Supplementary Material

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Description of contents:

This supplemental file contains three sections: Methods, Figures, and Tables. The Methods section provides further details regarding the data collection and analysis methods used in the study. The supplemental Figures and Methods provide more context to the main analysis, for those looking to get a deeper understanding of the data, statistical models, and results.

Methods

1.1 Effects of capture and device attachment

In some cases, the capture, handling, attachment and subsequent bearing of a biologging device has been shown to affect the behavior of wild animals (Evans et al., 2020; Gillies et al., 2020; Morganti et al., 2018). This is of concern when there is the possibility that changes in behavior will affect the individual's fitness or result in biased measurements that do not represent un-tracked animals. Here we present a summary of the evidence for why we believe that the tracking of Caspian Terns as performed in this study represents the recording of natural behaviors.

1.2 Nest success rate

Based on chick ringing data and opportunistic observations from a remote camera, we were able to estimate the colony-wide fledgling production and the nest success rate for the tracked individuals for each year. In 2013, the number of fledglings per pair in the colony at large was 0.82, while among the tracked birds the success rate (i.e., any chicks fledged) was 71%. Taking into account that Caspian Terns normally lay 1-3 eggs, this success rate falls within normal bounds for the colony at large. In 2014, the number of fledglings per pair for the colony was 1.0, while the known breeding success of the tracked birds was 50%. In 2014, many nests of the tracked birds were depredated by eagles, which we observed from a remote camera in the colony. Therefore, we do not believe the low success rate in 2014 was associated with device attachment.

We are not able to make a direct comparison of the nest success/failure rate of tracked versus un-tracked birds for Gubbstenen as no remote camera was placed in this colony in 2016.

1.3 Colony return rate

Of the 14 birds tracked from Stenarna in 2013 and 2014, 6 birds (3 from each year) were reported as returning to the colony from ring readings. The main predictor of colony return is breeding success in the previous year: of the 5 birds for which we could confirm breeding failure in 2013/14, 0 returned to the colony between 2014 and 2021. Of those who were successful in 2013/2014, 6 of 9 returned to breed at Stenarna.

Of the 6 birds tracked at Gubbstenen in 2016, four birds returned to breed in the colony in 2017. The single bird tagged in 2015 (SER06) came back to breed at Gubbstenen in 2016 (i.e. the data analysed herein). As there was no camera located in this colony in 2016 we cannot say how the subsequent rates of return relate to breeding success/failure for this colony.

Rings are read opportunistically via a remote camera located in the colony. All areas of each colony are not observable from the camera's vantage point so we cannot guarantee that tracked birds who lost their devices were present and went unnoticed.

Figures

Fig. S1. Figure for visual inspection of whether residuals from the linear mixed model of time spent per day on foraging trips meets assumption of normality. 11 outliers (of a total of 711 daily observations) were removed to meet assumptions of normality. Parameter estimates and effects did not qualitatively differ before and after outlier removal.

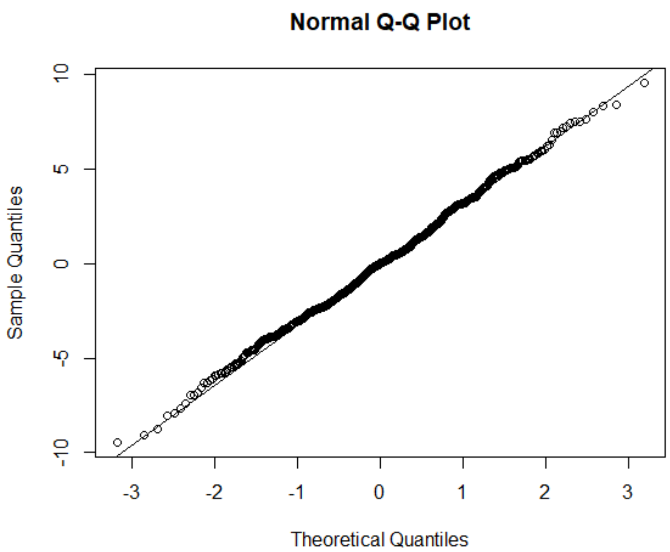


Fig. S2. Figure for visual inspection of whether residuals from the linear mixed model of the square root of daily travel distance meets assumption of normality. 19 outliers (of a total of 711 daily observations) were removed to meet assumptions of normality. Parameter estimates and effects did not qualitatively differ before and after outlier removal.

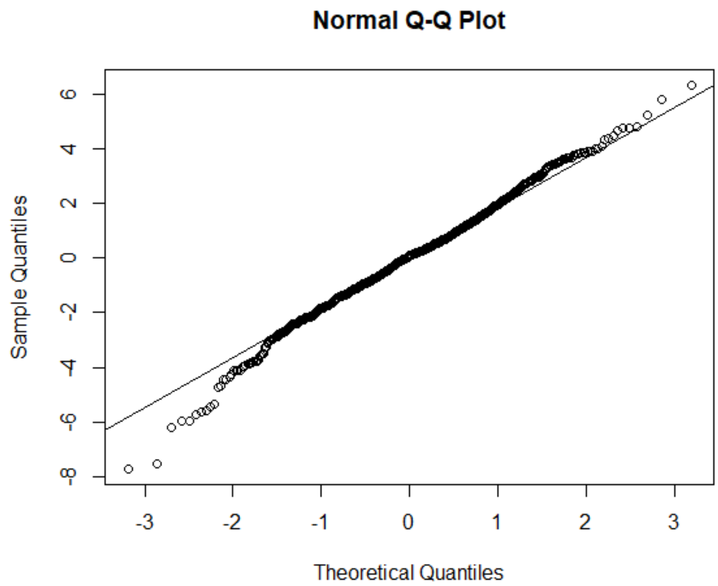


Fig. S3 – Density distribution of instantaneous speeds for all fixes derived from GPS. Dashed line is the threshold (1.5 m/s) used to distinguish flight from a grounded period.

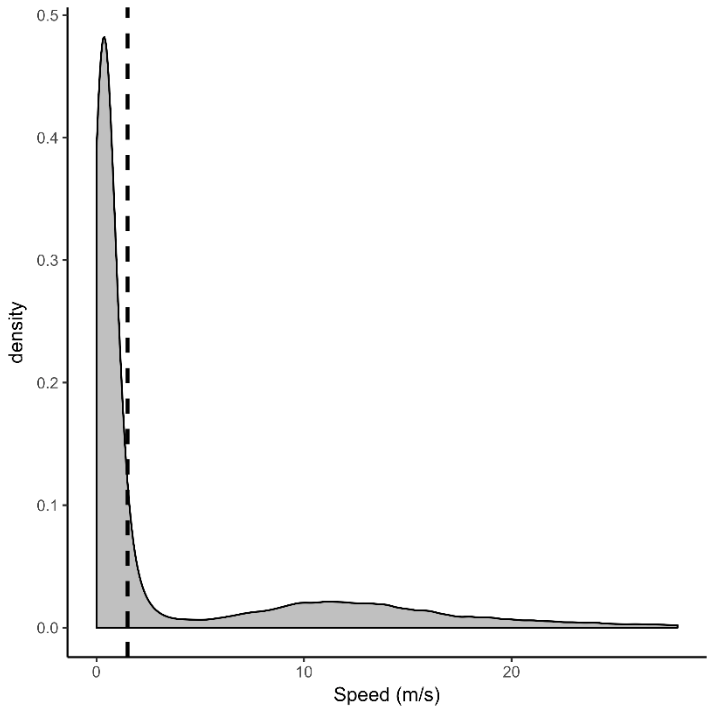


Fig. S4A – Weekly 50% core use areas for 6 individuals from Stenarna in 2013. Colors go from yellow to red with advancing week.

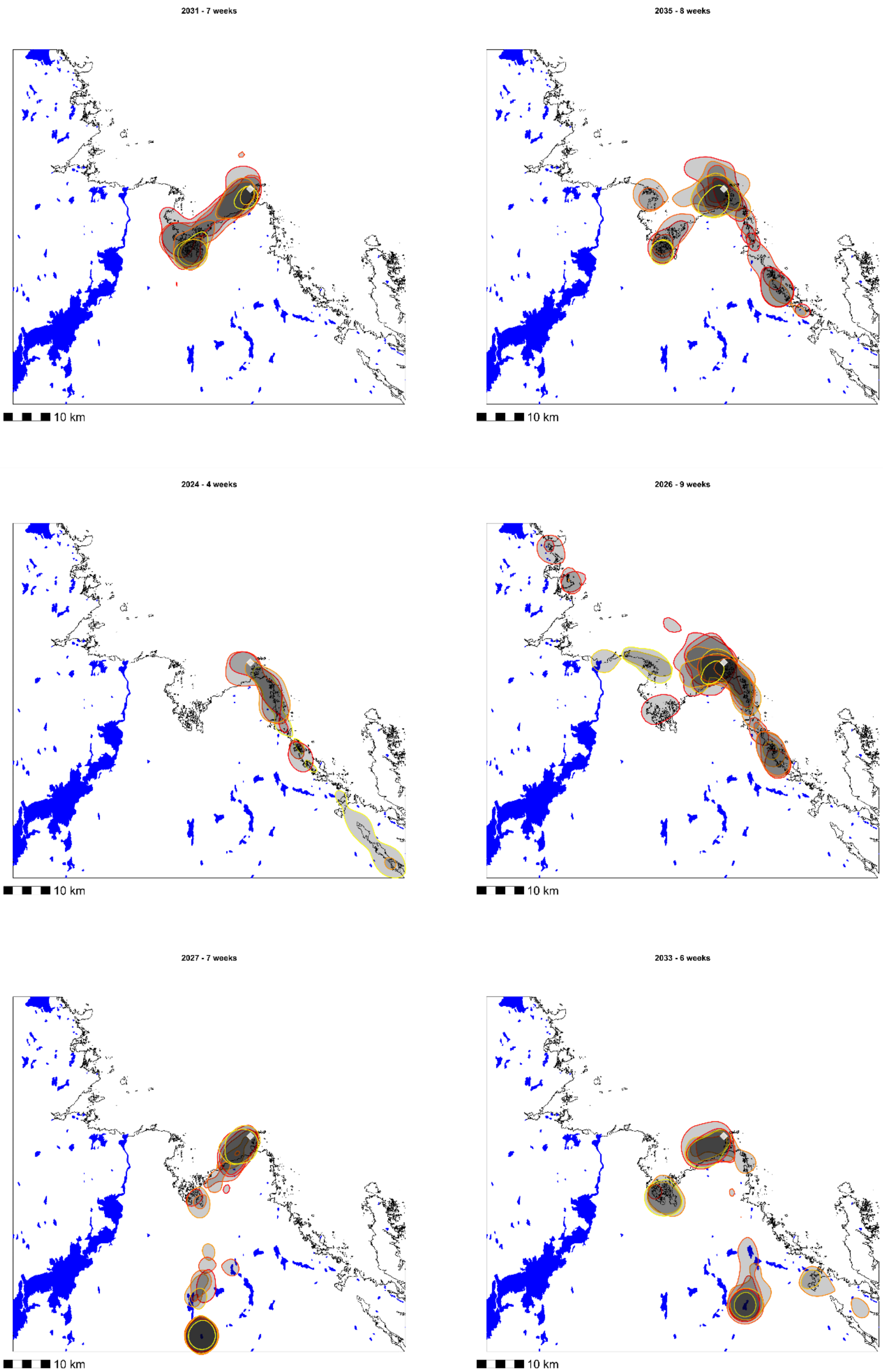


Fig. S4B – Weekly 50% core use areas for 6 individuals from Stenarna in 2014. Colors go from yellow to red with advancing week.

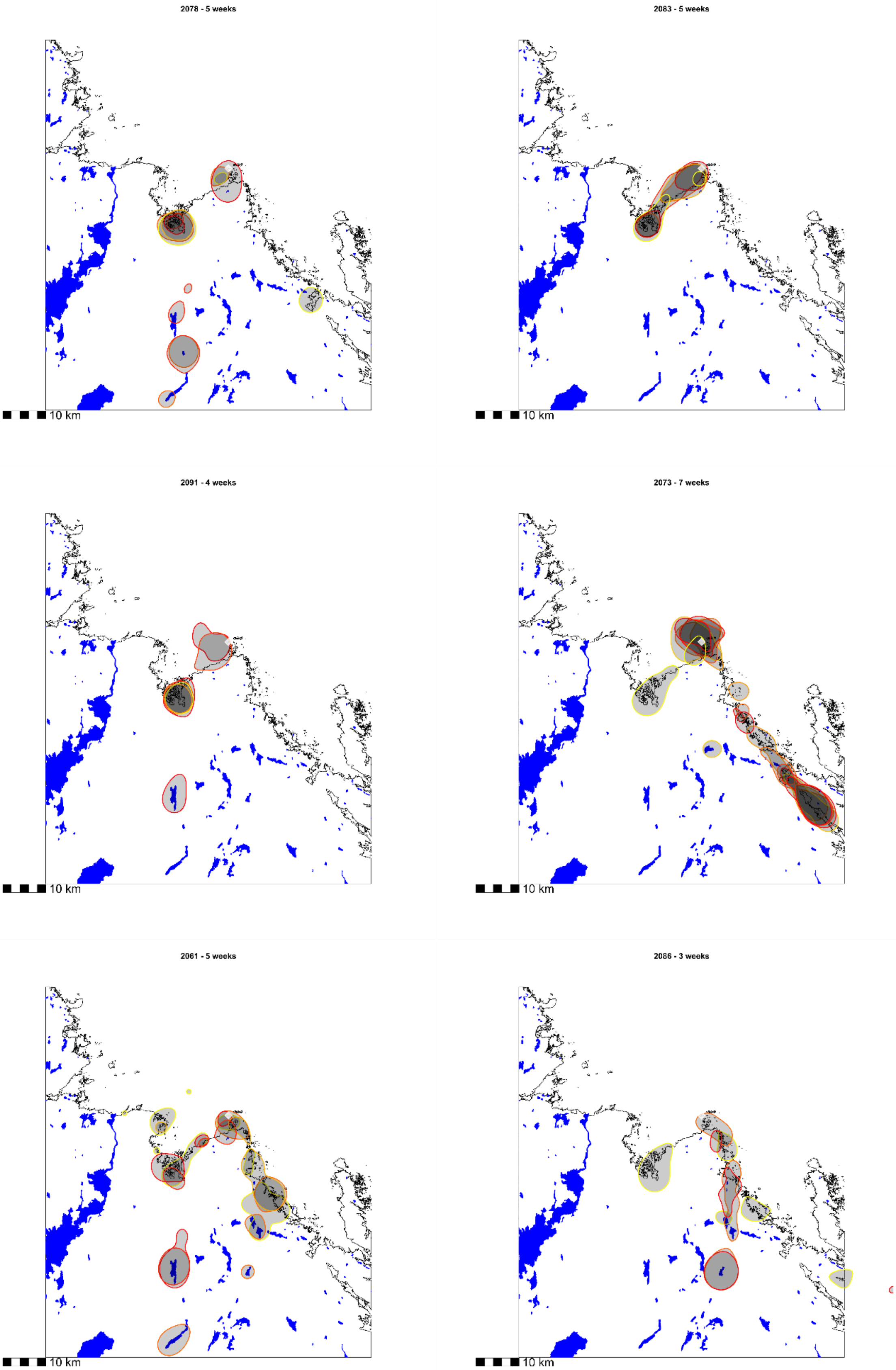


Fig. S4C – Weekly 50% core use areas for 6 individuals from Gubbstenen. Colors go from yellow to red with advancing week.

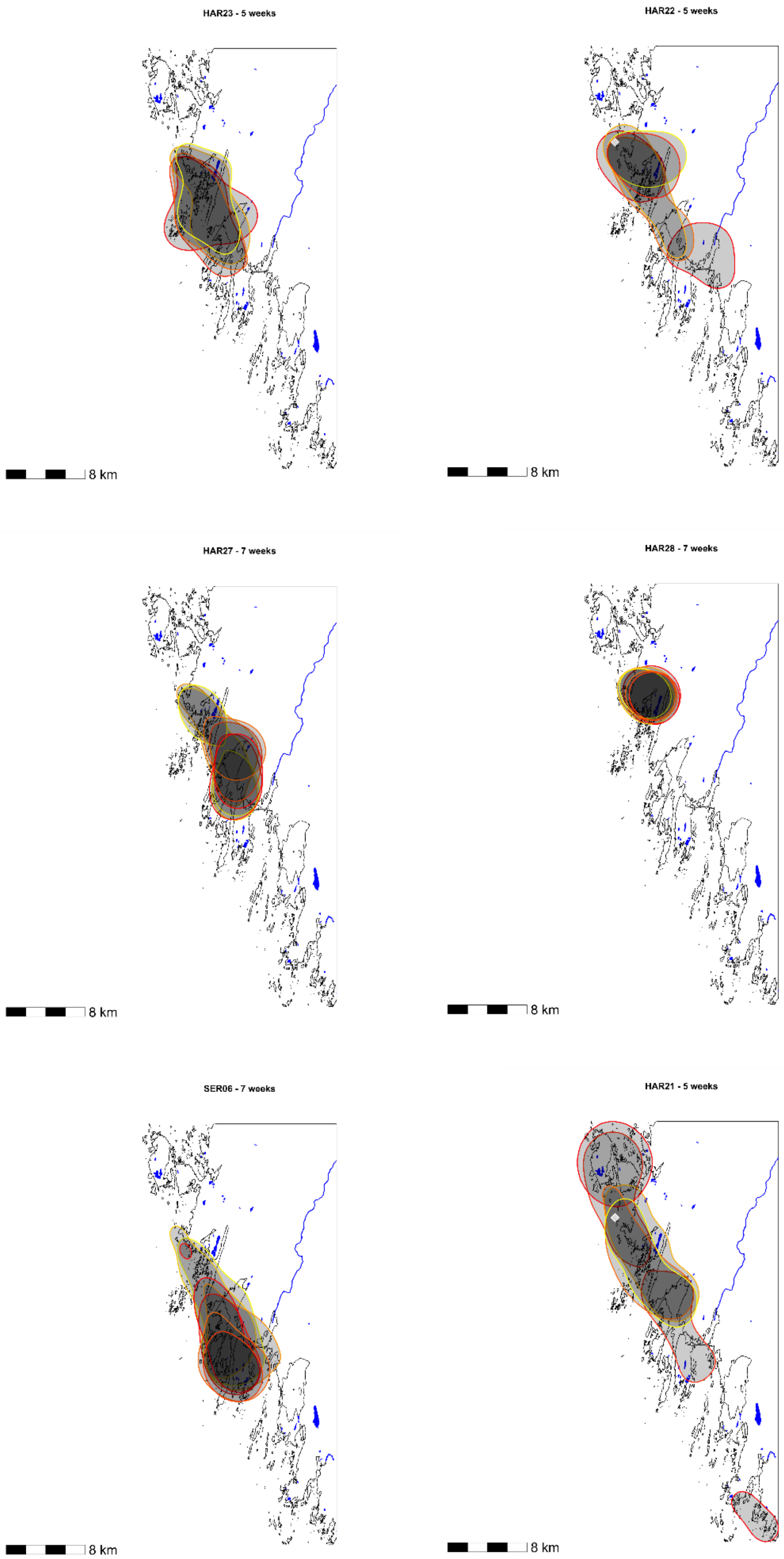
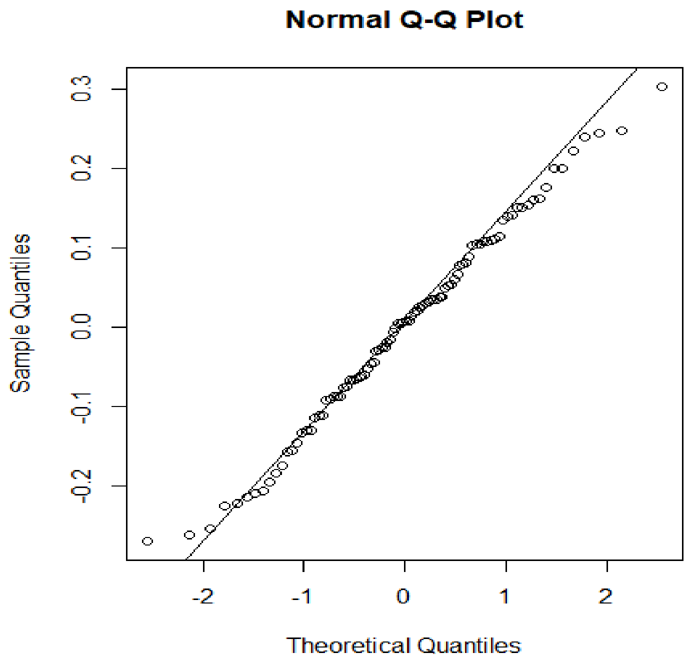


Fig. S5. Figure for visual inspection of whether residuals from the linear mixed model of the proportion of trips per week which are to already visited sites meets assumption of normality.



Tables

Table S1. Trip characteristics of birds breeding at Stenarna in 2013 (Relay) and in both 2013 and 2014 (Inland). 'Re-lay' indicates whether the birds in 2013 re-laid their clutch following an early-season nest failure (Re-lay: TRUE) and those that laid only one clutch (Re-lay: FALSE). Under the 'Inland' section is a comparison of the foraging trip characteristics of birds which selected inland lakes for foraging (Inland: TRUE) and those that did not (Inland: FALSE).

Re-lay	n	**max distance**	**sd**	**duration (min)**	**sd**
FALSE	4	16.3	2.4	144.5	9.6
TRUE	3	26.3	2.5	266.9	49.8
Inland					
FALSE	7	16.8	3.1	153.8	13.7
TRUE	7	25.7	4.7	302.9	66.8

Table S2. Habitat use selection ratios for different water types, made up of water depth intervals and inland water. 'o' indicates use of a water type by birds from a colony proportionate to availability in the movement area around the colony, '-' indicates use lower than expected by availability, and '+' indicates significant positive of selection or higher use than expected based on availability.

Stenarna (n=14)							
	Available	**Used**	**Wi**	**SE**	**CI upper**	**CI lower**	**Index**
Inland	0.05	0.19	4.22	1.89	-0.87	9.30	o
0-5 m	0.16	0.57	3.48	0.40	2.40	4.55	+
5-10 m	0.08	0.05	0.61	0.09	0.36	0.86	-
10-20 m	0.19	0.12	0.64	0.08	0.44	0.85	-
20-30 m	0.15	0.03	0.23	0.07	0.05	0.41	-
30-40 m	0.12	0.03	0.23	0.06	0.06	0.41	-
>40 m	0.26	0.01	0.04	0.02	0.00	0.09	-

Gubbstenen (n=6)							
	Available	**Used**	**Wi**	**SE**	**CI upper**	**CI lower**	**Index**
Inland	0.01	0.02	2.00	0.61	0.47	3.52	o
0-5 m	0.64	0.92	1.45	0.02	1.40	1.50	+
5-10 m	0.21	0.04	0.21	0.06	0.06	0.35	-
10-20 m	0.15	0.01	0.08	0.04	-0.01	0.16	-

Table S3. Model selection for testing effects of daily seasonal progression on foraging effort. Selection of fixed effects structure for models of (A) daily time spent away from the breeding colony, and (C) total daily distance travelled. (B, D) Using restricted maximum likelihood to determine whether a random intercepts or slope model is more informative and parsimonious. 'doy_cntr' is an ordinal variable representing the centered Julian day of the year and 'colony' is a two-level factor, referring to the breeding colonies Stenarna in Sweden, and Gubbstenen in Finland. Models in bold were selected based on minimizing parameters and information criteria.

A – foraging time					
Model		npar	AIC	BIC	logLik
Full	t_away ~ doy_cntr * colony + (1 **+ doy_cntr** |ID)	8	3836.6	3873.1	-1910.3
Reduce 1	t_away ~ doy_cntr + colony + (1 **+ doy_cntr** |ID)	7	3838	3870	-1912
Reduce 2	**t_away ~ doy_cntr + (1|ID)**	**6**	**3836.9**	**3864.3**	**-1912.4**
B – foraging time					
Model		npar	AIC	BIC	logLik
Intercept	t_away ~ doy_cntr + (1 | ID)	4	3840.1	3858.4	-1916.1
Slope	**t_away ~ doy_cntr + (1 + doy_cntr | ID)**	**6**	**3836.9**	**3864.3**	**-1912.4**
C – total distance					
Model		npar	AIC	BIC	logLik
Full	**sqrt(d_travel) ~ doy_cntr * colony + (1|ID)**	**6**	**3137.8**	**3165.2**	**-1562.9**
Reduce 1	sqrt(d_travel) ~ doy_cntr + colony + (1|ID)	5	3154.8	3177.6	-1572.4
Reduce 2	sqrt(d_travel) ~ doy_cntr + (1|ID)	4	3169	3187.3	-1580.5
D – total distance					
Model		npar	AIC	BIC	logLik
Intercept	**sqrt(d_travel) ~ doy_cntr * colony + (1|ID)**	**6**	**3137.8**	**3165.2**	**-1562.9**
Slope	sqrt(d_travel) ~ doy_cntr * colony + (1 + doy_cntr|ID)	8	3136.7	3173.2	-1560.3

Table S4. Results of selected models of foraging effort metrics. Model parameter estimates, standard errors, confidence intervals, and estimated significance for fixed effects on the daily time spent foraging ('t_away'), and the square root of total distance travelled ('d_travel') by breeding Caspian Terns. 'doy_cntr' is the mean-centered Julian day of the year, and 'colony' is a two-level factor, referring to the breeding colonies Stenarna in Sweden, and Gubbstenen in Finland. Random slopes and intercepts across the days of the year were specified per individual in the foraging time model, while random intercepts were specific per individual in the distance travelled model. 11 and 4 outliers (of a total of 711 daily observations) were removed to meet assumptions of normality. Parameter estimates and effects did not qualitatively differ before and after outlier removal.

Model: foraging time	**Fixed effect**	**Estimate**	**Std. Error**	**t value**	**CI 2.5%**	**CI 97.5%**	**alpha**
	(Intercept)	9.99	0.33	29.82	9.32	10.66	0.00
	doy_cntr	0.06	0.02	2.99	0.02	0.09	0.01
t_away ~ doy_cntr + (1 + doy_cntr | ID)	**Random effect**	**Variance**	**Std.Dev.**	**Corr**			
	ID (Intercept)	1.73	1.31				
	doy_cntr	0.00	0.07	0.08			
	Residual	10.06	3.17				
	N_{obs}=700	*N_{ID} = 20*					

Model: daily distance travelled	**Fixed effect**	**Estimate**	**Std. Error**	**t value**	**CI 2.5**	**CI 97.5**	**alpha**
	(Intercept)	9.15	0.43	21.12	8.31	10.00	0.00
	doy_cntr	0.01	0.01	1.39	-0.01	0.03	0.17
	colonyS	2.14	0.52	4.10	1.13	3.16	0.00
	doy_cntr:colonyS	0.05	0.01	4.16	0.03	0.08	0.00
sqrt(d_travel) ~ doy_cntr * colony + (1 | ID)							
	Random effect	**Variance**	**Std.Dev.**				
	ID (Intercept)	1.01	1.01				
	Residual	4.16	2.04				
	N_{obs}=707	*N_{ID} = 20*					

Table S5. Model selection for testing effects of weekly seasonal progression on foraging site fidelity. (A) Selection of fixed effects structure. 'rel_wk' refers to the relative 7-day period of tracking for each individual tern (ID). 'colony' is a two-level factor, referring to the breeding colonies Stenarna in Sweden, and Gubbstenen in Finland. (B) Using restricted maximum likelihood to determine whether a random intercepts or slope model is more informative and parsimonious. Models in bold are were selected based on minimizing parameters and information criterion.

A					
Model		npar	AIC	BIC	logLik
Full	p_revisit ~ rel_wk * colony + (1|ID)	6	-71.712	-58.921	38.547
Reduce 1	p_revisit ~ rel_wk + colony + (1|ID)	5	-71.439	-58.723	40.72
Reduce 2	**p_revisit ~ rel_wk + (1 | ID)**	**4**	**-69.094**	**-56.452**	**41.856**
B					
Model		npar	AIC	BIC	logLik
intercept	**p_revisit ~ rel_wk + (1 | ID)**	**4**	**-69.094**	**-58.921**	**38.547**
slope	p_revisit ~ rel_wk + (1 + rel_wk | ID)	6	-66.756	-51.497	39.378

Table S6. Result of selected model for foraging trip revisitation rate. 'prop_revisits' is the proportion of trips which are to sites which were previously visited by an individual tern within a week. Model estimates, standard errors, confidence intervals, degrees of freedom, and significance for the fixed effect 'rel_wk', which is the relative 7-day period in which the individual was tracked. Four individuals were not included in this analysis as they only had 3 or fewer weeks of tracking, making the total number of analyzed individuals 16.

Model	**Fixed effect**	**Estimate**	**Std.Error**	**t value**	**CI 2.5**	**CI 97.5**	**alpha**
prop_revisits ~ rel_wk + (1 | ID)	intercept	0.46	0.06	7.66	0.28	0.46	0.00
	rel_wk	0.00	0.01	-0.19	-0.02	0.01	0.85
	Random effect	**Variance**	**Std.Dev.**				
	ID (Intercept)	0.02	0.13				
	Residual	0.02	0.14				
	N_{obs}=94	N_{ID} = 16					

References

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