

Appendix

Methods

Swift movements across geographic positions were categorised as migration (corridor movements) and stationary (area-restricted search) using a two-state Hidden Markov Model (McClintock & Michelot 2018, HMM), with missing positions filled using continuous-time correlated random walk data (Johnson *et al.* 2008) to create a homogeneous six-hour time series. Step distances (i.e. Euclidean distances between subsequent GPS positions) were modelled using a gamma distribution, while turning angle distributions followed a von Mises distribution (initial parameters; gamma distributions: $\mu_f = 50$ km, $\sigma_f = 10$ km; $\mu_m = 80$ km, $\sigma_m = 10$ km; von Mises distributions: $\mu_f = 0$, $\kappa_f = 1$; $\mu_m = 0$, $\kappa_m = 2$, migration and stationary foraging denoted with subscripts m and f, respectively). State classes (i.e. migration, stationary) were returned using global encoding with the Viterbi algorithm (Zucchini *et al.* 2016, McClintock & Michelot 2018).

MDL atmospheric pressure recorded was converted to altitude (z) using the international standard atmosphere which is defined as:

$$z = \frac{T_0}{L} \left(\left(\frac{P_0}{P} \right)^{\frac{LR_0}{g}} - 1 \right) \quad \text{Eq. 1}$$

With T_0 the temperature at sea level (288.15 K), L the temperature lapse rate (-0.0065° K m⁻¹), P_0 the standard atmospheric pressure at sea level (1013.25 hPa), P the measured air pressure (hPa), g the gravitational acceleration (9.81 m s⁻¹) and R_0 the universal gas constant (287.053 J kg⁻¹ K⁻¹). The Migrate Technology Intigeo-CAR and Swiss Ornithological

Institute GDL accelerometer read bursts of 32 x-axis (pitch, zero is horizontal) and 32 z-axis samples at 50 Hz. The sampling bursts are set so that wing beat frequency from 1.6 Hz to 25 Hz should be validly recorded to avoid aliasing. Activity values reported are the sum of consecutive differences recorded (up down movements) or peak g-forces applied over the set measurement time interval (either 30 or 5 min, for Migrate Technology Intigeo-CAR or Swiss Ornithological Institute GDL sensors respectively).

Additional summary statistics to those described in the main manuscript are provided. We report mean average flight altitude and height, activity with their uncertainty (on standard deviation). Furthermore, we tabulate current and/or long term swift recapture rates and visualisation of the raw data as actograms.

Tables

Table S1. Overview table of the Multisensor Data Logger (MDL) meta-data. For each species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) and site we report the logger tag number, the sun angle used in geolocation calculations, the start and end date defining the maximum available data for the non-breeding foraging season, and the variables logged. Variables logged are denoted with T, Pr, Act, P, Alt for temperature, Pressure, Activity, Pitch and Altitude, respectively. All Multi Data Loggers (MDLs) register light levels, while all GPS units register altitude in addition to position.

Species	Site	Tag	Season	Sun angle	Start date	End date	variables
Common swift	Gent Voorhaven	CC874	2021	-6	2021-08-16	2021-12-19	T, Pr
		CC875	2021	-5	2021-08-15	2022-05-06	T, Pr
		CC876	2021	-5	2021-08-15	2022-04-29	T, Pr
		CC877	2021	-7	2021-08-15	2022-04-29	T, Pr
		CC893	2021	-7	2021-08-15	2022-05-05	T, Pr, Act, P
		CC895	2021	-5	2021-10-01	2022-04-28	T, Pr, Act, P
		CC896	2021	-7	2021-09-25	2022-04-28	T, Pr, Act, P
Pallid swift	Arrabida	CC883	2021	-5.5	2021-09-18	2022-03-09	T, Pr
		CC902	2021	-7.5	2021-09-15	2022-03-11	T, Pr, Act, P
		CC904	2021	-7	2021-09-27	2022-05-16	T, Pr, Act, P
		CC886	2021	-6.5	2021-11-01	2022-04-09	T, Pr
	Famalicão	CC906	2021	-4.5	2021-10-10	2022-04-14	T, Pr, Act, P
Alpine swift	Baden	CC907	2021	-6.5	2021-10-15	2022-04-09	T, Pr, Act, P
		CC899	2021	-7.5	2021-11-03	2022-03-23	T, Pr, Act, P
		24SW	2019	-6.5	2019-10-01	2020-03-15	T, Pr, Act, P
		24MP	2019	-6.5	2019-10-01	2020-03-15	T, Pr, Act, P
		24SK	2019	-7	2019-10-01	2020-03-15	T, Pr, Act, P
		24SI	2019	-7	2019-10-01	2020-03-15	T, Pr, Act, P
	22MA	2018	-7	2018-10-01	2019-03-15	T, Pr, Act, P	
	22LK	2018	-7.5	2018-10-01	2019-03-15	T, Pr, Act, P	
	Pirasali	22LE	2018	-7	2018-10-01	2019-03-15	T, Pr, Act, P
		22LA	2018	-7	2018-10-01	2019-03-15	T, Pr, Act, P
		22ME	2018	-6.5	2018-10-01	2019-03-15	T, Pr, Act, P

Table S2. Overview table of GPS meta-data. For each species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) and site we report the logger tag number, the start and end date defining the maximum available data for the non-breeding foraging season, and the variables logged. All GPS units register altitude in addition to position.

Species	Site	Tag	Season	Start date	End date	variables
Common swift	Gent Voorhaven	Tag21900	2020	2020-08-26	2020-12-06	Alt
		Tag57085	2021	2021-08-20	2022-05-05	Alt
Pallid swift	Arrabida	Tag21417a	2019	2019-08-26	2020-03-24	Alt
		Tag21453	2019	2019-08-28	2020-04-14	Alt
		Tag21482	2019	2019-08-23	2020-05-07	Alt
	Famalicão	Tag21472	2019	2019-08-27	2020-04-28	Alt
		Tag21460	2019	2019-08-27	2020-04-11	Alt
Alpine swift		Tag21417b	2020	2020-09-12	2021-04-03	Alt
	Gent Vorhaven	Tag56597	2021	2021-09-19	2022-03-03	Alt
		Tag57069	2021	2021-09-23	2022-04-04	Alt

Table S3. Overview table of the GPS meta-data. For each species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) and site we report the deployment site, logger tag number, the moon phase and the mean night-time flight height. All GPS units register position and altitude.

Species	Site	Moon phase	Continental flight height (mean ± sd)	Coastal flight height (mean ± sd)	Surface elevation (mean ± sd)	N (continental / coastal)
Common swift	Gent Voorhaven	New	276 ± 244	/	521 ± 250	97 / 0
		First Quarter	370 ± 404	350 ± 66	527 ± 330	110 / 2
		Full	921 ± 684	270 ± 267	514 ± 381	113 / 12
		Last Quarter	518 ± 555	/	529 ± 352	107 / 0
Pallid swift	Arrabida	New	564 ± 481	452 ± 491	277 ± 136	281 / 121
		First Quarter	713 ± 556	549 ± 574	274 ± 151	264 / 151
		Full	1075 ± 516	841 ± 739	267 ± 141	278 / 126
		Last Quarter	701 ± 492	530 ± 535	278 ± 138	246 / 120
	Famalicão	New	444 ± 288	767 ± 521	263 ± 183	83 / 2
		First Quarter	591 ± 285	592 ± 479	260 ± 194	61 / 13
		Full	1075 ± 391	1007 ± 1240	277 ± 194	70 / 14
		Last Quarter	617 ± 482	903 ± 749	270 ± 190	84 / 3

Table S4. Overview table of the Multisensor Data Logger (MDL) meta-data. For each species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) and site we report the deployment site, logger tag number, the moon phase and the mean night-time flight altitude, flight height and activity level.

Species	Site	Moon phase	Altitude (mean ± sd)	Activity (mean ± sd)	Flight Height (mean ± sd)	N
Common swift	Gent Voorhaven	New	978 ± 434	974 ± 656	332 ± 327	6798
		First Quarter	1201 ± 733	953 ± 669	615 ± 699	7244
		Full	1810 ± 954	1097 ± 643	1226 ± 909	7689
		Last Quarter	1231 ± 714	1001 ± 647	649 ± 676	7374
Pallid swift	Arrabida	New	746 ± 397	972 ± 663	401 ± 332	1630
		First Quarter	804 ± 492	910 ± 675	421 ± 424	1683
		Full	948 ± 563	1040 ± 671	606 ± 462	1878
		Last Quarter	919 ± 466	1086 ± 636	523 ± 407	1762
Alpine swift	Famalicão	New	640 ± 360	800 ± 652	298 ± 311	4190
		First Quarter	761 ± 481	819 ± 658	393 ± 421	4657
		Full	974 ± 593	938 ± 650	634 ± 502	4562
		Last Quarter	791 ± 477	906 ± 656	432 ± 421	4038
Alpine swift	Baden	New	861 ± 282	30 ± 37	196 ± 183	3843
		First Quarter	827 ± 294	28 ± 39	187 ± 168	4144
		Full	928 ± 315	38 ± 48	253 ± 209	3828
		Last Quarter	903 ± 299	26 ± 37	219 ± 201	3542
Alpine swift	Pirasali	New	1303 ± 366	31 ± 40	331 ± 264	3739
		First Quarter	1261 ± 375	33 ± 42	342 ± 303	3893
		Full	1382 ± 402	42 ± 47	406 ± 334	3343
		Last Quarter	1300 ± 371	42 ± 48	319 ± 281	3533

Table S5. Overview of GPS and MDL logger recapture rates as compared to seasonal or historical long term values by Costa & Elias (1998, *). For each sensor type, species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) and site we report the number of deployed and recaptured swifts in addition recapture rate (%), control group recapture rate (%) and average recapture rates (%). Note that for Gent Voorhaven only two GPS tracks covered the fixed sampling scheme required for this study.

Sensor	Site	species	# deployed	# recaptured	% recaptured	Control group recaptures (%, reference year)	% recapture (by species)
GPS	Gent Voorhaven	Common swift	7	4	57	47 (2021)	57
	Arrabida	Pallid swift	6	5	83	65*	66.5
	Famalicão	Pallid swift	6	3	50	52 (2021)	
MDL	Gent Voorhaven	Common swift	9	7	78	47 (2021)	78
	Arrabida	Pallid swift	5	2	40	65*	45
	Famalicão	Pallid swift	10	5	50	52 (2021)	
	Baden	Alpine swift	8	4	50	86 (2019)	46
	Pirasali	Alpine swift	26	11	42	37 (2018)	

Table S6. Model output of quantifying activity in relation to species and time-of-day (TOD, night / day). The tag is nested within species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) as a random intercept to account for species and bird specific behaviour. Reporting fixed effects only relative to the Common swift.

Fixed effects predictor	Estimate	SE	t-value	p-value
<i>Intercept</i>	694	183	3.78	0.999
<i>Species: Pallid swift</i>	-140	259	-0.542	0.999
<i>Species: Alpine swift</i>	-648	259	-2.5	0.999
<i>TOD</i>	312	9.22	33.8	<.0001
<i>Species: Pallid swift:TOD</i>	26.2	12.2	2.15	<.0001
<i>Species: Alpine swift:TOD</i>	-324	11.1	-29.1	<.0001

Table S7. Pearson's correlation coefficient (ρ) between altitude and activity by species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) during night-time.

Species	ρ
Common swift	0.15
Pallid swift	0.14
Alpine swift	-0.09

Figures

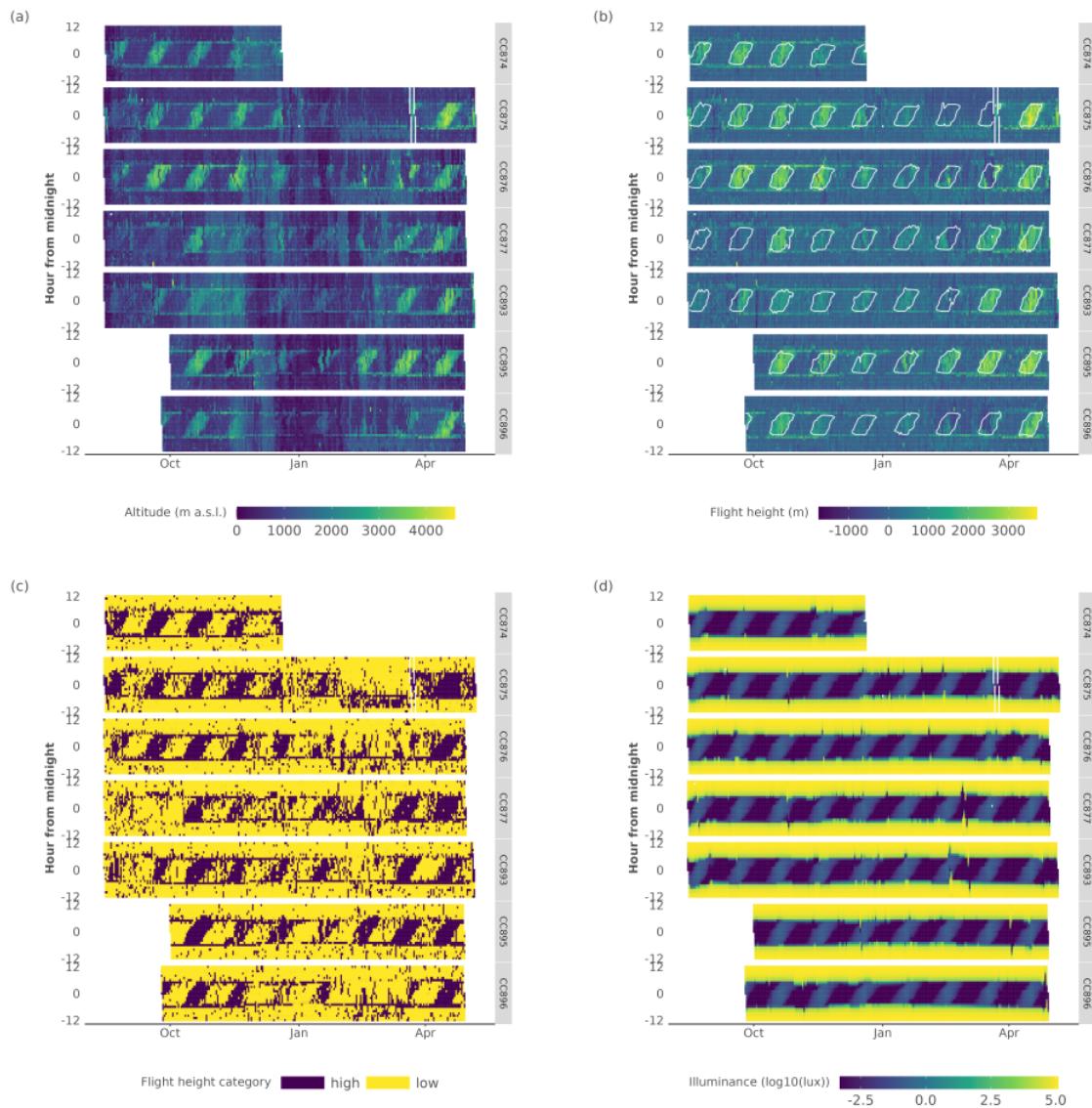


Figure S1. Overview plots (actograms) of the Common swift (*Apus apus*) Multisensor Data Logger (MDL) data for flight altitudes (a), normalised flight heights (b) and the derived binary flight height classes (c). In addition, we provide the (log10) total illuminance for a given day (d). Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel (b). Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel (b).

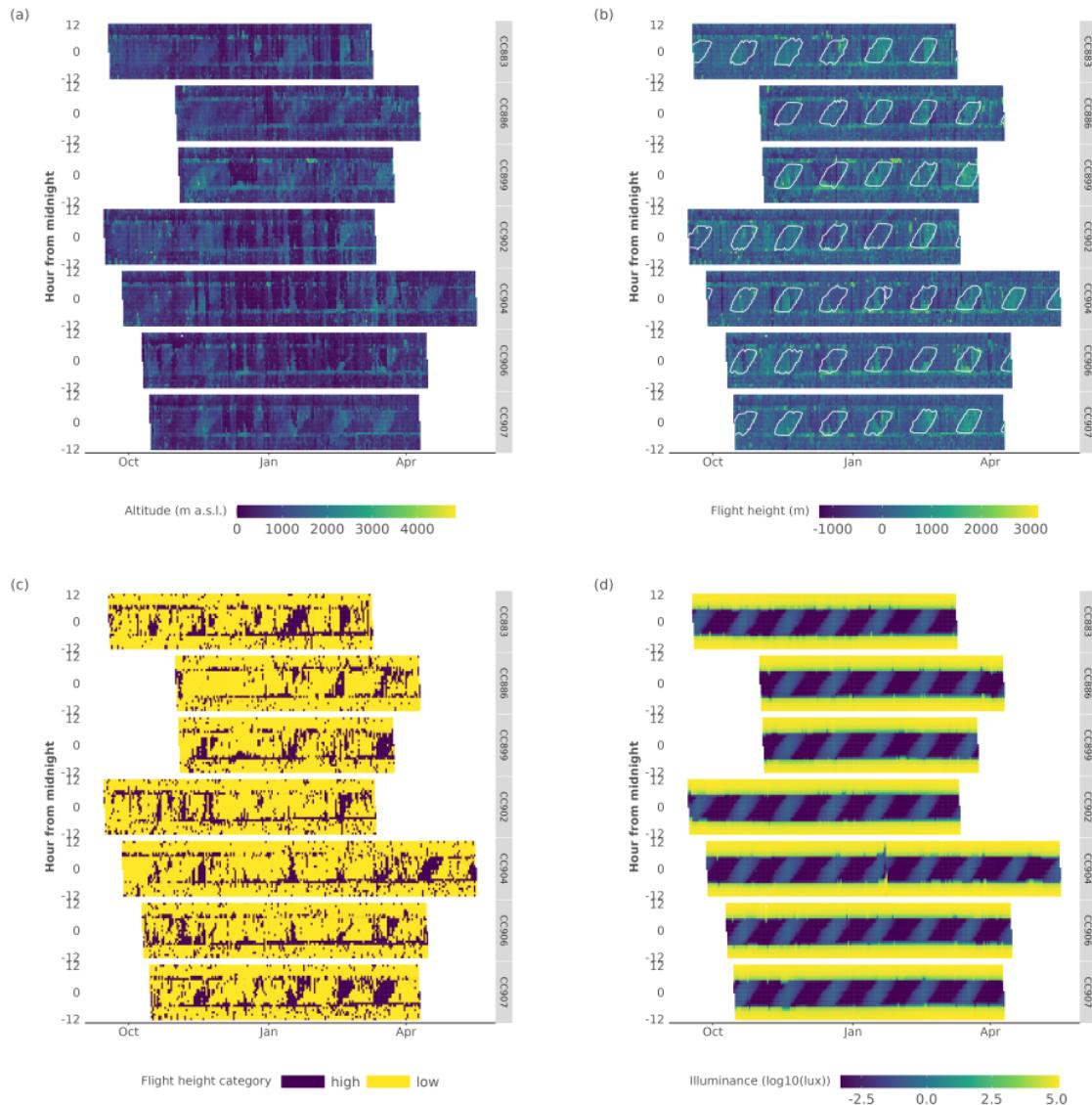


Figure S2. Overview plots (actograms) of Pallid swift (*Apus pallidus*) Multisensor Data Logger (MDL) data for flight altitudes (a), normalised flight heights (b) and the derived binary flight height classes (c). In addition, we provide the (\log_{10}) total illuminance for a given day (d). Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel (b).

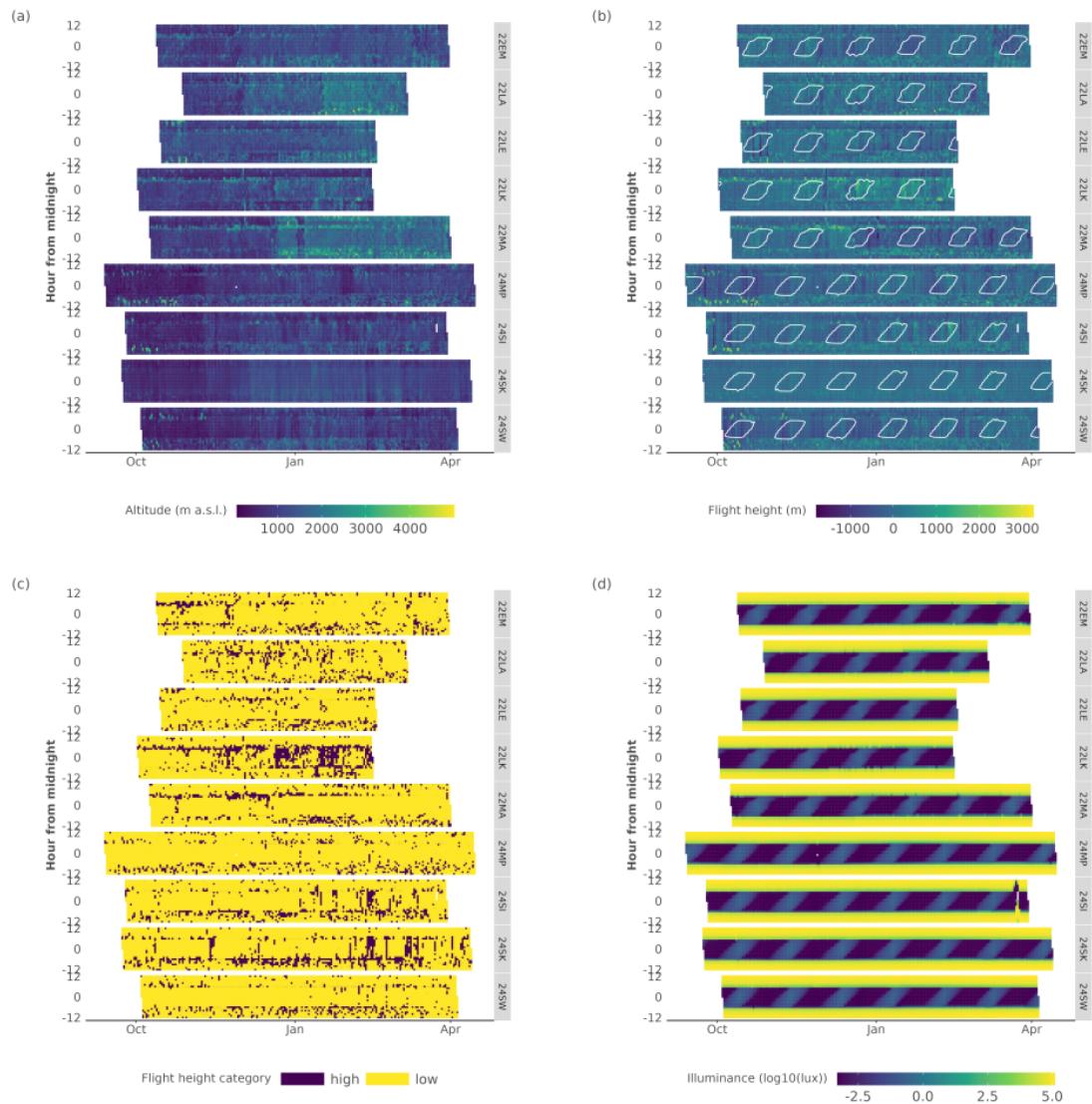


Figure S3. Overview plots (actograms) of Alpine swift (*Tachymarptis melba*) Multisensor Data Logger (MDL) data for flight altitudes (a), normalised flight heights (b) and the derived binary flight height classes (c). In addition, we provide the (\log_{10}) total illuminance for a given day (d). Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel (b).

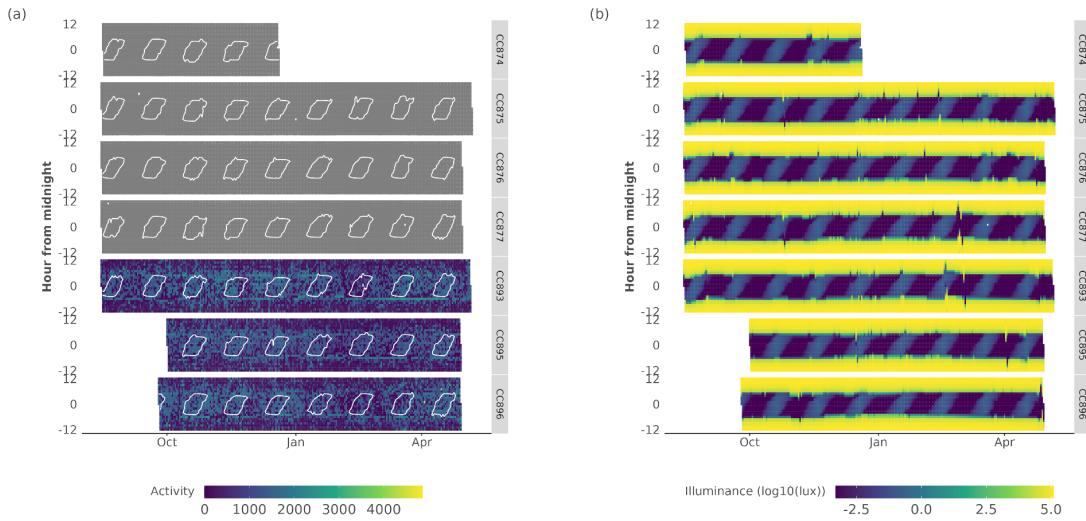


Figure S4. Overview plots (actograms) of the Common swift (*Apus apus*) Multisensor Data Logger (MDL) data for flight activity (grey values are missing data) **(a)**. In addition, we provide the (\log_{10}) total illuminance for a given day **(b)**. Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel **(a)**. Missing values are shown as grey.

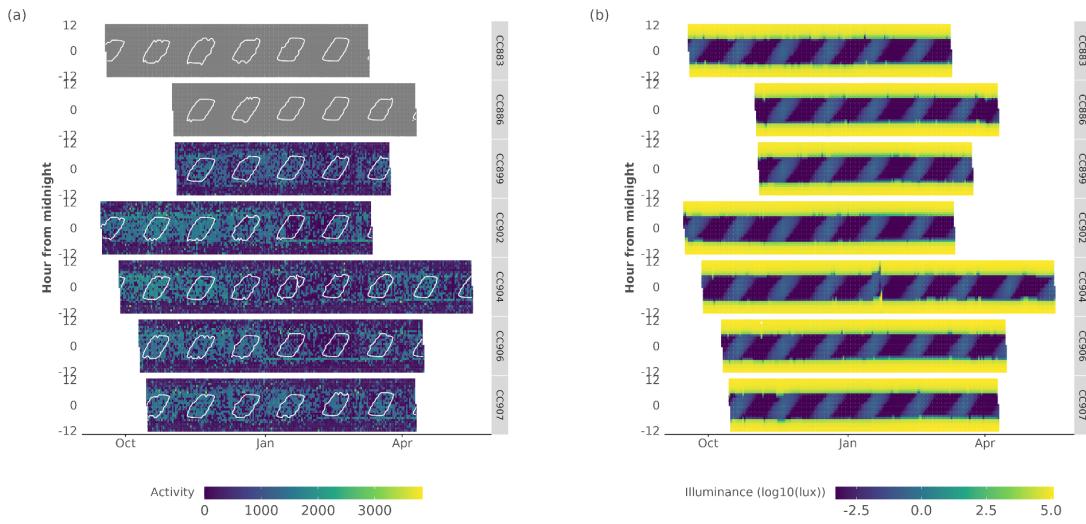


Figure S5. Overview plots (actograms) of the Pallid swift (*Apus pallidus*) Multisensor Data Logger (MDL) data for flight activity (grey values are missing data) **(a)**. In addition, we provide the (\log_{10}) total illuminance for a given day **(b)**. Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel **(a)**. Missing values are shown as grey.

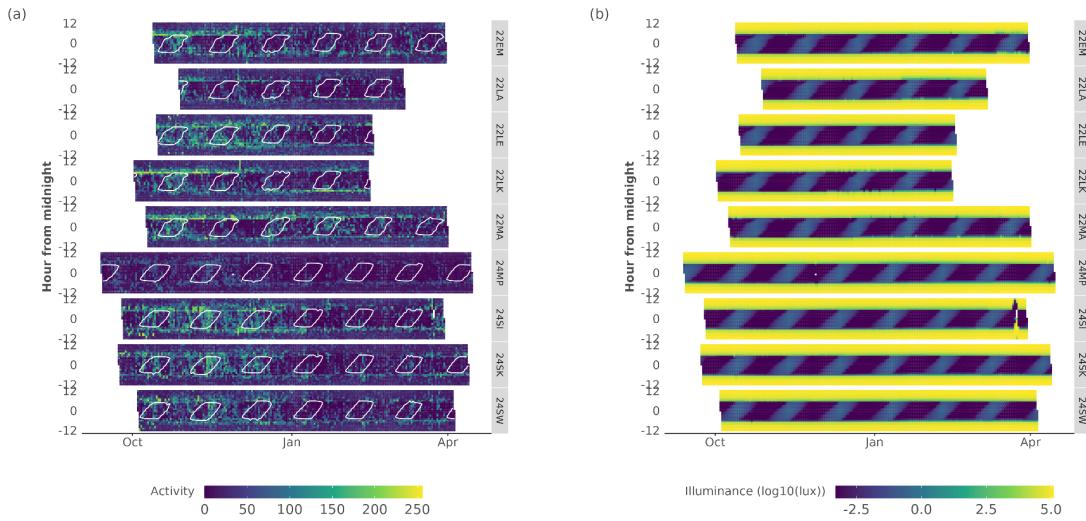


Figure S6. Overview plots (actograms) of the Alpine swift (*Tachymarptis melba*) Multisensor Data Logger (MDL) data for flight activity (grey values are missing data) **(a)**. In addition, we provide the (log10) total illuminance for a given day **(b)**. Data is shown for all MDL tags, with time centred on local midnight. Moon illuminance values outlining all values larger than 0.01 are contoured in panel **(a)**. Missing values are shown as grey.

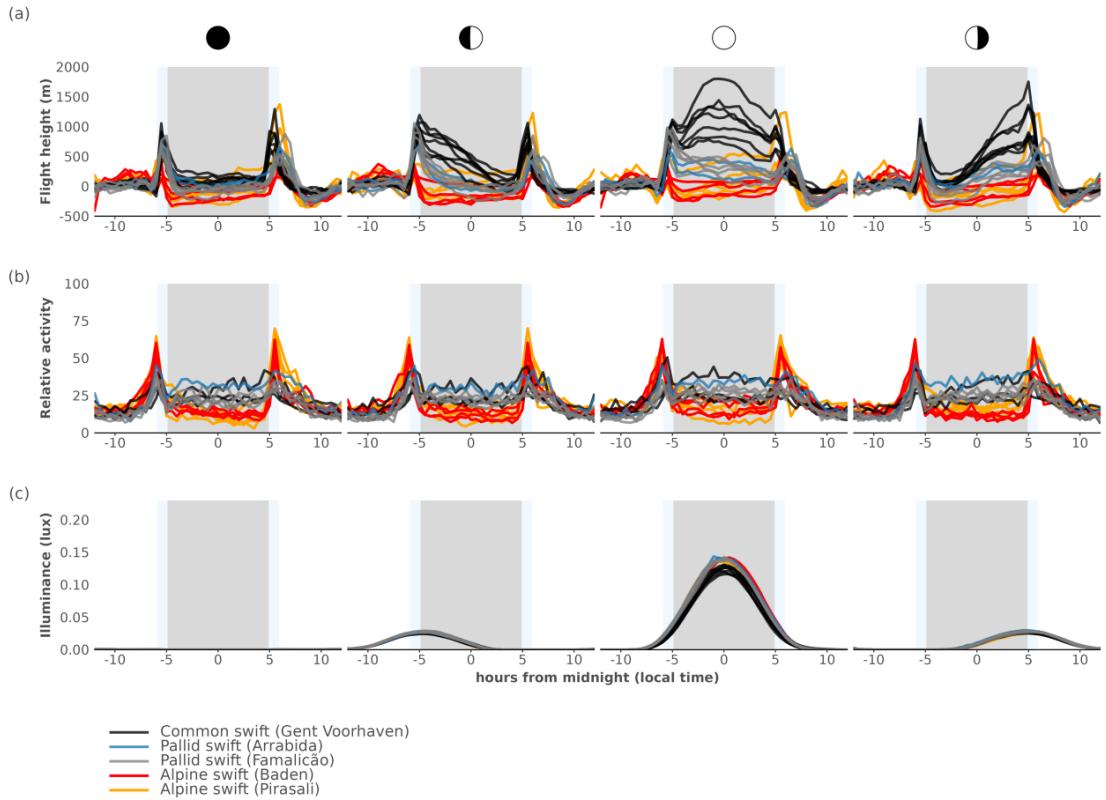


Figure S7. Average flight height (flight height in m, centred on a daytime mean of 0), the relative flight activity and derived moon illuminance (lux) centred on midnight during moon phases (**a - c**) for individually tagged birds. Different sites and species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) are indicated by the colour of the full lines, different lines represent different tags. The grey rectangle in plots (**a - c**) indicate the average astronomical night, where light blue rectangles approximate twilight as mean dusk and dawn ± 1 sd, respectively.

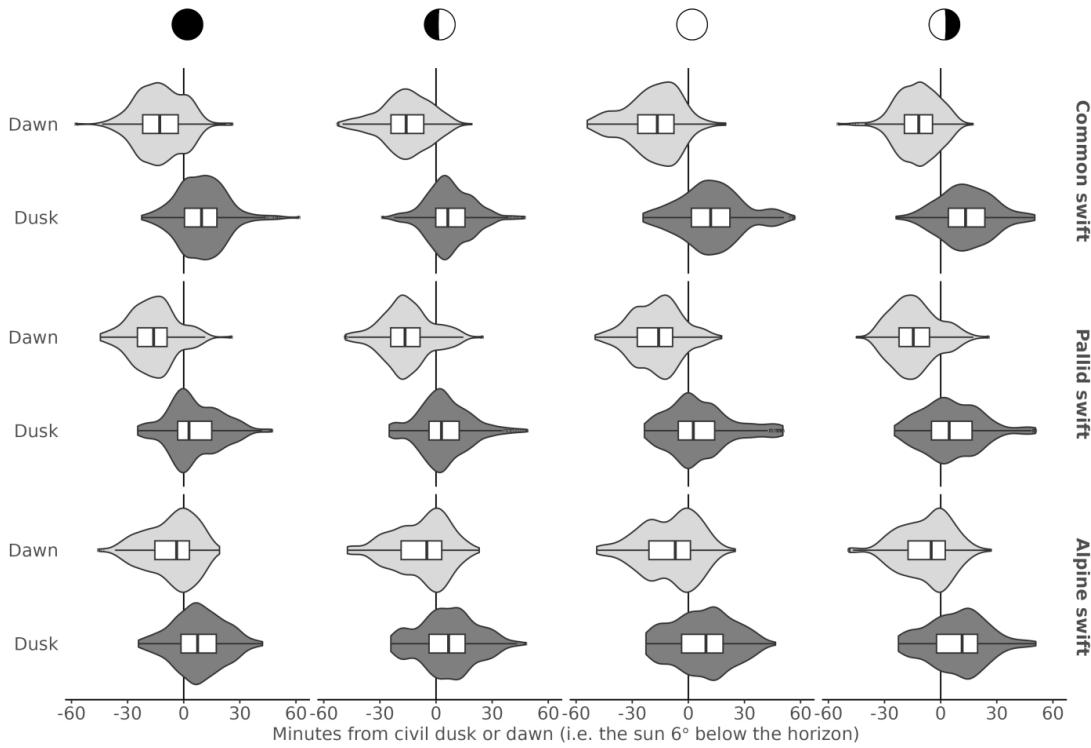


Figure S8. Box and violin plots of the distribution of the timing of maximum flight height during twilight, relative to civil dusk or dawn, by moon phase and species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively). The black vertical line at 0 indicates the timing of civil dusk or dawn. Values are expressed as minutes leading or lagging civil dusk or dawn events.

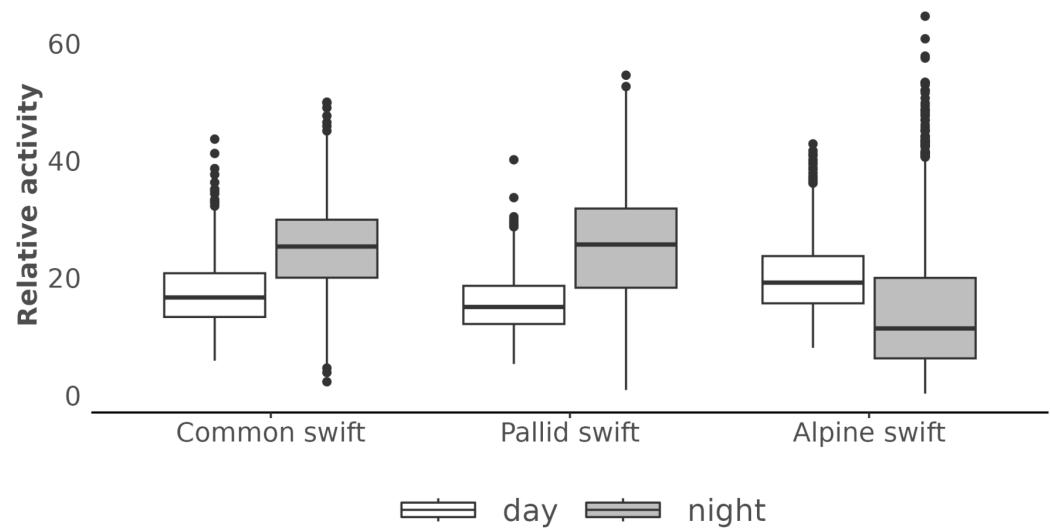


Figure S9. Box plots of the distribution of daytime and night-time flight activity by species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) as derived from Multisensor Data Logger (MDL) data.

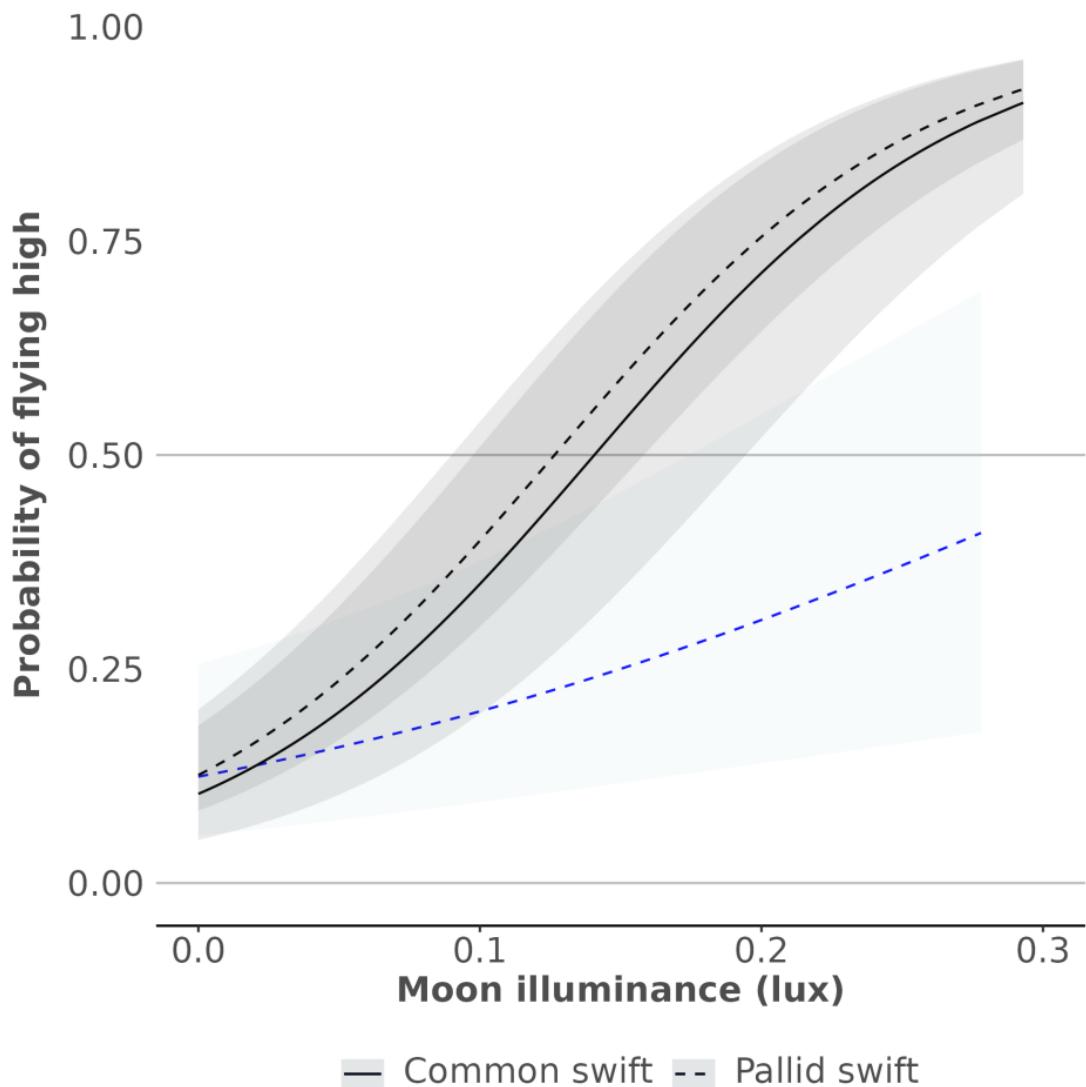


Figure S10. Marginal effect sizes by species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) for the generalised linear mixed effects logistic models relating moon illuminance with flight height for GPS based data across continental (black lines) or coastal (blue lines) positions for the Pallid swift. Grey or light blue 95% Confidence Intervals (CIs) were computed using a Wald z-distribution, for continental and coastal positions. No data is shown for the Common swift at coastal positions as the dataset was too small for a meaningful analysis ($n = 14$).

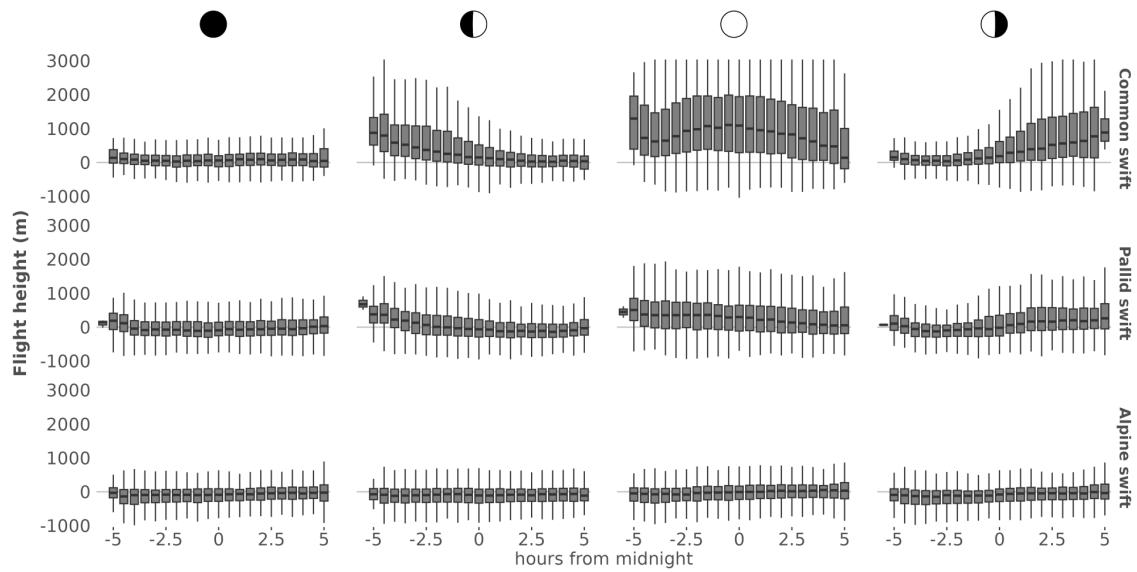


Figure S11. Box plots of the distribution of half-hourly night-time flight heights (m) relative to midnight by species (i.e. the Common, Pallid and Alpine swift, or *Apus apus*, *Apus pallidus* and *Tachymarptis melba* respectively) and moon phase for as derived from Multisensor Data Logger (MDL) data.

References

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