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Wildlife Research

Supplementary Material

Ground-based counting methods underestimate true numbers of a threatened colonial mammal: an evaluation using drone-based thermal surveys as a reference

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Table S1. Flying-fox colony size estimates derived from visual point counts of thermal orthomosaics, ground counts conducted by the experimenter and National Flying-Fox Monitoring Program (NFFMP) participants, as well as median air temperature, colony area, and orthomosaic resolution for seven flying-fox roosts across the Greater Sydney region. Counts were conducted between October 2019 and August 2020. Air temperature data was downloaded from the Australian Bureau of Meteorology (Bureau of Meteorology 2020) from the nearest weather station to each colony within two days of conclusion of each drone survey.

Roost	**Geographic coordinates (°)**	**Date of thermal orthomosaic survey**	**Count from drone-acquired thermal orthomosaic**	**Ground count by experimenter**	**Ground count by NFFMP participant**	**Median air temperature (°C)**	**Colony area (m^2)**	**Orthomosaic resolution (cm^2/pixel)**
Campbelltown	-34.0658, 150.8088	14-Oct-2019	9888	3770	-	11.2	7634	3.55
		15-Nov-2019	9417	3920	5027	20.2	9386	2.21
		18-Feb-2020	5723	2850	2860	21.8	10438	2.71

		20-Jun-2020	1917	1570	1034	10.3	6339	3.17
		11-Aug-2020	1851	550	530	10.9	5164	2.38
Camellia Gardens	-34.0426, 151.1128	22-Oct-2019	1126	710	675	17.0	1451	3.55
		19-Nov-2019	1115	560	994	16.2	2296	2.2
		20-Feb-2020	2945	1840	1001	20.0	4075	4.21
Emu Plains	-33.7408, 150.6803	19-Oct-2019	12131	6420	-	21.6	10192	2.53
		24-Feb-2020	10698	5000	612	19.9	14824	4.27
Kareela	-34.0233, 151.0855	21-Oct-2019	2452	1570	900	16.6	2654	3.45
		19-Nov-2019	2396	840	1190	22.7	3927	2.01
		21-Feb-2020	6723	4450	2260	20.4	6253	5.08
		30-Jun-2020	4545	1695	5400	12.0	4476	2.16
		12-Aug-2020	3773	1830	1750	10.6	4424	2.52

Macquarie Fields	-33.9901, 150.8794	27-Feb-2020	6384	7290	7670	19.4	10983	4.66
		18-Jun-2020	2783	2920	1870	14.5	6217	2.44
Warriewood	-33.6948, 151.2950	25-Feb-2020	2566	2240	3000	22.6	12746	8.24
Yarramundi	-33.6213, 150.6924	09-Dec-2019	3358	670	-	19.8	2149	2.61
		29-Jan-2020	2240	820	-	22.7	1268	3.07
		05-Feb-2020	2003	1050	-	21.4	1640	2.54
		23-Feb-2020	5321	2230	-	20.4	6133	7.36
		06-Mar-2020	1347	1350	-	22.5	6183	9.68
		13-Mar-2020	2638	1230	-	17.5	2065	4.74
		20-Mar-2020	1381	930	-	22.7	2489	10.8

Table S2. Parameters used to generate thermal orthomosaics in Agisoft Metashape Professional Version 1.5 (LLC Agisoft 2019).

Alignment parameters	
Accuracy	High
Generic preselection	Yes
Reference preselection	Yes
Key point limit	40000
Tie point limit	4000
Adaptive camera model fitting	Yes
Mesh	
Source data	Depth maps
Quality	High
Face count	High
Calculate vertex colors	Yes
Orthomosaic	
Projection	Geographic (WGS 84)
Surface	Mesh
Blending mode	Mosaic
Enable hole filling	Yes

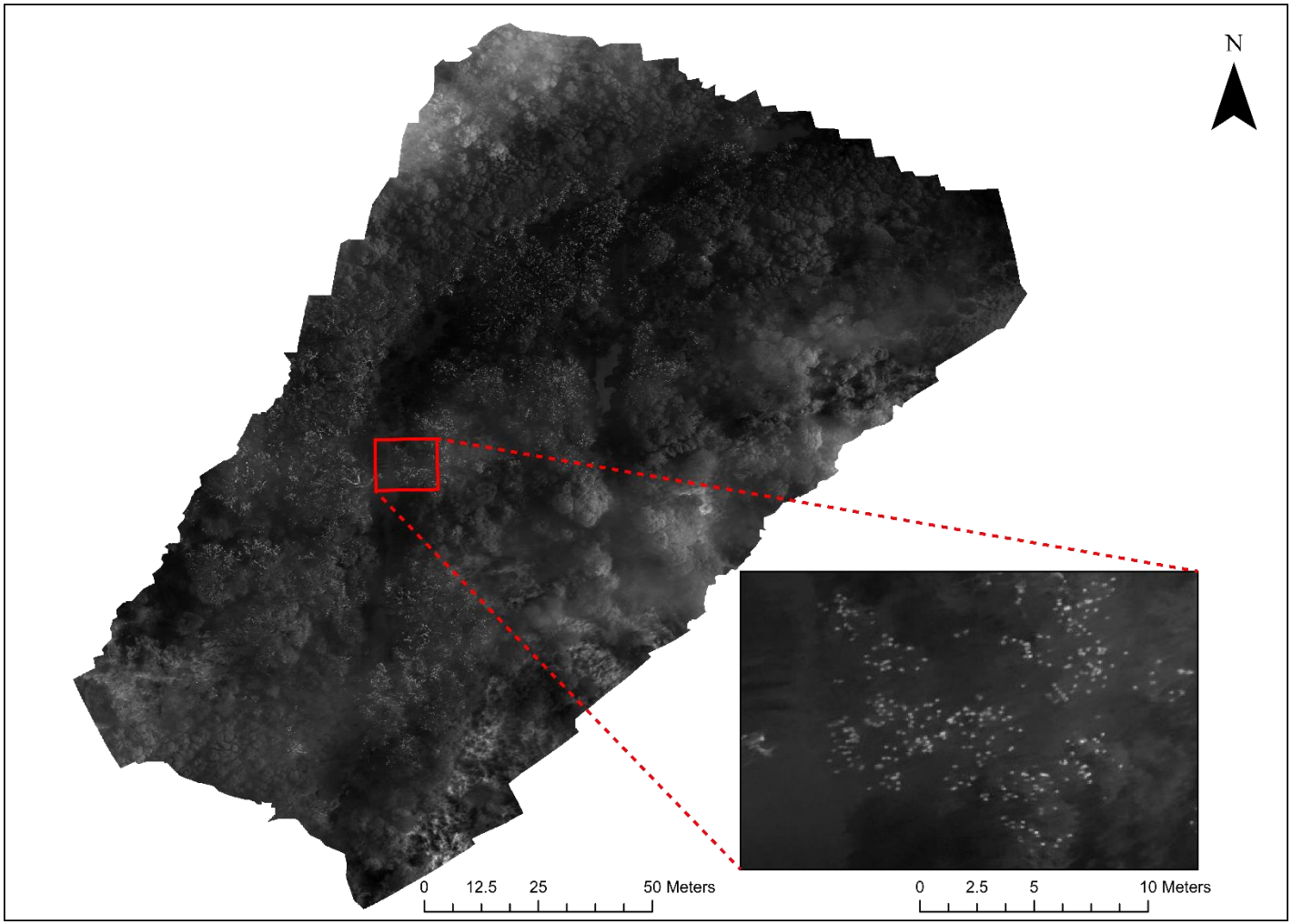

Figure S1. Thermal orthomosaic from the Campbelltown roost on the 14th of October 2019. The image in the corner right of the figure shows a zoomed-in view of the colony, where individual flying-foxes are discernible.

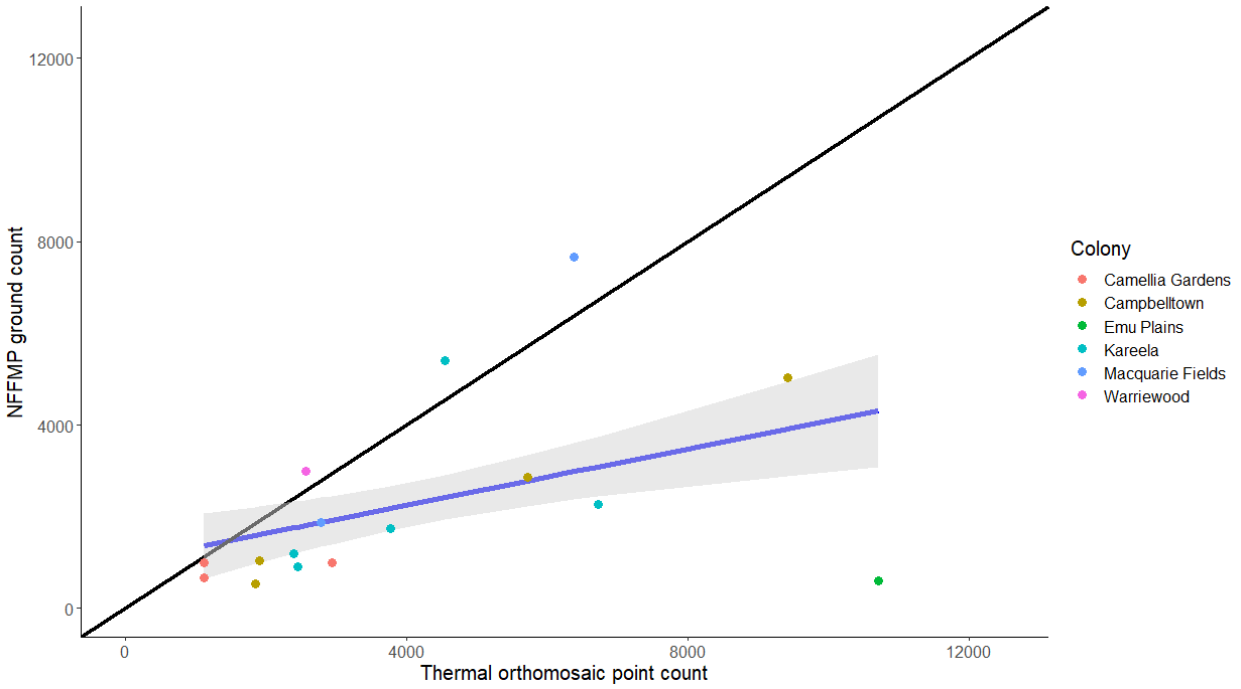

Figure S2. Across 6 colonies, ground counts of grey-headed flying-foxes by NFFMP counters were not correlated with counts from drone-acquired thermal orthomosaics when the Emu Plains outlier was retained (($F_{1,9}$ = 3.20, P = 0.073, marginal R^2 = 0.18, n = 16). Grey shaded area indicates standard error. Blue lines show fits from linear models. Black lines are lines of equality.

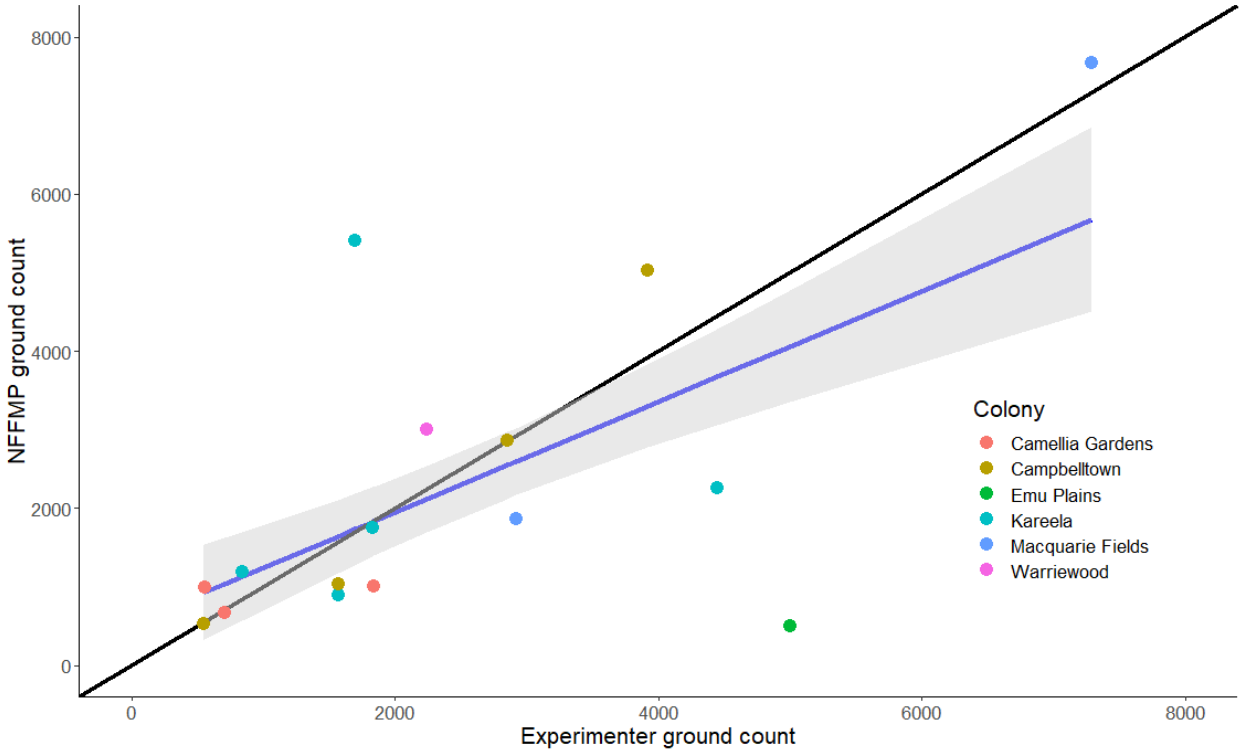

Figure S3. Across 6 colonies, ground counts of grey-headed flying-foxes conducted by the experimenter and counts from NFFMP counters were positively correlated (GLMM: $F_{1,9}$ = 9.46, P = 0.004, marginal R^2 = 0.39, n = 16). Grey shaded area indicates standard error. Blue lines show fits from linear models. Black lines are lines of equality.

Item S1

Calculation for predicting true colony abundance from ground count:

GLMM 1: lme(experimenter ground count ~ orthomosaic point count, random= ~1 | colony, data = experimenter_vs_orthomosaic_point_count)

y = 0.07304[a] + **x**(0.80769[b] x ([0 - 4268.84[c]]/[2x3225.89[d]]))

when **y** = 467,000[e]

x = (467,000 - 0.07304)/(0.80769 x ([0 - 4268.84]/[2x3225.89]))

= 873,860

a) Intercept of the model

b) Estimate of 'orthomosaic point count' variable

c) Mean of all orthomosaic point count values

d) Standard deviation of orthomosaic point count values

e) November 2019 estimate of the Australia's total grey-headed flying-fox population (Commonwealth Scientific and Industrial Research Organisation 2019)

*Underlined calculation is required to unstandardize the estimate which was standardized using the standardize function within the *arm* package (Gelman et al 2009).

Lower CI - derived from confint(model) function in *stats* package (R Core Team 2018):

y = 0.07304[a] + **x**(0.5854782[b] x ([0 - 4268.84[c]]/[2x3225.89[d]]))

when **y** = 467,000[e]

x = (467,000 - 0.07304)/(0.5854782 x ([0 - 4268.84]/[2x3225.89]))

= 1,205,524

Upper CI:

$\mathbf{y} = 0.07304^{a} + \mathbf{x}(1.0306597^{b} \times \underline{([0 - 4268.84^{c}]/[2x3225.89^{d}]))}$

when $\mathbf{y} = 467{,}000^{e}$

$\mathbf{x}$ = (467,000 - 0.07304)/(1.0306597 x ([0 - 4268.84]/[2x3225.89]))

= 684,812

GLMM 2: lme(NFFMP ground count ~ orthomosaic point count, random= ~1 | colony, data = NFFMP_vs_orthomosaic_point_count)

$\mathbf{y} = 0.0105^{a} + \mathbf{x}(0.7259^{b} \times \underline{([0 - 4268.84^{c}]/[2x3225.89^{d}]))}$

when $\mathbf{y} = 467{,}000^{e}$

$\mathbf{x}$ = (467,000 - 0.0105)/(0.7259 x ([0 - 4268.84]/[2x3225.89]))

= 972,321

a) Intercept of the model

b) Estimate of ‘orthomosaic point count’ variable

c) Mean of all orthomosaic point count values

d) Standard deviation of orthomosaic point count values

e) November 2019 estimate of the Australia’s total grey-headed flying-fox population (Commonwealth Scientific and Industrial Research Organisation 2019)

*Underlined calculation is required to unstandardize the estimate which was standardized using the standardize function within the *arm* package (Gelman et al 2009).

Lower CI:

$\mathbf{y} = 0.0105^{a} + \mathbf{x}(0.3507560^{b} \times ([0 - 4268.84^{c}]/[2x3225.89^{d}]))$

when $\mathbf{y} = 467{,}000^{e}$

$\mathbf{x} = (467{,}000 - 0.0105)/(0.3507560 \times ([0 - 4268.84]/[2x3225.89]))$

$= 2{,}012{,}248$

Upper CI:

$\mathbf{y} = 0.0105^{a} + \mathbf{x}(1.0965114^{b} \times ([0 - 4268.84^{c}]/[2x3225.89^{d}]))$

when $\mathbf{y} = 467{,}000^{e}$

$\mathbf{x} = (467{,}000 - 0.0105)/(1.0965114 \times ([0 - 4268.84]/[2x3225.89]))$

$= 643{,}685$

Literature cited

Bureau of Meteorology. (2020). *Latest Weather Observations for the Sydney Area*. Available at http://www.bom.gov.au/nsw/observations/sydney.shtml?ref=hdr [Accessed 10 Oct 2020].

Commonwealth Scientific and Industrial Research Organisation (CSIRO). (2019). *The National Flying-fox Monitoring Program - Report on the November 2019 survey*. Available at https://www.environment.gov.au/system/files/pages/391f5fed-e287-4dd3-85ac-640037926ef5/files/flying-fox-nov2019-count-report.pdf [Accessed 5 Jun 2020].

LLC Agisoft (2019) 'Agisoft Metashape User Manual: Professional Edition, Version 1.5.' (St. Petersburg, Russia).