Oikos

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Rat, M., Mathe-Hubert, H., McKechnie, A. E., Sueur, C. and Cunningham, S. J. 2020. Extreme and variable environmental temperatures are linked to reduction of social network cohesiveness in a highly social passerine. – Oikos doi: 10.1111/oik.07463

Supplementary material

Apppendix 1.

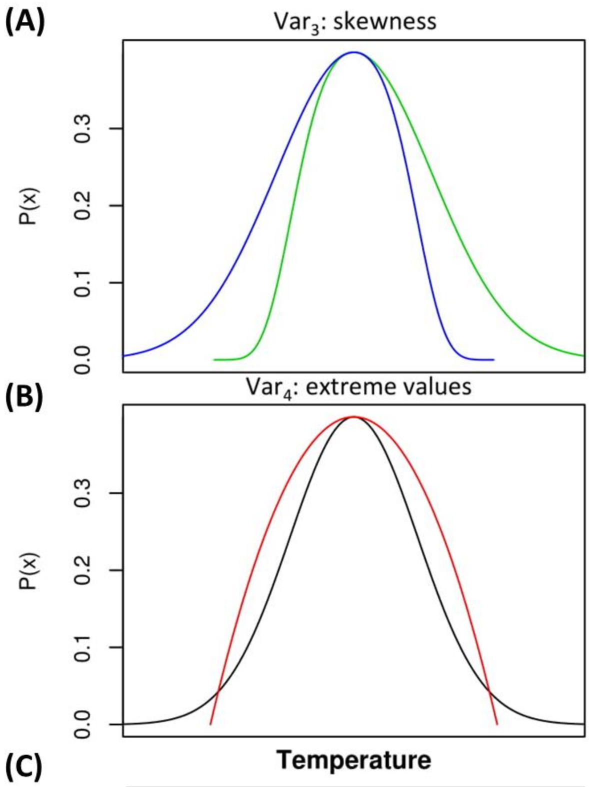
Supplementary material 1 - Method: Description of the methodology used to correct social metrics by network size

The social metrics computed from the HWi networks were corrected for the network size, by removing from each metric the estimated effect of the network size on the metric (more details on this procedure in Smyth 2005). We used box-cox models to estimate the effect of the network size on each metric to account for non-linear relationships.

We used a randomisation approach to correct the social metrics describing the instant networks for the size of the network. For each instant network, we randomly assigned each individual to a feeder and computed the social metrics defined in Table 2 for each of these random instant networks. This procedure was repeated 10000 times so that we obtained the distribution of the expected value of the metrics for a random network of the same size as the observed one. Then, we divided each instant network social metric by its average expected value for a random network of the same size and averaged each of these corrected social metrics over the 2-hr observation block.

Supplement material 2 – Figure A1: Moments of variance

An illustration of the three central moments used to measure the variation of the temperatures; and the information they add to the mathematical variance.
The panels A and B show four theoretical curves having the same mathematical variance or moment of order 2 (*Var*). Panel A illustrates variation in the moment of order 3 (Var_3), i.e. the variance due to the skewness of the data, so that negative values for Var_3 indicate a high variance due to the presence of very low values in relation to the mean (blue curve) while positive values of Var_3 indicate a high variance due to the presence of very high values in relation to the mean (green curve). Panel B illustrates variation in the moment of order 4 (Var_4), the variance due the presence of extreme values in relation to the mean (red and black curves have respectively a low and high moment of order 4). Panel C summarises the values of the three moments for each of the theoretical curves.



(C)

Order of the moment	2	3	4
Abbreviation	Var	Var_3	Var_4
—	1	**−1**	3
—	1	**1**	3
—	1	0	**2**
—	1	0	3

Supplementary material 3 - Table A1: Full report of the random forest models

The table shows the effects of all the predictors tested against the variation in network size and structure. For each of the network features, Network size, the PC_1 (network cohesiveness), PC_2 (instant network cohesiveness) and PC_3 (cluster fragility), Panting (the proportion of time spent panting). The first column describes the standardized effect sizes ('ES'; from -1 to 1 with 0 indicating no effect). The second column gives the *p*-values without correction ('*P*'), the third column gives FDR-adjusted *p*-values ('P_{ADJ}') testing the null hypothesis that the variable does not have any simple or interactive relationship with the response variable. The fourth column gives the conditional importance of the predictor in explaining variance in the response variable. The percentage of variance explained by the model was obtained from out-of-the-bag data (R^2). Stars (*) indicates the level of statistical significance (e.g. * = $p < 0.05$). Effects with significant FDR-adjusted *p*-values are in bold.

		Network size (R^2 = 15.3%)				**PC1 (R^2 = 11.8%)**				**PC2 (R^2 = 1%)**				**PC3 (R^2 = 28.4%)**				**Panting (R^2 = 48.5)**			
		ES	*P*	P_{ADJ}	Importance	ES	*P*	F_{ADJ}	Importance	ES	*P*	P_{ADJ}	Importance	ES	*P*	P_{ADJ}	Importance	ES	*P*	P_{ADJ}	Importance
Colony	*37*	**0.1**	**0.001 *** **	**0.01 ** **	**0.02 * **	**-0.2**	**0.002 ** **	**0.02 * **	**0.4**	-0.01	0.4	0.5	-0.02	**0.6**	**0.001 *** **	**0.02 * **	**1**	2.10-3	0.1 .	0.2	<1.10^{-4}
	50	-0.1				0.6				-0.03				-1				<1.10-4			
	52	0.005				-0.3				0.04				0.6				2.10-4			
Day period	*AM*	**-0.01**	**0.01 ** **	**0.1 .**	6.10-3	0.02	0.2	0.6	0.009	0.03	0.1 .	0.5	-0.007	0.002	0.5	0.6	<1.10^{-4}	-0.01	0.1 .	0.2	<1.10^{-4}
	MID	-0.02				0.05				0.02				-0.002				0.01			
	PM	0.03				-0.08				-0.04				<1.10^{-4}				<1.10-4			
N Sparrow		**0.1**	**0.001 *** **	**0.01 ** **	**0.02**	0.001	0.7	0.7	-0.02	**-0.2**	**0.001 *** **	**0.03 * **	**0.4**	3.10-3	0.6	0.7	<1.10^{-4}	<1.10-4	0.1 .	0.2	<1.10^{-4}
Mean T_{env} °C Ground		<1.10^{-4}	0.6	0.7	<1.10^{-4}	-0.06	0.1 .	0.5	0.04	0.009	0.3	0.5	-0.001	-0.002	0.3	0.5	4.10^{-4}	0.01	0.1 .	0.2	<1.10^{-4}
Mean T_{env}°C Tree		<1.10^{-4}	0.4	0.6	<1.10^{-4}	<1.10^{-4}	0.2	0.6	0.02	-0.001	0.2	0.5	0.001	-0.05	0.1 .	0.5	0.01	**0.06**	**5.10^{-3} ** **	**0.03 * **	**<1.10^{-4}**
Range T_{env}°C Ground		**0.2**	**0.001 *** **	**0.01 ** **	**0.02**	**-0.4**	**0.004 ** **	**0.03 * **	**0.4**	0.006	0.6	0.7	-0.002	-0.001	0.5	0.6	-0.002	1.10-3	0.1 .	0.2	<1.10^{-4}
$Q_{0.05}$ T_{env}°C Ground		<1.10^{-4}	0.5	0.6	<1.10^{-4}	-0.02	0.5	0.6	-0.009	0.006	0.3	0.5	0.001	0.005	0.2	0.5	<1.10^{-4}	**0.03**	**4.10^{-3} ** **	**0.03 * **	**<1.10^{-4}**
$Q_{0.95}$ T_{env}°C Ground		<1.10^{-4}	0.4	0.6	<1.10^{-4}	-0.05	0.2	0.6	0.02	0.04	0.2	0.5	-0.004	-0.03	0.04 *	0.3	0.01	**0.06**	**1.10^{-3} *** **	**8.10^{-3} ** **	**4.10^{-4}**
E(|ΔT_{env}°C|) Ground		<1.10^{-4}	0.5	0.6	3.10^{-4}	-0.05	0.6	0.6	-0.01	0.07	0.9	0.9	-0.01	-0.1	0.09 .	0.5	0.03	4.10-3	0.1 .	0.2	<1.10^{-4}
Var T_{env}°C Ground		0.006	0.3	0.6	3.10^{-4}	**-0.7**	**0.001 *** **	**0.02 * **	**0.4**	0.04	0.4	0.6	-0.004	-0.003	0.2	0.5	<1.10^{-4}	**0.02**	**1.10^{-3} *** **	**8.10^{-3} ** **	**2.10^{-4}**
Var_3 T_{env}°C Ground		4.10^{-4}	0.5	0.6	<1.10^{-4}	0.009	0.5	0.6	-0.003	0.05	0.1 .	0.5	-0.007	-0.03	0.9	0.9	-0.01	8.10-3	0.02 *	0.08 .	<1.10^{-4}
Var_4 T_{env}°C Ground		**0.01**	**0.02 * **	**0.1 .**	**2.10^{-3}**	**-0.6**	**0.001 *** **	**0.02 * **	**0.5**	0.01	0.4	0.6	-0.005	-0.003	0.2	0.5	-0.001	**0.04**	**1.10^{-3} *** **	**8.10^{-3} ** **	**3.10^{-4}**
Range T_{env}°C Tree		-0.005	0.3	0.6	<1.10^{-4}	0.01	0.5	0.6	-0.005	-0.04	0.3	0.5	-0.002	<1.10^{-4}	0.5	0.6	<1.10^{-4}	3.10-3	0.3	0.3	<1.10^{-4}
$Q_{0.05}$ T_{env}°C Tree		<1.10^{-4}	0.3	0.6	<1.10^{-4}	0.001	0.3	0.6	7.10^{-4}	0.02	0.3	0.5	<1.10^{-4}	-0.02	0.2	0.5	0.005	**0.05**	**0.01 ** **	**0.05 * **	**<1.10^{-4}**
$Q_{0.95}$ T_{env}°C Tree		-0.02	0.2	0.6	5.10^{-4}	-0.003	0.3	0.6	0.007	0.007	0.3	0.5	2.10-4	-0.3	0.02 *	0.2	0.08	**0.05**	**1.10^{-3} *** **	**8.10^{-3} ** **	**1.10^{-4}**
E(|ΔT_{env}°C|) Tree		-0.05	0.3	0.6	2.10^{-3}	0.002	0.5	0.6	-0.007	0.03	0.3	0.5	0.004	**-0.4**	**0.001 *** **	**0.02 * **	**0.2**	0.01	0.05 *	0.2	<1.10^{-4}
Var T_{env}°C Tree		-0.001	0.5	0.6	<1.10^{-4}	0.05	0.7	0.7	-0.02	-0.02	0.2	0.5	<1.10^{-4}	-0.004	0.4	0.6	-0.001	4.10-3	0.3	0.3	<1.10^{-4}
Var_3 T_{env}°C Tree		-0.002	0.5	0.6	<1.10^{-4}	-0.2	0.03 *	0.2	0.1	0.09	0.06 .	0.5	0.003	-0.004	0.4	0.6	-0.001	4.10-3	0.1 .	0.2	<1.10^{-4}
Var_4 T_{env}°C Tree		-0.008	0.8	0.9	<1.10^{-4}	0.02	0.6	0.7	-0.01	-0.004	0.1 .	0.5	0.001	-0.006	0.8	0.9	-0.002	5.10-3	0.1 .	0.2	<1.10^{-4}
−2h Var T_{env}°C		0.003	0.2	0.6	1.10^{-4}	-0.05	0.6	0.6	-0.01	-0.07	0.06 .	0.5	-0.001	9.10^{-4}	0.4	0.6	<1.10^{-4}	2.10-3	0.3	0.3	<1.10^{-4}
−2h Var_3 T_{env}°C		-0.04	0.6	0.7	2.10^{-3}	0.02	0.5	0.6	-0.003	0.001	0.3	0.5	-0.01	0.007	0.2	0.5	-0.001	3.10-3	0.2	0.2	<1.10^{-4}
−2h Var_4 T_{env}°C		0.008	0.5	0.6	6.10^{-4}	-0.02	0.5	0.6	-0.006	-0.1	0.04 *	0.5	0.1	<1.10^{-4}	0.5	0.6	<1.10^{-4}	8.10-4	0.3	0.3	<1.10^{-4}
−24h Var T_{env}°C		<1.10^{-4}	0.7	0.8	<1.10^{-4}	-0.008	0.5	0.6	-0.007	0.04	0.2	0.5	-0.01	0.009	0.2	0.5	<1.10^{-4}	3.10-3	0.1 .	0.2	<1.10^{-4}
−24h Var_3 T_{env}°C		0.01	0.9	0.9	6.10^{-4}	7.10-4	0.3	0.6	0.001	-0.05	0.6	0.7	0.01	0.03	0.3	0.5	<1.10^{-4}	2.10-3	0.1 .	0.2	<1.10^{-4}
−24h Var_4 T_{env}°C		<1.10^{-4}	0.4	0.6	<1.10^{-4}	0.009	0.5	0.6	-0.008	0.02	0.8	0.8	-0.006	0.005	0.8	0.9	-0.001	2.10-3	0.2	0.3	<1.10^{-4}
−2h Mean T_{env}°C		0.006	0.3	0.6	3.10^{-4}	-0.005	0.4	0.6	-0.003	-0.02	0.3	0.5	0.003	-0.01	0.8	0.9	0.007	6.10-3	0.1 .	0.2	<1.10^{-4}
−24h Mean T_{env}°C		0.006	0.7	0.8	5.10^{-4}	0.08	0.03 *	0.2	0.09	0.1	0.8	0.8	0.02	<1.10^{-4}	0.2	0.5	-0.004	2.10-3	0.2	0.3	<1.10^{-4}
−2h $Q_{0.05}$ T_{env}°C		4.10^{-4}	0.4	0.6	<1.10^{-4}	-0.002	0.4	0.6	<1.10^{-4}	0.006	0.6	0.7	<1.10^{-4}	-0.01	0.1 .	0.5	0.005	0.02	0.04 *	0.2	<1.10^{-4}
−24h $Q_{0.05}$ T_{env}°C		0.005	0.5	0.6	<1.10^{-4}	0.003	0.6	0.6	-0.01	0.008	0.3	0.5	0.003	-0.001	0.5	0.6	-0.002	7.10-4	0.2	0.3	<1.10^{-4}
−2h $Q_{0.95}$ T_{env}°C		2.10^{-4}	0.4	0.6	<1.10^{-4}	-0.008	0.4	0.6	-0.003	-0.03	0.2	0.5	0.001	<1.10^{-4}	0.5	0.6	<1.10^{-4}	8.10-3	0.1 .	0.2	<1.10^{-4}
−24h $Q_{0.95}$ T_{env}°C		0.005	0.2	0.6	<1.10^{-4}	0.07	0.2	0.6	0.01	0.09	0.3	0.5	0.004	0.01	0.4	0.6	-0.003	<1.10-4	0.2	0.2	<1.10^{-4}
Individual ID																		7.10-3	0.3	0.3	<1.10^{-4}

Supplement material 4: PC_2 - Instant network cohesiveness

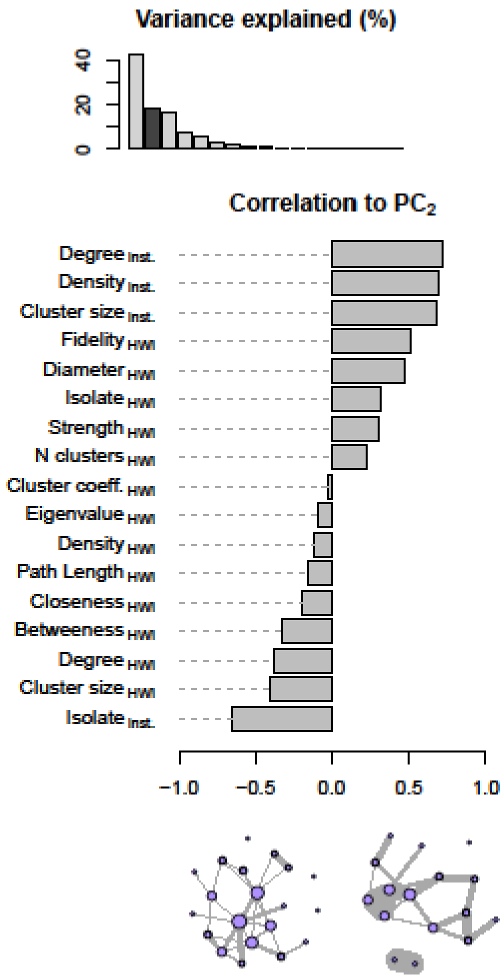


Figure A2a: Illustration of social networks characterised by PC_2; indicating instant network cohesiveness.

Upper panel: Percentage of variation in social metrics captured by the principal components (18%; PC_2 leftmost: dark grey).

Middle panel: Correlation of social metrics defined in Table 2 to PC_2.

PC_2 is mostly characterized by ‘instant networks’ with high loadings representing dense ‘instant networks’ with a low proportion of isolates (correlation of -0.65) and clusters of numerous individuals (correlations around 0.7). At high “instant cohesiveness” (i.e. high loading on PC_2) occurs either when all the individuals are feeding in the same time (high HWi and instant network cohesiveness, or when specific individuals are feeding together at different moment of the observation period so that the value of the social metric fidelity is positively correlated to PC_2 (0.52).

Lower panel: Visualisation of social network structures with low (left) versus high (right) loadings on PC_2.

Nodes (individuals) are represented by circles, edges (social associations) by straight lines. Circle size indicates the number of associations involving the individual. Edge thickness indicates the number of associations between the two connected individuals. Metrics were calculated controlling for network size; N = 84 sociable weaver networks.

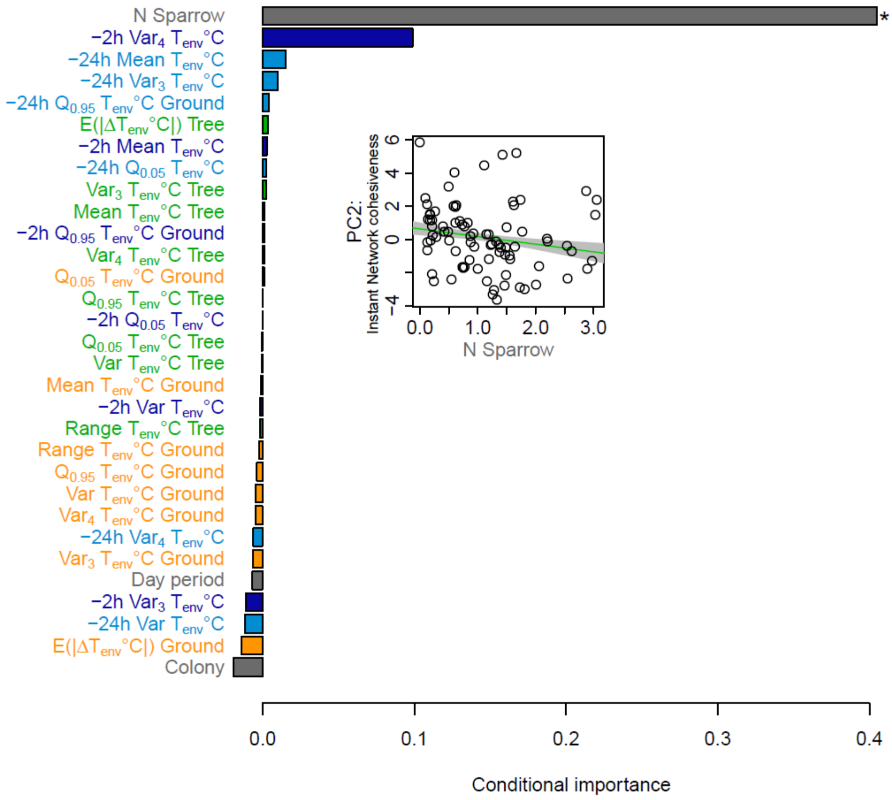


Figure A2b: Factors associated with the variation in the instant network cohesiveness (PC_2). Coloured horizontal bars (left) indicate conditional importance of predictors, including both simple and interactive effects, as estimated by a Random Forest model. Orange bars: temperatures recorded on the ground next to feeders (*T_{env} C° Ground*); green bars: temperatures in the tree hosting the colonial nest (*T_{env} C° Tree*); blue bars: mean of ground and tree temperatures recorded over the preceding 2 hours *(−2h T_{env} C°*, dark blue) or 24 hours (*−24h T_{env} C°*, light blue). Stars at the end of a bar indicate FDR adjusted statistical significance (e.g. * = $P_{ADJ} < 0.05$). Inset scatterplot: the effect of *N sparrow* on PC_2 (instant network cohesiveness), with fitted linear regression (green line) ± S.E. (grey shading).

For the 2nd PC (Instant network cohesiveness), the RF only detected an effect of the average number of sparrows observed per minutes (*N Sparrow*) which decreased the instant network cohesiveness, suggesting that the weavers are feeding together more, at the same feeders, in the absence of sparrows (P_{ADJ} = 0.03; effect size = -0.2; conditional importance = 0.4; Table A1)

Supplementary material 5: PC_3 – ‘cluster fragility’

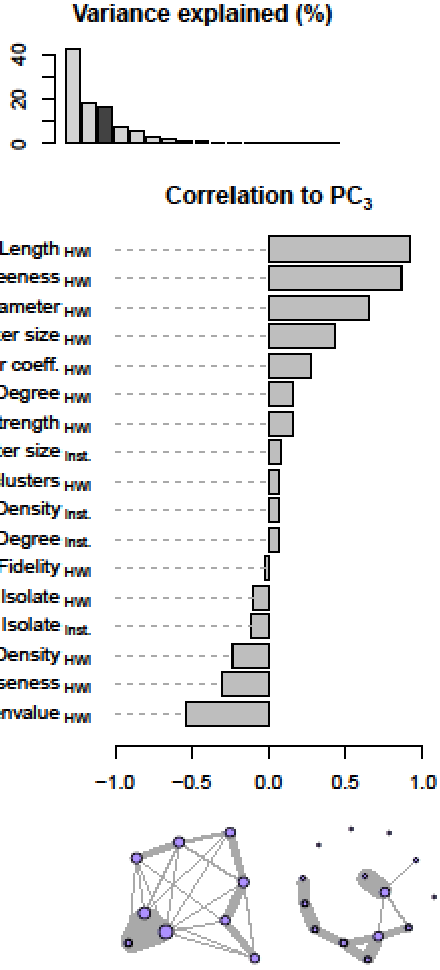


Figure A3a: Correlation of social metrics to the 3rd PC

Upper panel: Percentage of variation in social metrics captured by the principal components (16 %; PC_3 leftmost: dark grey).

Middle panel: Correlation of social metrics defined in Table 2 to PC_3. PC_3 characterises observation periods with high loadings had ‘HWi networks’ with high path length, betweenness, diameter, and low eigenvalue. Thus, this PC indicates that the cluster(s) rely mostly on weak indirect connections between individuals, making them likely to break down upon the deletion of a random link between two individuals while the cluster(s) of ‘HWi networks’ with very low loadings are unlikely to be strongly affected by such deletion.

Lower panel: Visualisation of social network structures with low (left) versus high (right) loadings on PC_3. Nodes (individuals) are represented by circles, edges (social associations) by straight lines. Circle size indicates the number of associations involving the individual. Edge thickness indicates the number of associations between the two connected individuals. Metrics were calculated controlling for network size; N = 84 sociable weaver networks.

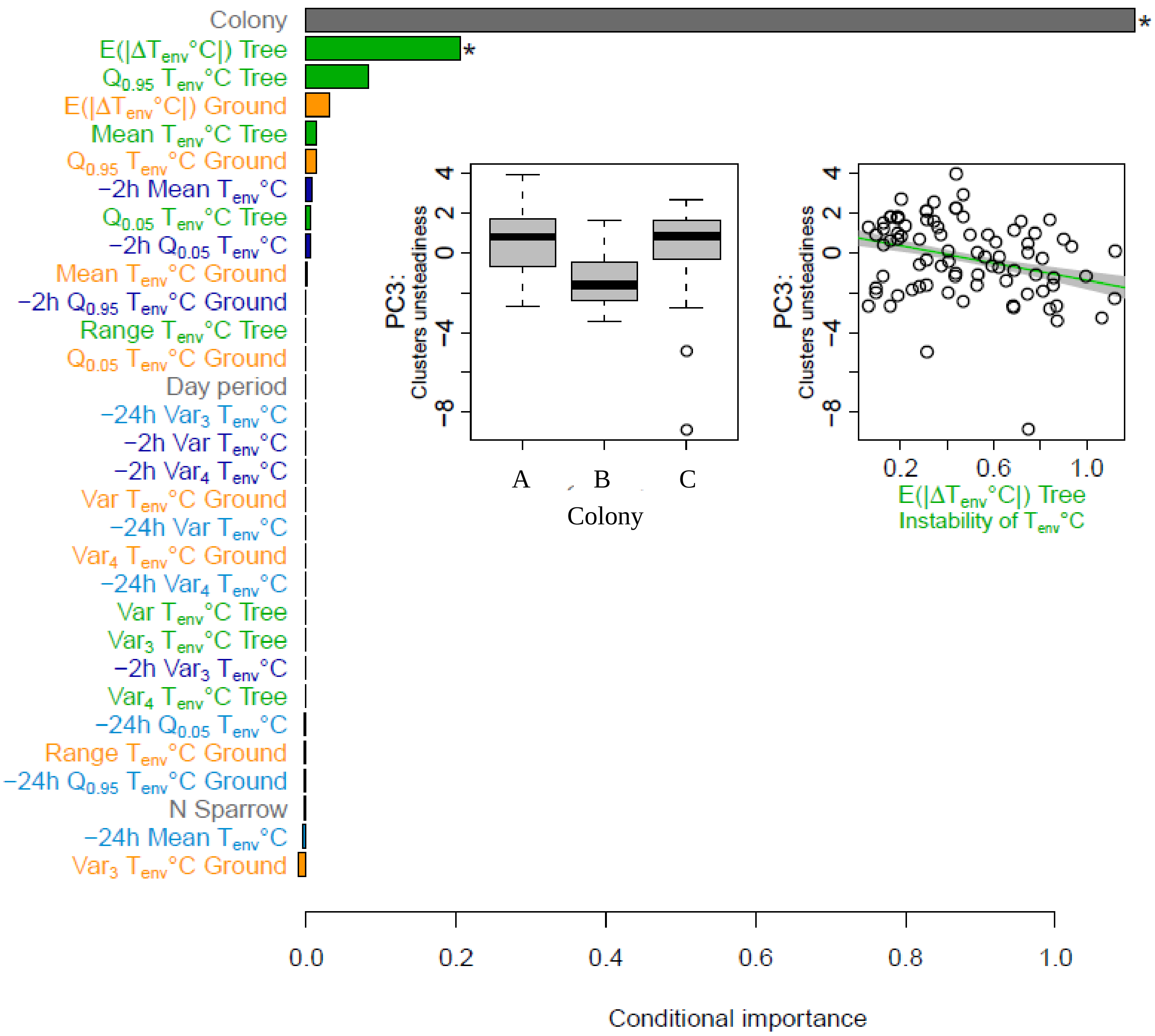


Figure A3b: Factors associated with variation in the clusters fragility (PC_3).

Coloured horizontal bars (left) indicate conditional importance of predictors, including both simple and interactive effects, as estimated by a Random Forest model. Orange bars: temperatures recorded on the ground next to feeders (*T_{env} C° Ground*); green bars: temperatures in the tree hosting the colonial nest (*T_{env} C° Tree*); blue bars: mean of ground and tree temperatures recorded over the preceding 2 hours *(−2h T_{env} C°*, dark blue) or 24 hours (*−24h T_{env} C°*, light blue). Stars at the end of a bar indicate FDR adjusted statistical significance (e.g. * = $P_{ADJ} < 0.05$). Inset scatterplot: the effect of *Colony* (colony identity) and *E(|ΔT_{env} C°|)* (temperature instability) on PC_3 (instant network cohesiveness), with fitted linear regression (green line) ± S.E. (grey shading).

For PC_3 (Clusters fragility), the RF detected a strong effect of the identity of the colony ($P_{ADJ} = 0.02$; effect sizes = 0.6, -1 and 0.6; Table A1), and a less pronounced effect of the instability of the temperatures measured in the tree hosting the colonial nest. This decreased the ‘Cluster fragility’ so that the less instable these temperatures were, the less unsteady the clusters were ($P_{ADJ} = 0.02$; effect size = -0.4; Table A1