single measure of similarity between two distributions; to test if this similarity is significant, a randomisation test is needed (refer to Chopra et al. (2024)). However, we do not conduct randomisation tests because our primary objective was to describe general patterns of space-use distribution associated with bunching behaviour, rather than to formally test hypotheses about statistical significance.

Through visual inspection of the space-use distributions, it is clear that the cattle spent more time at the feed face (approximately $y = 22$ m) during periods of low bunching (115 of 203 time periods = P5 (fresh feed time); Fig S1.C), compared to periods of high bunching (2 of 203 time periods = P5; Fig S1.B), and across the entire study (Fig S1.A). Figure S2.I further reflects higher space-use intensity around the feeding zone during P5.

For each time period, there is large overlap between periods of low and high bunching (BC = 0.982 to 0.995 for each time period; Fig S2, Table S1). During periods of high bunching for each time period, there is high overlap between distribution maps (BC = 0.919 to 0.989), and the case is similar for periods of low bunching (BC = 0.903 to 0.987) (Fig S2, Table S2-3), but there is generally less overlap between P5 and the remaining time periods (e.g., BC = 0.919 to 0.962 during high bunching).

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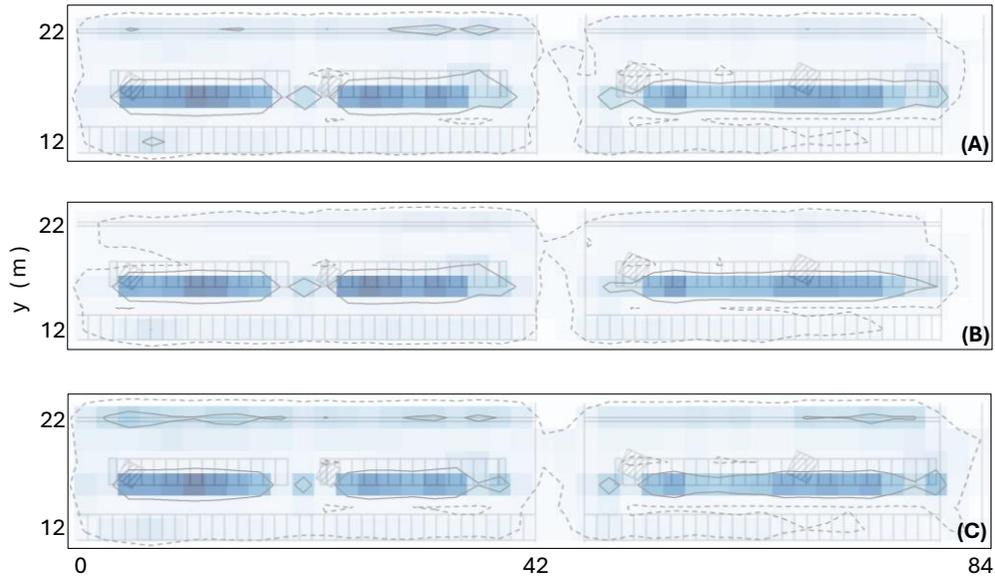


Figure S1. Space-use distributions across the herd (A) over the entire study, and during (B) low bunching and (C) high bunching. Herd core range (50 %) is shown within the solid grey boundary and herd full range (95 %) is shown within the dashed grey boundary.

Table S1. Bhattacharyya coefficients (BC) comparing space-use intensity distributions between low (highest 10 % of values) and high bunching periods (lowest 10 % of values) for each time period: P1 (00:00 h to 03:59 h), P2 (06:00 h to 09:59 h), P3 (10:00 h to 13:59 h), P4 (16:00 h to 19:59 h) and P5 (20:00 h to 23:59 h).

Time period	BC
1	0.995
2	0.989
3	0.983
4	0.986
5	0.995

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Table S2. Bhattacharyya coefficients (BC) comparing space-use intensity distributions during high bunching periods (lowest 10 % of values) between time periods: P1 (00:00 h to 03:59 h), P2 (06:00 h to 09:59 h), P3 (10:00 h to 13:59 h), P4 (16:00 h to 19:59 h) and P5 (20:00 h to 23:59 h).

Time period	1	2	3	4	5
1	-	0.989	0.967	0.981	0.961
2	0.989	-	0.967	0.980	0.959
3	0.967	0.967	-	0.962	0.962
4	0.981	0.980	0.962	-	0.919
5	0.961	0.959	0.962	0.919	-

Table S3. Bhattacharyya coefficients (BC) comparing space-use intensity distributions during low bunching periods (highest 10 % of values) between time periods: P1 (00:00 h to 03:59 h), P2 (06:00 h to 09:59 h), P3 (10:00 h to 13:59 h), P4 (16:00 h to 19:59 h) and P5 (20:00 h to 23:59 h).

Time period	1	2	3	4	5
1	-	0.987	0.981	0.981	0.956
2	0.987	-	0.979	0.982	0.946
3	0.981	0.979	-	0.953	0.980
4	0.981	0.982	0.953	-	0.903
5	0.956	0.946	0.980	0.903	-

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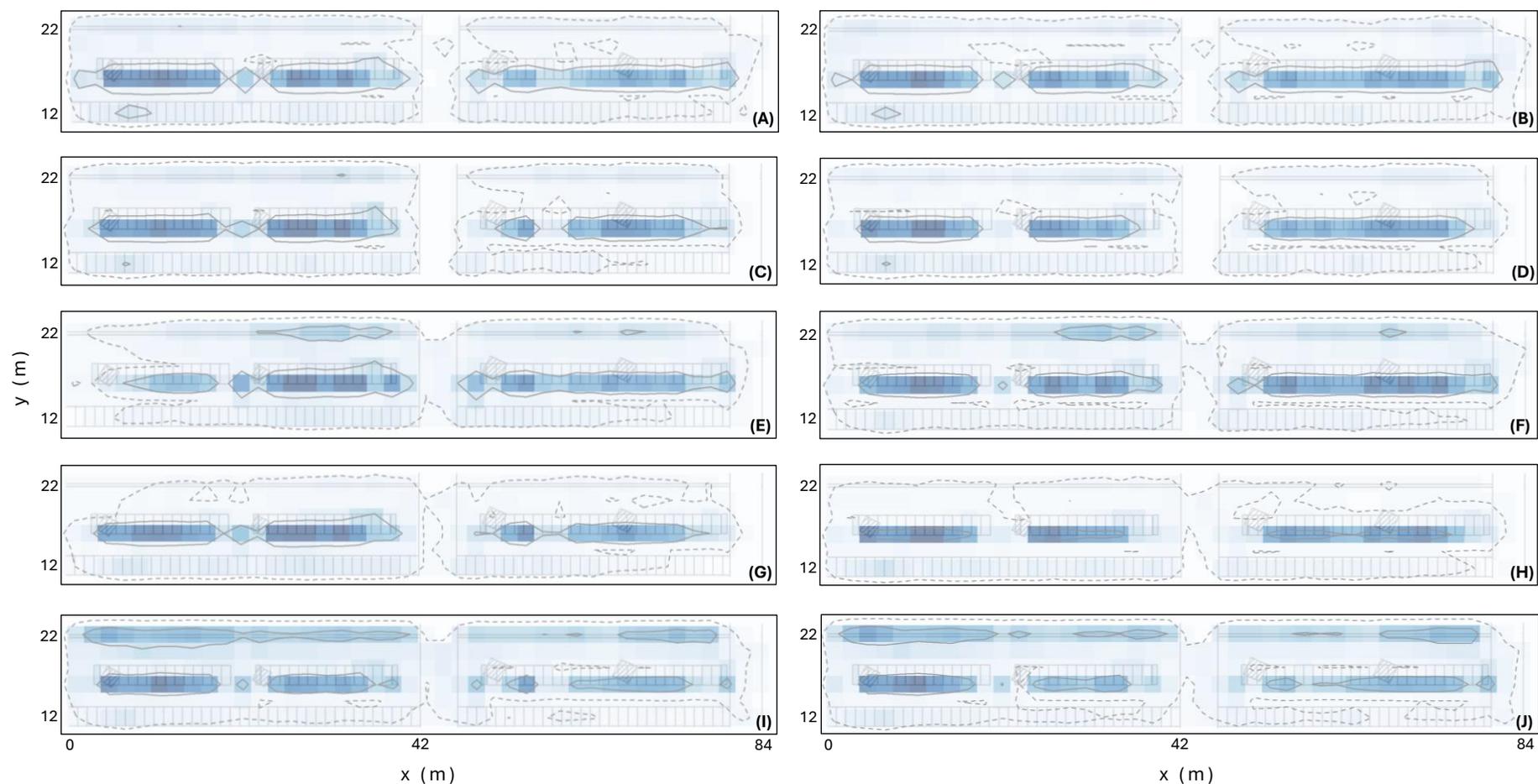


Figure S2. Space-use distributions across the herd for each time period: (A-B) P1 (00:00 h to 03:59 h) (C-D) P2 (06:00 h to 09:59 h), (E-F) P3 (10:00 h to 13:59 h), (G-H) P4 (16:00 h to 19:59 h), and (I-J) P5 (20:00 h to 23:59 h), during (A,C,E,G,I) low and (B,D,F,H,J) high bunching. Herd core range (50 %) is shown within the solid grey boundary and herd full range (95 %) is shown within the dashed grey boundary.

3.2. Temperature and space use

Temperature data were obtained from the cow-equipped positional sensors (sensor temperature; ST). By matching the spatial location and sensor-measured temperature at each time point for all animals across the herd (adapting the method described in Section 2.4.4.1 of the main paper), spatially resolved mean temperature per time period for each 4 m² (2 m x 2 m) virtual cell of the barn can be determined, which we define as ST_{xy}. Hence, we can create a spatial (heat)map distribution of the variations in temperature across the barn across different times (e.g., time period or monthly). It should be stressed that both ST (the mean sensor-measured temperature across the whole barn; i.e., the mean of all ST_{xy} values for a given time period) and ST_{xy} are not true measures of either ambient or localised temperature(s) within the barn; as the sensor is mounted directly on a neck collar (albeit in an insulated housing) it will be affected by the heat generated by the animal itself (refer to Supplemental File S1 in Chopra et al. (2024)). Nevertheless, relative differences in ST_{xy} across the barn offer a useful measure of how the temperature experienced by each animal, and by the herd as a whole, may vary across the barn.

The herd spent most of their time in the cubicle area, irrespective of time period, but there are differences in space use by time period (Fig S3.C,E,G,I). Notably, during P5 (20:00 h to 23:59 h) the density of space use is higher near the feed face, where fresh feed was placed at approximately 20:00 h (Fig S3.I). Temperature is shown as more evenly distributed across the barn (coefficient of variation (CV) = 2.03 %, 2.62 %, 3.22 %, 3.76 % and 2.26 % during P1 to P5 respectively) compared to the space-use distributions (CV = 112.83 %, 129.66 %, 102.34 %, 138.69 % and 83.74 % during P1 to P5 respectively), with slightly hotter temperatures recorded in the centre of the barn across all time periods compared to the sides (Fig S4.B,D,F,H,J), generally matching where cows spent most of their time (Fig S4.C, E,G,I). Furthermore, the hottest temperatures are consistently shown to be in the centre of the barn across all months (Fig S4).

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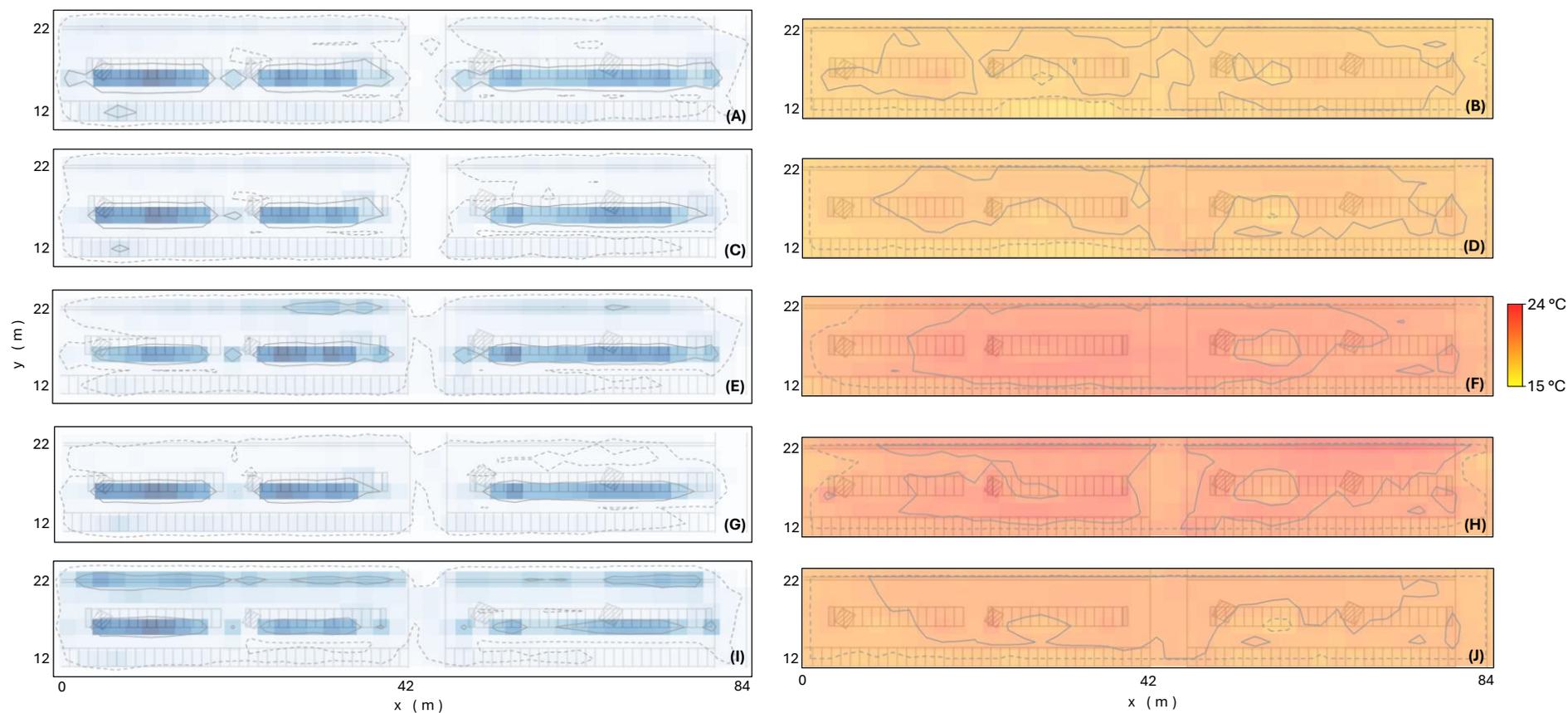


Figure S3. (A,C,E,G,I) Space-use and (B,D,F,H,J) temperature distributions across the herd over time periods: (A-B) P1 (00:00 h to 03:59 h) (C-D) P2 (06:00 h to 09:59 h), (E-F) P3 (10:00 h to 13:59 h), (G-H) P4 (16:00 h to 19:59 h), and (I-J) P5 (20:00 h to 23:59 h). Herd core range (50 %) is shown within the solid grey boundary and herd full range (95 %) is shown within the dashed grey boundary.

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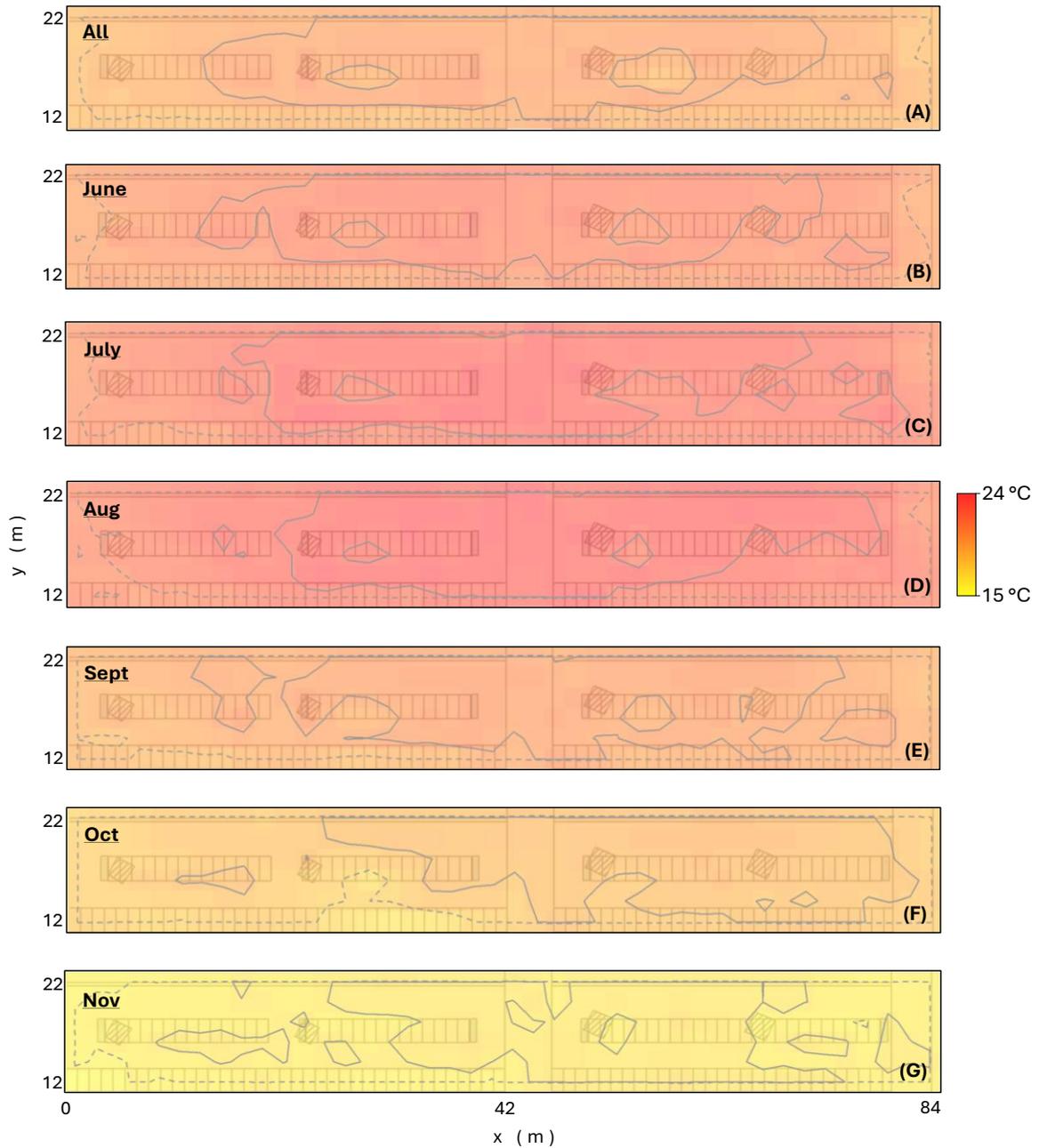


Figure S4. Temperature distributions across the herd (A) across the entire study, and by month: (B) June, (C) July, (D) August, (E) September, (F) October and (G) November (including 1st December). Herd core range (50 %) is shown within the solid grey boundary and herd full range (95 %) is shown within the dashed grey boundary.

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References

- Chopra, K., Hodges, H.R., Barker, Z.E., Diosdado, J.A.V., Amory, J.R., Cameron, T.C., Croft, D.P., Bell, N.J., Thurman, A., Bartlett, D., Codling, E.A., 2024. Bunching behavior in housed dairy cows at higher ambient temperatures. *Journal of Dairy Science* 107, 2406–2425.
<https://doi.org/10.3168/jds.2023-23931>