The following supplement accompanies the article

Escaping the oligotrophic gyre? The year-round movements, foraging behaviour and habitat preferences of Murphy's petrels

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Defining breeding stage and phenology

Breeding stage and phenology were based on a combination of movements, activity patterns and knowledge of their breeding biology (Brooke 1995). A completely dry night within 500 km of the colony (Guilford et al. 2009) indicated that the bird was most likely at the breeding colony. Both members of the pair return in late April for copulation and spend at least one night dry on the colony before departing on a pre-laying exodus. For males, incubation trips follow a long dry period on the egg (c. 19 days), whereas females depart following a few days incubating the egg (before males take over for their first incubation shift; Brooke 1995). Immersion data from two members of the same pair confirmed that this methodology could be used to delineate breeding and migratory schedules for the other birds (Fig. 1).

Habitat modelling methods

The appropriate number of pseudo-absences in habitat models was determined by measuring changes in χ^2 values and AUC (area under the receiver operator curve) scores of each predictor with an increasing number of pseudo-absences up to 50 per presence (Zydelis et al. 2011, Clay et al. 2016). We chose 50 pseudo-absences as in most cases χ^2 values and AUC scores had stabilised (Fig. S1).

We initially considered mixed-layer depth as a variable in habitat models, but chose not to include it due to the coarse temporal and spatial resolution of the available data (monthly climatologies at a 2° resolution; http://www.ifremer.fr/cerweb/deboyer/mld/Surface_Mixed_Layer_Depth.php). Additionally, while the inclusion of a random intercept can control for individual variability in response to the environment (i.e. generalized additive mixed models, GAMMs; Wood 2006), model selection and inference on large datasets is computationally demanding. In order to reduce pseudo-replication within datasets, we only selected one incubation trip per individual year, and for other breeding stages, we removed individuals with substantially shorter tracking durations. As we carried out cross-validation using each individual as a data fold, individual differences are taken into account in model performance scores.

We also checked model residuals for spatial autocorrelation using semi-variograms in the R package geoR (Ribeiro and Diggle 2015), and it was not detected at the relevant spatial scale and so not controlled for in models. For all calculations of distances, we used great-circle distances in the R package *fields* (Nychka et al. 2016). Minimum convex polygons were calculated using the *adehabitatHR* package (Calenge 2006), and environmental layers were manipulated in the R package *raster* (Hijmans et al. 2016).

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Żydelis R, Lewison RL, Shaffer SA, Moore JE, Boustany AM, Roberts JJ, Sims M, Dunn DC, Best BD, Tremblay Y, Kappes MA, Halpin PN, Costa DP, Crowder LB (2011) Dynamic habitat models: using telemetry data to project fisheries bycatch. Proc Biol Sci 278:3191–200.

Table S1. Summary of GLMM testing the effects of sex, year, and the interaction between sex and year on the timings and of movements of Murphy's petrels. *X* indicates predictors that were retained in the most parsimonious models, and - indicates predictors that were not retained in the analysis.* indicates that incubation trip type was also included as a predictor and ¥ that it was retained as an important predictor. AICc = Akaike information criterion corrected for small sample sizes. ΔAICc = difference in AICc from best supported model. Where ΔAICc > 0, another model had a lower AICc, but not to the extent of incurring the penalty of extra parameters.

	Sex	Year	Sex:Year	*d.f.*	AICc	ΔAICc
Last night at colony	-	-	-	3	300.4	1.10
Migration						
Outbound departure date	-	-	-	3	346.7	0.00
Outbound arrival date	-	-	-	3	326.2	0.00
Outbound duration	-	-	-	3	169.3	0.00
Inbound departure date	-	-	-	3	237.0	0.00
Inbound arrival date	-	-	-	3	262.4	0.00
Inbound duration	-	-	-	3	163.4	0.00
Non-breeding						
NB duration	-	-	-	3	235.7	0.67
Mean longitude	-	-	-	3	248.5	0.00
Mean latitude	-	*X*	-	4	146.9	0.00
Pre-laying exodus						
First night back at colony	-	-	-	3	273.0	0.00
Departure date	-	*X*	-	4	211.1	0.00
Return date	-	*X*	-	4	207.3	0.00
Duration	-	*X*	-	5	160.2	1.30
Max. distance colony	*X*	-	-	4	479.5	1.14
Mean longitude	-	-	-	3	245.9	1.90
Mean latitude	-	-	-	3	158.1	0.07
Incubation						
Departure date 1st trip	*X*	-	-	4	191.2	0.00
Return date 1st trip	*X*	-	-	4	197.4	0.00
Duration 1st trip*	-	*X*	-	4	154.6	0.00
Max. dist. colony 1st trip*	-	-	-	4	443.3	0.00¥
Proportion long trips	-	-	-	2	37.1	0.00
Mean longitude	-	-	-	3	206.4	0.00
Mean latitude	-	-	-	3	177.8	0.43

Table S2. Percentage of deviance explained by important habitat variables for each breeding stage. - indicates predictors that were not retained in the analysis.

Variable	Non-breeding	Pre-laying exodus	Incubation	Late breeding
Full model	18.5	1.1	25.2	10.1
Depth	-	-	-	-
Depth slope	3.8	-	-	1.1
Chlorophyll a concentration	-	1.1	-	-
Distance to the colony	n/a	-	-	6.0
Eddy kinetic energy	-	-	4.1	-
Sea level anomaly	1.4	-	15.6	-
Sea surface temperature	12.2	-	-	3.2
Sea surface temperature gradient	-	-	-	-
Wind speed	-	-	-	-
Year	-	-	<0.1	-

Table S3. Summary of the performance of individual cross-validation of models with and without sex-differences for each stage of the annual cycle. Interaction indicates that models included sex-specific smoothers for each environmental variable and the differences between the AUC scores with and without the interaction for each individual are also shown. Where there are significant differences between AUC scores with and without the interaction, they are emphasized in bold along with the best model. For each model, means ± SD are shown with ranges in parentheses.

Model	Interaction	No interaction	Difference	*T test*	*P*
Non-breeding	0.850 ± 0.029 (0.806 – 0.902)	0.850 ± 0.028 (0.805 – 0.895)	<0.001 ± 0.005 (-0.012 – 0.006)	$t_{17} = -0.09$	0.925
Pre-laying exodus	0.678 ± 0.064 (0.560 – 0.806)	0.666 ± 0.064 (0.528 – 0.795	0.012 ± 0.018 (-0.032 – 0.055)	$t_{15} = 2.64$	**0.019**
Incubation	0.869 ± 0.063 (0.752 – 0.950)	0.869 ± 0.065 (0.746 – 0.951)	<-0.001 ± 0.005 (-0.012 – 0.010)	$t_{17} = -0.57$	0.578
Late breeding	0.757 ± 0.064 (0.608 – 0.859)	0.762 ± 0.059 (0.624 – 0.858)	-0.005 ± 0.007 (-0.017 – 0.003)	$t_{16} = -2.83$	**0.012**

Table S4. Summary of GLMM testing the effects of breeding stage, daylight or darkness (LoD), year, and the interaction between LoD and breeding stage, on the activity patterns of Murphy's petrels. *X* indicates predictors that were retained in the most parsimonious models, whilst - indicates predictors that were not retained in the analysis. AICc = Akaike information criterion corrected for small sample sizes. ΔAICc = difference in AICc from best supported model. Where ΔAICc > 0, another model had a lower AICc, but not to the extent of incurring the penalty of extra parameters. The most parsimonious model is shown in bold.

LoD	Stage	Year	LoD:Stage	*d.f.*	AICc	ΔAICc
Time on water (h)						
X	**X**	**-**	**X**	**12**	**35499.2**	**0.00**
X	X	X	X	13	34999.2	0.00
X	X	-	-	8	36389.8	890.58
X	X	X	-	9	36390.0	890.79
-	X	-	-	7	37664.1	2164.91
Time on water (%)						
X	X	X	X	13	6264.3	0.00
X	**X**	**-**	**X**	**12**	**6265.9**	**1.58**
X	X	X	-	9	6777.2	512.86
X	X	-	-	8	6778.6	514.23
-	X	X	-	8	7330.3	1065.92
No. landings (day^{-1})						
X	**X**	**-**	**X**	**12**	**24902.5**	**0.00**
X	X	X	X	13	24902.6	0.13
X	X	-	-	8	25314.2	411.75
X	X	X	-	9	25314.4	411.91
-	X	-	-	7	25759.9	857.39
No. landings (h^{-1})						
X	X	-	X	12	-4626.9	0.00
X	**X**	**X**	**X**	**13**	**-4626.8**	**0.01**
X	X	-	-	8	-4298.2	328.70
X	X	X	-	9	-4298.1	328.71
-	X	-	-	7	-1969.5	2657.38
Duration of flight bouts (min)						
X	**X**	**X**	**X**	**13**	**11069.5**	**0.00**
X	X	-	X	12	11072.6	3.10
X	X	X	-	9	11413.6	344.14
X	X	-	-	8	11416.5	347.04
-	X	X	-	8	11419.6	350.17

Table S5. *P*-values of Tukey's post-hoc tests comparing differences between breeding stages for each activity metric: a) no. landings (h^{-1}), b) no. landings (d^{-1}), c) time on water (h), d) time on water (%) and d) duration of flight bouts (min). As the interaction between light or dark and breeding stage was significant, *P*-values were calculated separately for light and dark periods (unshaded and shaded light grey, respectively), and significant differences between groups are shown in bold.

a) No. landings (h^{-1})

Stage	Outward migration	Non-breeding	Return migration	Pre-laying exodus	Incubation
Outward migration		**<0.001**	**0.038**	**<0.001**	**<0.001**
Non-breeding	**<0.001**		**<0.001**	**<0.001**	**<0.001**
Return migration	0.387	**<0.001**		**<0.001**	**<0.001**
Pre-laying exodus	**<0.001**	**<0.001**	**<0.001**		0.164
Incubation	**<0.001**	**<0.001**	**<0.001**	0.856	

b) No. landings (d^{-1})

Stage	Outward migration	Non-breeding	Return migration	Pre-laying exodus	Incubation
Outward migration		**<0.001**	**0.040**	**<0.001**	**<0.001**
Non-breeding	**<0.001**		**<0.001**	**<0.001**	**<0.001**
Return migration	0.222	**<0.001**		**<0.001**	**<0.001**
Pre-laying exodus	0.914	**<0.001**	**0.008**		**0.009**
Incubation	0.091	**<0.001**	**<0.001**	0.139	

c) Time on water (h)

Stage	Outward migration	Non-breeding	Return migration	Pre-laying exodus	Incubation
Outward migration		**<0.001**	1.00	0.320	**<0.001**
Non-breeding	**<0.001**		**<0.001**	**<0.001**	**<0.001**
Return migration	1.000	**<0.001**		0.238	**<0.001**
Pre-laying exodus	**<0.001**	**<0.001**	**<0.001**		**<0.001**
Incubation	**<0.001**	**<0.001**	**<0.001**	**<0.001**	

d) Time on water (%)

Stage	Outward migration	Non-breeding	Return migration	Pre-laying exodus	Incubation
Outward migration		**<0.001**	0.960	0.986	**<0.001**
Non-breeding	**<0.001**		**<0.001**	**<0.001**	**<0.001**
Return migration	0.992	**<0.001**		0.996	**<0.001**
Pre-laying exodus	**<0.001**	**<0.001**	**<0.001**		**<0.001**
Incubation	**<0.001**	**<0.001**	**<0.001**	**<0.001**	

e) Duration of flight bouts (min)

Stage	Outward migration	Non-breeding	Return migration	Pre-laying exodus	Incubation
Outward migration		**<0.001**	0.093	**<0.001**	1.000
Non-breeding	**<0.001**		**<0.001**	**<0.001**	**<0.001**
Return migration	0.286	**<0.001**		**<0.001**	0.134
Pre-laying exodus	0.980	**<0.001**	0.311		**<0.001**
Incubation	1.00	**<0.001**	0.290	0.967	

Table S6. Summary of GLMM testing the effects of breeding stage, photoperiod (daylight, darkness and morning and evening twilight), year, and their interaction, on the proportion of time spent on water by Murphy's petrels. *X* indicates predictors that were retained by the most parsimonious models, whilst - indicates predictors that were not retained in the analysis. AICc = Akaike information criterion corrected for small sample sizes. ΔAICc = difference in AICc from best supported model. Where ΔAICc > 0, another model had a lower AICc, but not to the extent of incurring the penalty of extra parameters.

Photoperiod	Stage	Year	Photoperiod:Stage	*d.f.*	AICc	ΔAICc
X	X	-	X	18	–548.0	0.00
X	X	X	X	19	–546.9	1.15
X	X	-	-	9	–310.8	237.22
X	X	X	-	10	–309.2	238.82
X	X	-	-	6	–188.2	359.86

Table S7. *P*-values of Tukey's post-hoc tests comparing the proportion of time spent on water by Murphy's petrels during darkness, daylight and morning and evening twilight for each breeding stage: a) non-breeding, b) pre-laying exodus, and c) incubation. As the interaction between photoperiod and breeding stage was significant, *p*-values were calculated separately for each breeding stage. Significant differences between groups are shown in bold.

a) Non-breeding

Photoperiod	Darkness	Morning twilight	Daylight	Evening twilight
Darkness				
Morning twilight	**<0.001**			
Daylight	**<0.001**	**<0.001**		
Evening twilight	0.995	**<0.001**	**<0.001**	

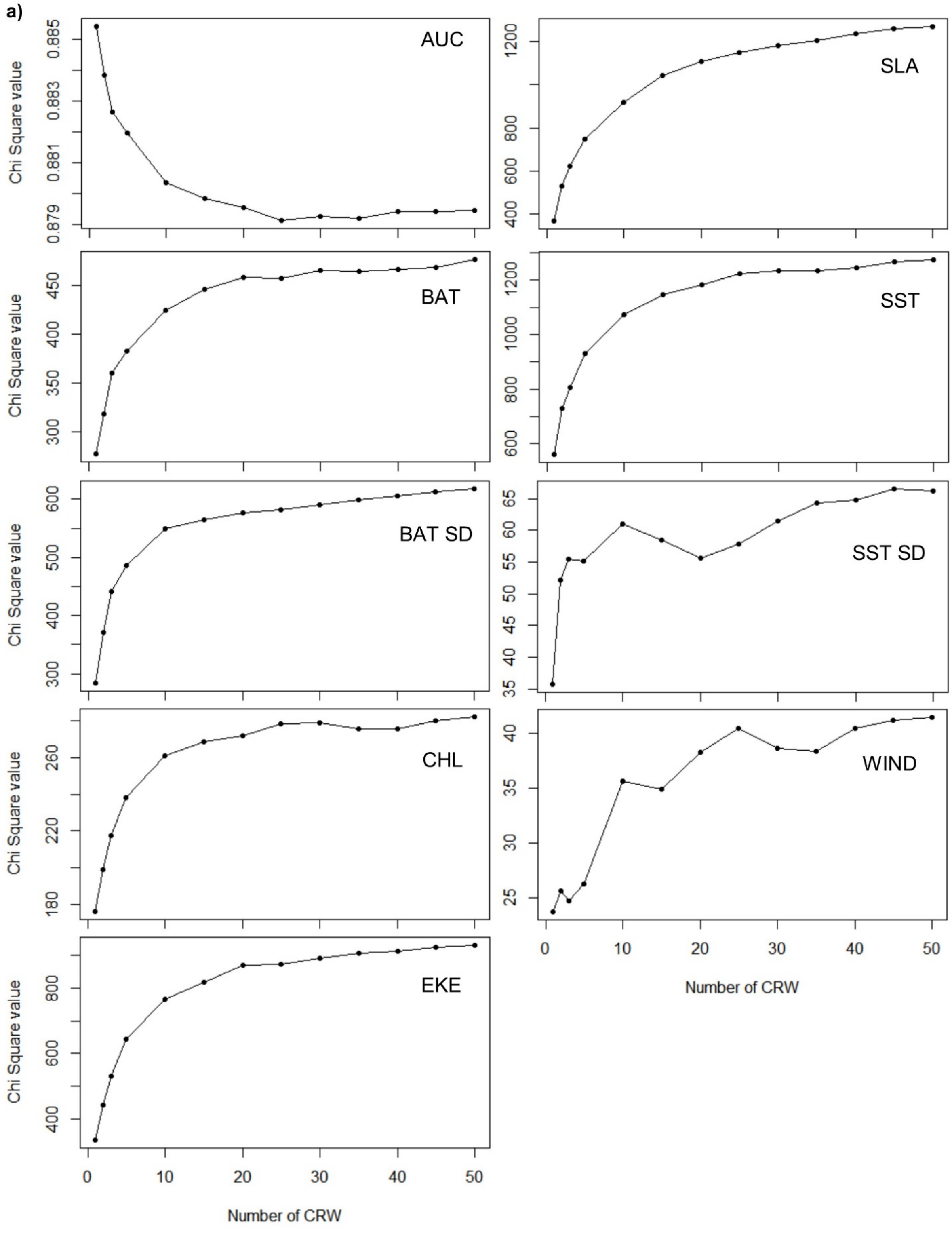
b) Pre-laying exodus

Photoperiod	Darkness	Morning twilight	Daylight	Evening twilight
Darkness				
Morning twilight	**<0.001**			
Daylight	0.903	**0.002**		
Evening twilight	0.056	0.378	0.237	

c) Incubation

Photoperiod	Darkness	Morning twilight	Daylight	Evening twilight
Darkness				
Morning twilight	1.000			
Daylight	**0.002**	**<0.001**		
Evening twilight	0.435	0.497	**0.005**	

a)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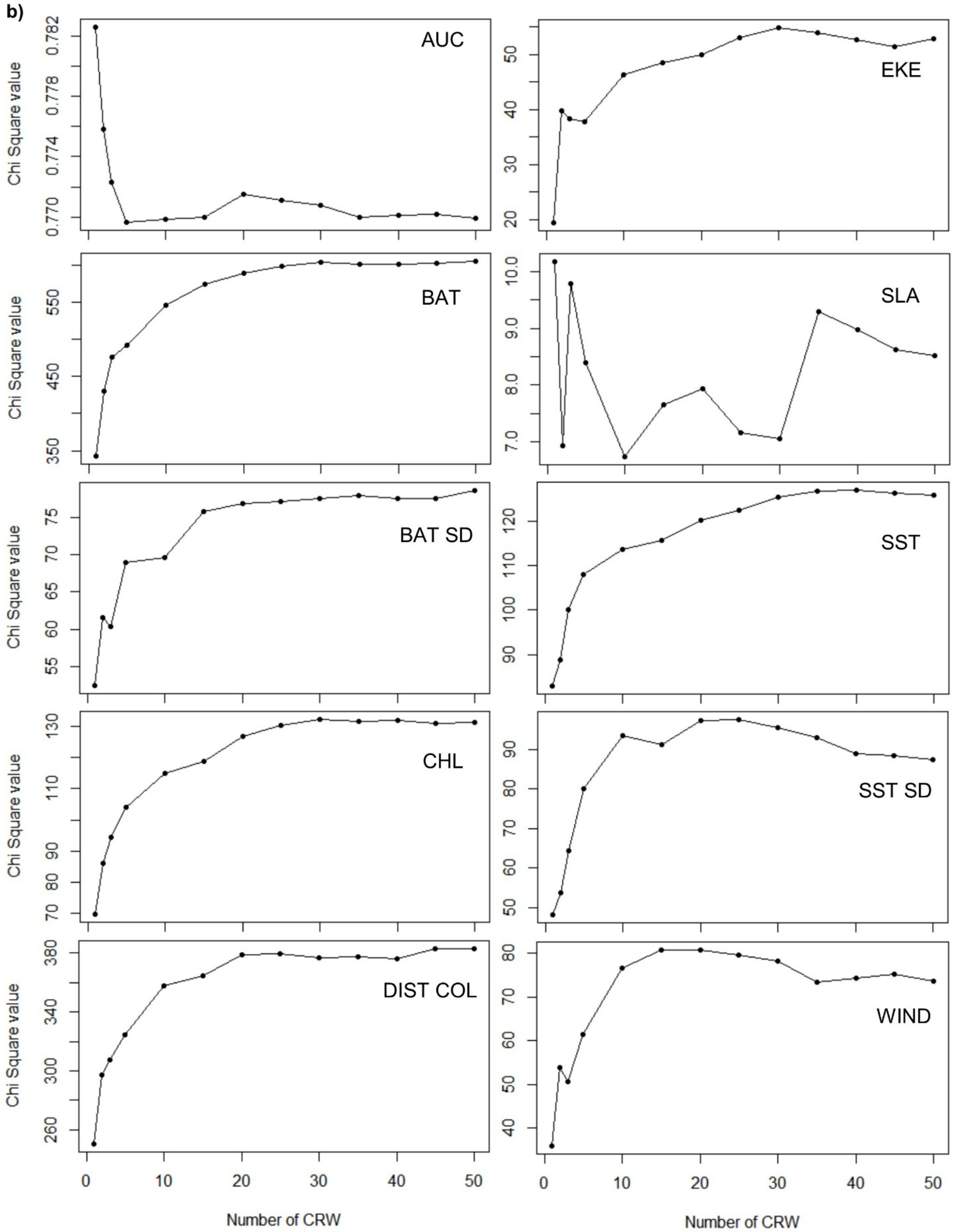
SLA
BAT
SST
BAT SD
SST SD
CHL
WIND
EKE
Chi Square value
Number of CRW

b)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WIND
Chi Square value
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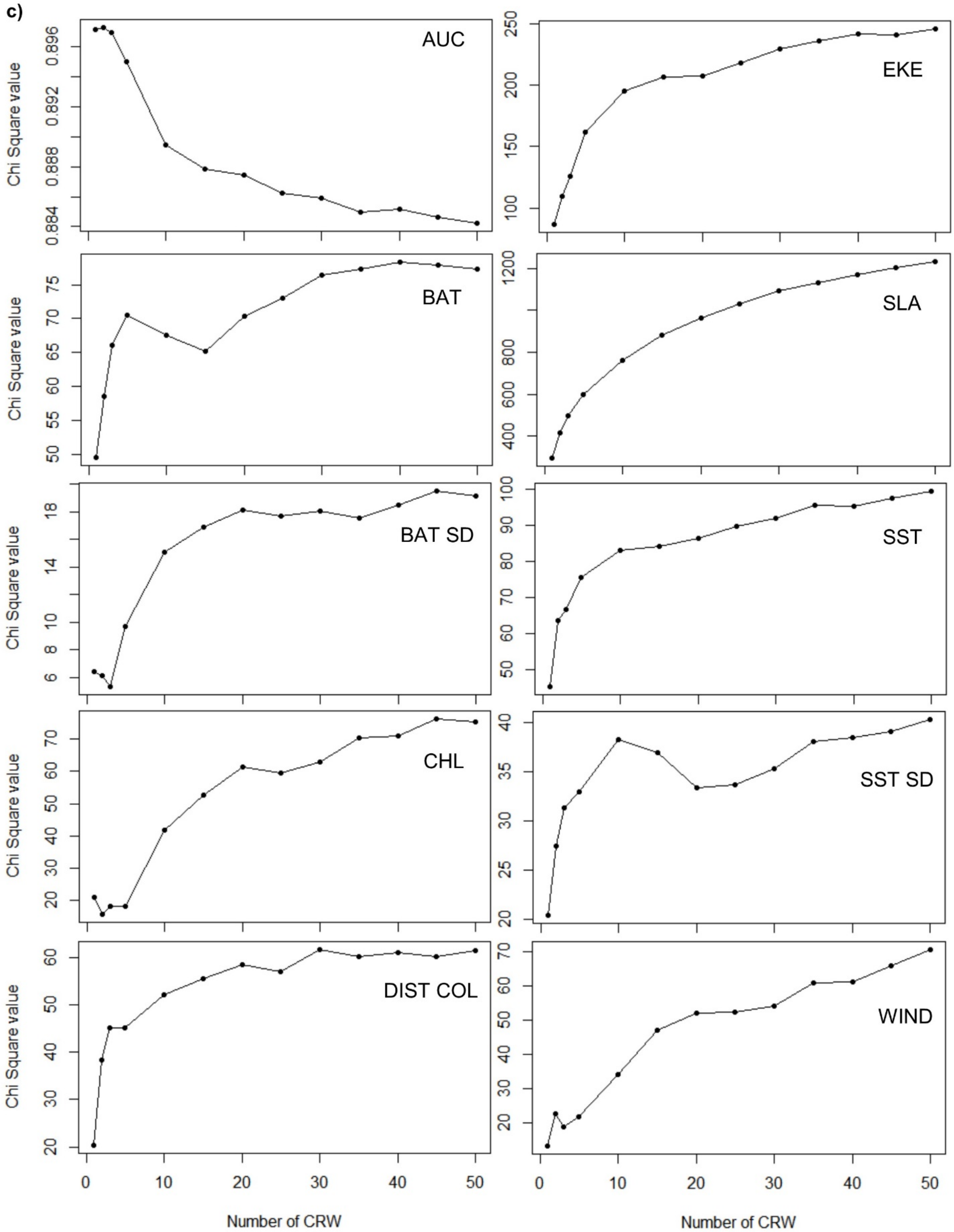
c)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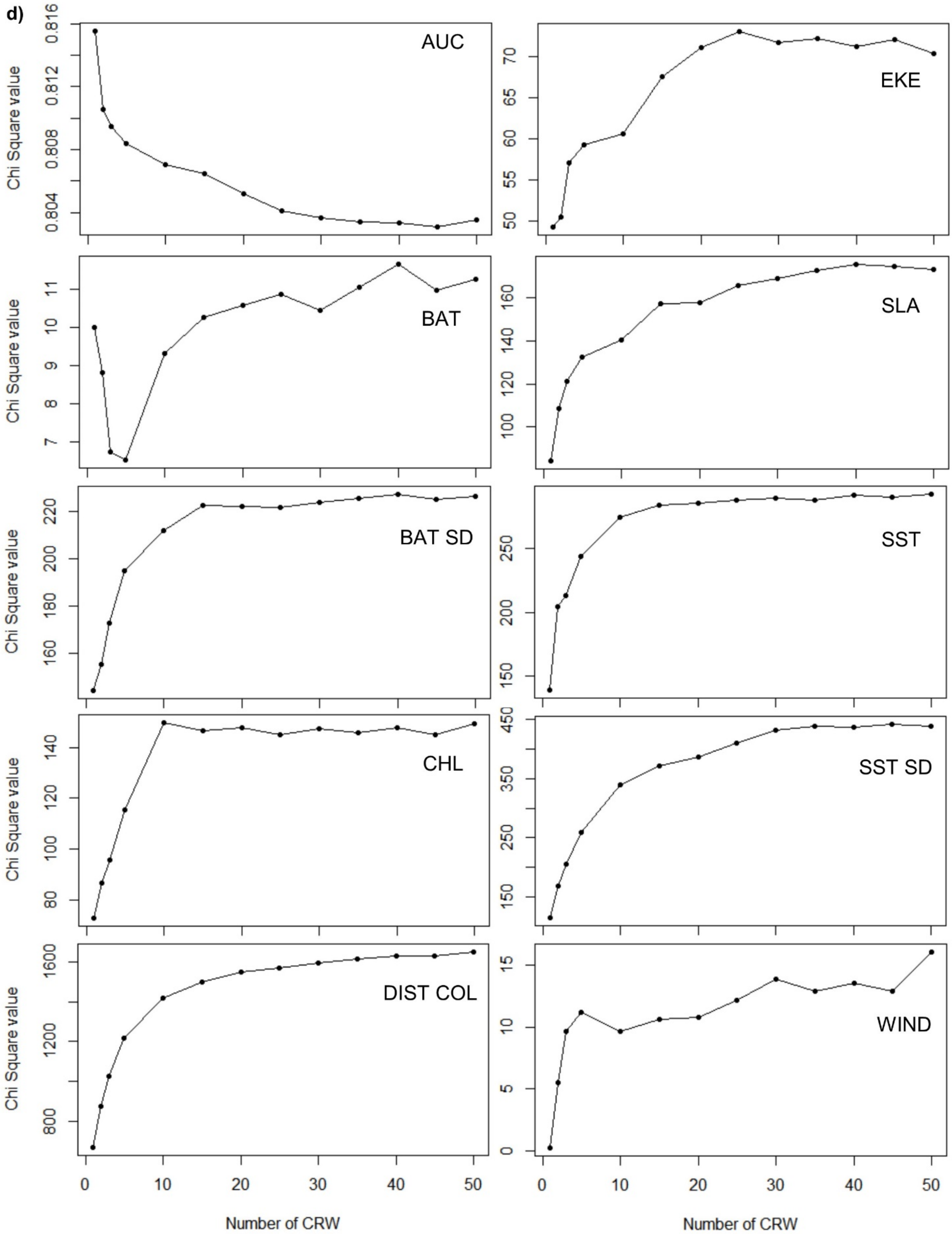

Figure S1. Chi-square values of predictor variables and AUC of habitat models with an increasing number of pseudo-absences for a) non-breeding b) pre-laying exodus c) incubation and d) late breeding**.**