Variability in sea ice cover and climate elicit sex specific responses in an Antarctic predator

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Supplementary information

Table S1 | General information of the 43 post-moulting SESs (22 males and 21 females). It includes sex, dive start and end date, date of return when the tag did not stopped, number of Argos position transmitted daily, animal weight and snout-to-tail length upon deployment, total number of dives, mean number of dives per day and mean distance travelled per day between the first and last locations of each day. Additional information on behaviour towards sea ice is also included such as their maximal distance from the sea ice edge and their hunting time per dive. Negative distances refer to distances into the pack from the ice edge, and positive distances refer to distances north of the ice edge. Mean are expressed ± SD. Finally, individuals not included in all analysis are detailed in the analysis column.

ID	Sex	Dive start date	Dive end date	Date of return to the colony (if tag did not stopped)	Number of position transmitted daily	Weight (kg)	Length (cm)	Total dives	Daily number of dives	Distance travelled per day (km)	Maximal distance from the sea ice edge (km)	Hunting time per dive within sea ice from March (min)	Analysis
2004_1	M	04/03/2004	29/03/2004		8 ± 4	368	250	553	25 ± 12	75 ± 49	-62	5,4 ± 3,9	×
2004_2	M	27/02/2004	09/07/2004		18 ± 7	385,5	267	6133	46 ± 20	34 ± 33	-192	11,3 ± 7,3	×
2004_3	F	01/03/2004	19/07/2004		14 ± 9	297,5	233	5363	38 ± 20	34 ± 29	-345	14,6 ± 11,3	×
2004_5	M	25/02/2004	06/08/2004		17 ± 6	469,5	282	7209	46 ± 18	22 ± 31	-341	14 ± 10	×
2004_6	F	22/02/2004	07/08/2004		12 ± 6	347	240	4248	27 ± 12	28 ± 26	-165	22 ± 10,2	×
2004_7	F	29/02/2004	02/08/2004		15 ± 9	295,5	238	6021	40 ± 19	42 ± 28	-110	8,5 ± 4	×
2004_8	M	27/02/2004	08/08/2004	6 then South	17 ± 9	274	235	7530	50 ± 25	40 ± 34	-610	5,4 ± 4,7	×
2004_10	F	29/02/2004	08/08/2004		16 ± 10	363,5	258	7503	46 ± 24	31 ± 29	-367	13 ± 10	×
2008_1	M	01/01/2008	08/09/2008		9 ± 5	266	230	8815	39 ± 30	33 ± 26	-161	10 ± 7,5	×
2008_2	F	24/12/2007	27/05/2008		14 ± 7	169	200	6031	39 ± 16	44 ± 30	-8	-	Only used in sea ice advance analysis
2008_6	F	24/01/2008	16/08/2008		11 ± 4	290	242	6200	31 ± 10	42 ± 26	-3	11,3 ± 6,2	×
2008_7	F	27/01/2008	11/07/2008		15 ± 7	377	267	5253	32 ± 13	44 ± 32	-244	17 ± 9,8	×
2009_16	M	01/01/2009	03/06/2009	6	17 ± 7	258	249	5887	40 ± 18	34 ± 28	-155	9,4 ± 7	×
2011_4	M	31/01/2011	16/05/2011		26 ± 7	800	330	4438	42 ± 11	33 ± 39	-316	13,5 ± 7,1	×
2011_6	F	19/02/2011	16/05/2011		31 ± 9	284,6	233	4230	50 ± 11	32 ± 31	-4	10,6 ± 5,8	Absent in sea ice advance analysis
2011_7	M	26/01/2011	15/04/2011		34 ± 10	452,5	280	4749	60 ± 19	36 ± 39	-302	9,3 ± 6,5	×
2011_9	M	27/01/2011	16/05/2011		18 ± 6	628,5	326	3487	32 ± 12	29 ± 37	-409	14,6 ± 9	×
2011_10	F	24/02/2011	16/05/2011		20 ± 9	330	250	3041	37 ± 11	35 ± 28	-37	14,5 ± 8	×
2012_1	M	23/01/2012	14/09/2012		18 ± 6	523	291	9799	43 ± 18	31 ± 28	-434	10,6 ± 11,1	×
2012_3	M	23/01/2012	26/04/2012		24 ± 6	454	277	4297	45 ± 11	36 ± 38	-286	13,2 ± 6,2	×

2012_2	F	07/02/2012	28/09/2012	9	20 ± 9	303	233	7178	31 ± 12	28 ± 21	-58	17 ± 9,1	×
2013_1	F	27/02/2013	19/10/2013	10	18 ± 6	340	262	8079	34 ± 9	43 ± 30	-130	17,5 ± 10,4	×
2013_2	M	08/03/2013	02/11/2013	11	17 ± 10	1100	370	8321	39 ± 17	33 ± 41	-482	17,4 ± 10,5	×
2013_3	M	10/02/2013	17/03/2013		22 ± 9	468	280	1513	46 ± 9	67 ± 41	-140	7,2 ± 5,7	×
2013_4	M	03/03/2013	09/09/2013	9	18 ± 7	850	333	6064	35 ± 12	36 ± 36	-699	18,1 ± 11,5	×
2013_5	F	24/02/2013	17/12/2013	9 then South	22 ± 8	336	254	11732	43 ± 16	29 ± 27	-745	16 ± 11,9	×
2013_7	F	17/02/2013	13/10/2013		19 ± 7	410	248	9204	42 ± 14	43 ± 36	-256	15,1 ± 10,7	×
2013_9	M	11/02/2013	14/03/2013		24 ± 6	470	300	1517	47 ± 15	63 ± 45	-157	9,1 ± 5,8	×
2013_11	M	11/02/2013	08/10/2013		23 ± 7	556	256	10151	44 ± 13	22 ± 32	-962	12 ± 8,1	×
2013_12	M	17/02/2013	07/10/2013	10	19 ± 7	1150	375	7728	36 ± 12	31 ± 21	-164	23,3 ± 10	×
2013_13	M	10/02/2013	20/04/2013		23 ± 6	600	321	3501	50 ± 17	50 ± 37	-221	6,8 ± 6	×
2013_14	M	17/03/2013	24/11/2013	11	20 ± 8	300	270	10074	42 ± 16	19 ± 32	-743	15 ± 11,2	×
2013_15	F	10/02/2013	29/09/2013	10	20 ± 7	366	248	8335	38 ± 9	47 ± 26	-121	17,8 ± 10,3	×
2013_18	F	07/02/2013	03/08/2013		23 ± 9	346	255	6723	41 ± 15	34 ± 30	-192	21,6 ± 8,5	×
2014_2	F	25/01/2014	30/03/2014		24 ± 10	304	255	2793	48 ± 15	56 ± 31	-34	8,3 ± 6,3	×
2014_3	F	25/01/2014	04/10/2014	10	16 ± 6	293	244	7038	29 ± 8	28 ± 21	-64	28 ± 10,1	×
2014_4	F	30/01/2014	12/03/2014		22 ± 9	265	236	1840	45 ± 13	57 ± 32	31	-	Only used in sea ice advance analysis
2014_6	F	28/01/2014	30/09/2014	9	19 ± 6	266	243	8241	36 ± 10	32 ± 23	-128	22,7 ± 9,2	×
2014_7	M	26/12/2013	23/10/2014	7 then South	19 ± 9	405	277	11722	46 ± 21	32 ± 32	-857	9,1 ± 8,3	×
2014_8	F	30/01/2014	21/09/2014		17 ± 6	270	247	7249	34 ± 10	28 ± 25	-203	21,2 ± 10,1	×
2014_9	M	29/12/2013	11/09/2014		12 ± 6	700	322	4233	22 ± 10	35 ± 32	-195	23,5 ± 11,1	×
2014_10	M	27/12/2013	27/09/2014	6 then North	14 ± 8	700	306	7876	35 ± 14	27 ± 36	-241	14,5 ± 8,7	×
2014_11	F	29/01/2014	17/09/2014		24 ± 13	295	249	8346	38 ± 19	28 ± 26	-148	14,7 ± 9,2	×
Mean ± SD or sum	–	–	–		18 ± 9	–	–	273542	39 ± 17	34 ± 31		14 ± 10	–
Mean ± SD or sum males	–	–	–		–	554 ± 248	292 ± 40	135534	41 ± 19	32 ± 34	-370 ± 254 (min males = -962)	13 ± 10	–
Mean ± SD or sum females	–	–	–		–	312 ± 51	245 ± 14	138008	38 ± 15	36 ± 28	-159 ± 174 (min females = -745)	17 ± 11	–

Individual variability in seal foraging activity response to inter-annual sea ice cover anomaly

Males

When taking into account the individual variability in the analysis, only 14/21 males were foraging in both negative and positive SIC anomalies and among these individuals the same relation (i.e. hunting times were longer in years with lower sea ice concentration) was observed on 9/14 males and was significant for 9/14 males (Figure S1a). When bootstrapping at the individual level for males, the same relation was observed with hunting times 4.9 min/dive longer in negative sea ice concentration anomalies (50% of the median hunting time; Figure S2a), confirming the significance of the relation despite individual variability.

Regarding the effect of the timing of sea ice advance on male foraging activity when taking into account the individual variability in the analysis, only 14/19 males were foraging in both groups of earlier and later sea ice advance and among these individuals higher hunting times in earlier sea ice advance was only observed for 5/14 males and significant for only 2/14 males. This confirmed the weak effect of the timing of sea ice advance on males in this study (Figure S1c). Moreover, when bootstrapping at the individual level for males, the difference between hunting times was very low (i.e. 0.6 min/dive longer, 7% of the median hunting time; Figure S2c), confirming a second time the weakness of this relation for males and the important individual variability.

Females

When taking into account the individual variability in the analysis, only 12/17 females were foraging in both negative and positive SIC anomalies and among these individuals the same relation (i.e. hunting times were longer in years with higher sea ice concentration) was observed on 8/12 females and was significant for 5/12 females (Figure S1b). When bootstrapping at the individual level for females, the same relation was observed with hunting times 4.6 min/dive longer (28% of the median hunting time; Figure S2b), confirming the significance of the relation despite individual variability.

Regarding the effect of the timing of sea ice advance on female foraging activity when taking into account the individual variability in the analysis, 14/14 females were foraging in both groups of earlier and later sea ice advance and among these individuals higher hunting times in earlier sea ice advance was observed for 9/14 females and significant for 7/14 females. This confirmed the important effect of earlier sea ice advance on the majority of individuals (Figure S1d). However, when bootstrapping at the individual level for females, the same relation was observed but the difference in hunting times was lower (i.e. 3.5 min/dive longer, 30% of the median hunting time; Figure S2d), suggesting that individual variability was driving in part the relation.

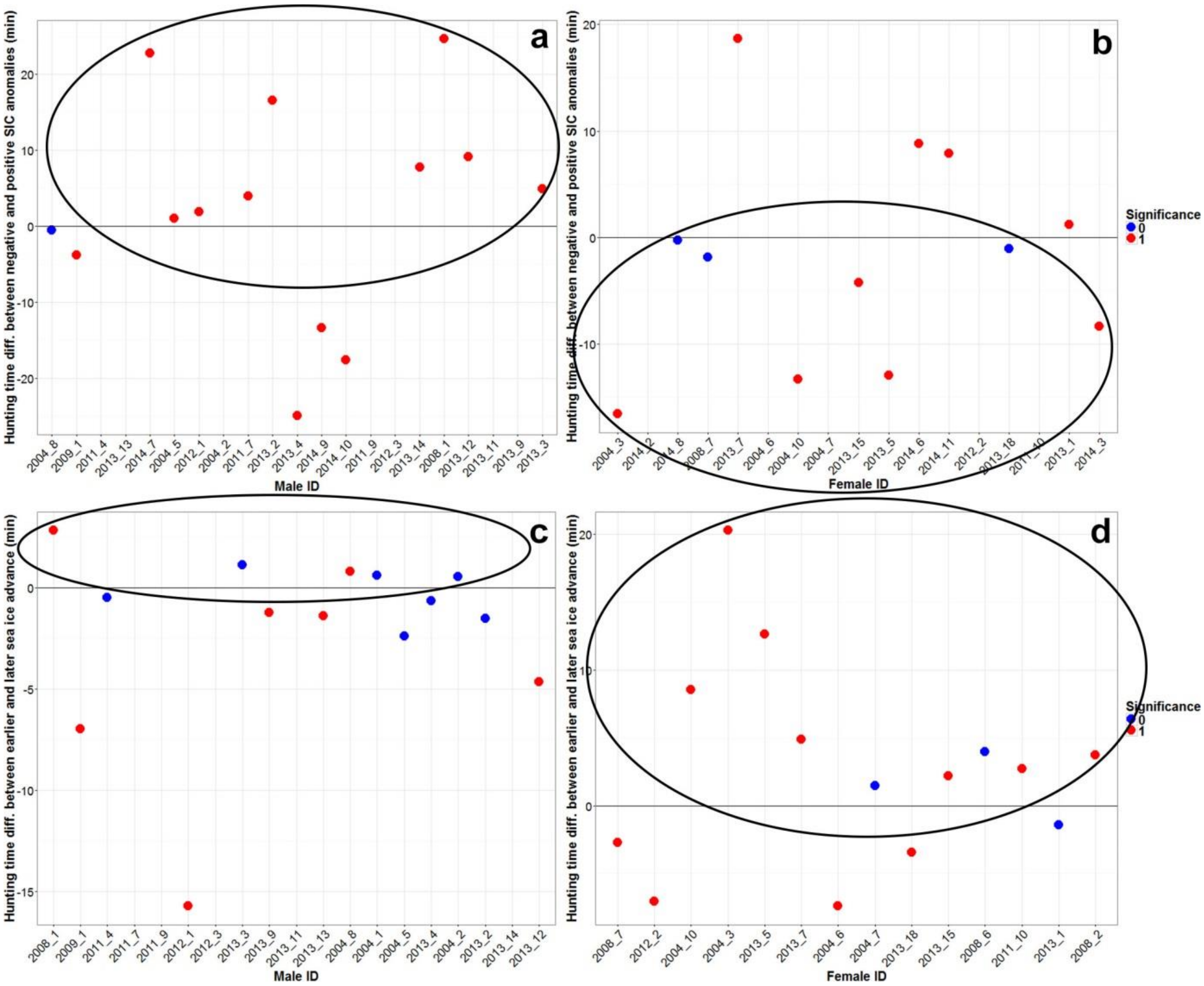

Figure S1 | Individual variability of the influence of sea ice changes on male and female foraging activity from 2004 to 2014. Observed differences between negative and positive sea ice concentration anomalies per individual are represented for the (**a**) 21 males and (**b**) 17 females. Observed differences between earlier and later sea ice advance per individual are represented for the (**c**) 19 males and the (**d**) 14 females. Significance of the relation was obtained from the comparison of the distribution of the 10,000 differences in hunting time from the 10,000 random pairs of groups, to the observed difference of hunting time from the two groups based on sea ice concentration anomalies for each individual. Significant relations are represented by a red dot (i.e. p-value < 0.05) in contrast to blue dot representing non-significant relations (i.e. p-value ≥ 0.05). Absence of dots for some individuals means they used only one type of sea ice groups along their total trip. Ellipses represent where most seals should be based on the relation computed on all individuals.

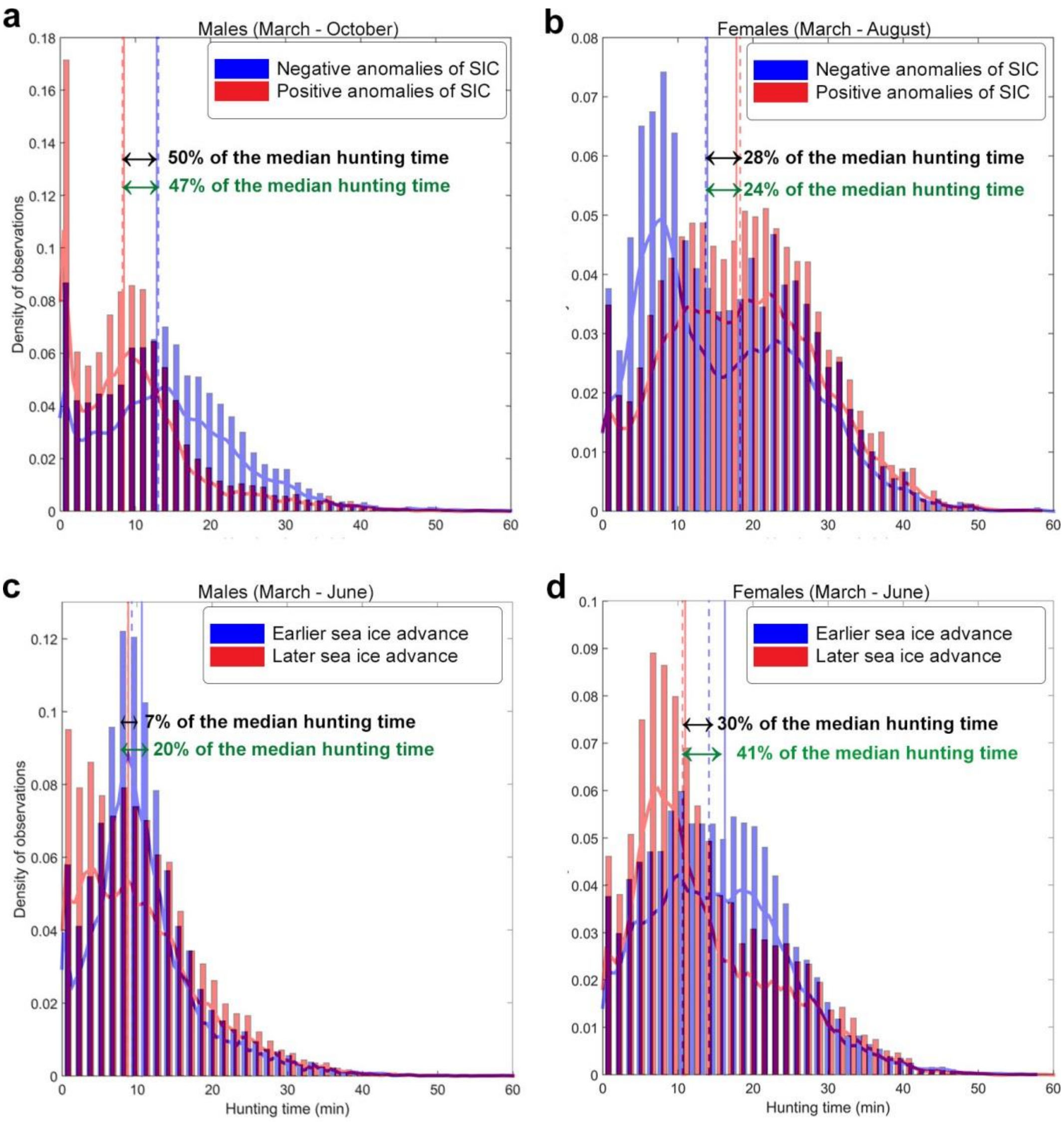

Figure 2 | Influence of sea ice changes on male and female foraging activity from 2004 to 2014 taking into account individual variability. Normalized histograms of the sum of observations in each bin of hunting time (*i.e.* a proxy of seal foraging activity expressed in minutes) are represented for negative or positive sea ice concentration anomalies (see Methods) for 100 bootstrap samples. For each bootstrap sample, sample composition was randomized at the individual level to assess whether the observed population-level difference could be due to between-individual variability. We randomly selected with replacement **(a)** 21 males among the 21 males and **(b)** 17 females among 17 females. The same histograms are presented for earlier and later advance of sea ice for 100 bootstrap samples where we randomly selected with replacement **(c)** 19 males among the 19 males and **(d)** 14 females among the 14 females. For each group of anomalies, the probability density function was superimposed and the dashed lines represent the bootstrapped median hunting time for each group of anomalies for males and females. Continuous lines represent the observed median hunting times when selecting all individuals, not taking in account individual variability (as presented in Fig. 3 of the main text). The percentages of difference in hunting times between two groups are written in black for the bootstrap samples and in green for the observed sample: except for the effect of sea ice advance on males, the bootstrap and observed samples were similar, suggesting that the difference in hunting was not the sole result of individual. Please note that hunting times equal to 0 were removed for illustration purposes.

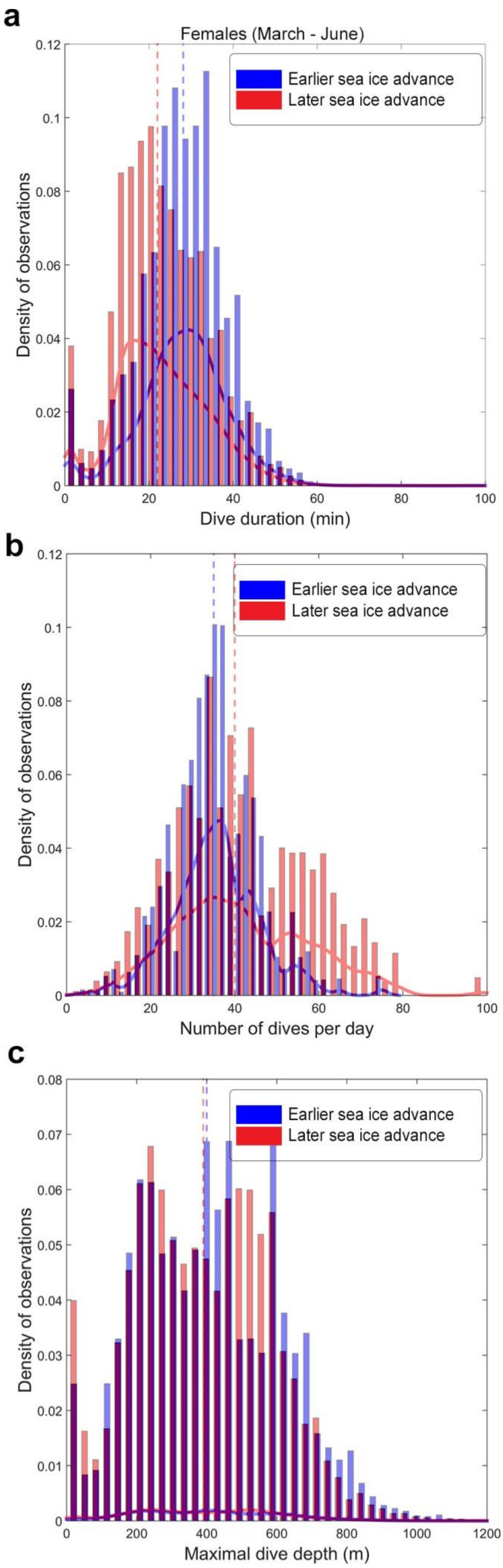
a
Females (March - June)
Earlier sea ice advance
Later sea ice advance
Density of observations
Dive duration (min)
b
Earlier sea ice advance
Later sea ice advance
Density of observations
Number of dives per day
c
Earlier sea ice advance
Later sea ice advance
Density of observations
Maximal dive depth (m)

Figure S3 | Influence of the timing of sea ice advance on female diving behaviour from 2004 to 2014. Normalized histograms of the sum of observations in each bin of (**a**) dive duration (expressed in minutes), (**b**) the number of dives per day and (**c**) the maximal dive depth (expressed in meters) are represented for earlier and later advance of sea ice. For each group of anomalies, the probability density function was superimposed and the dashed lines represent the median of each parameter for each group of anomalies for females.

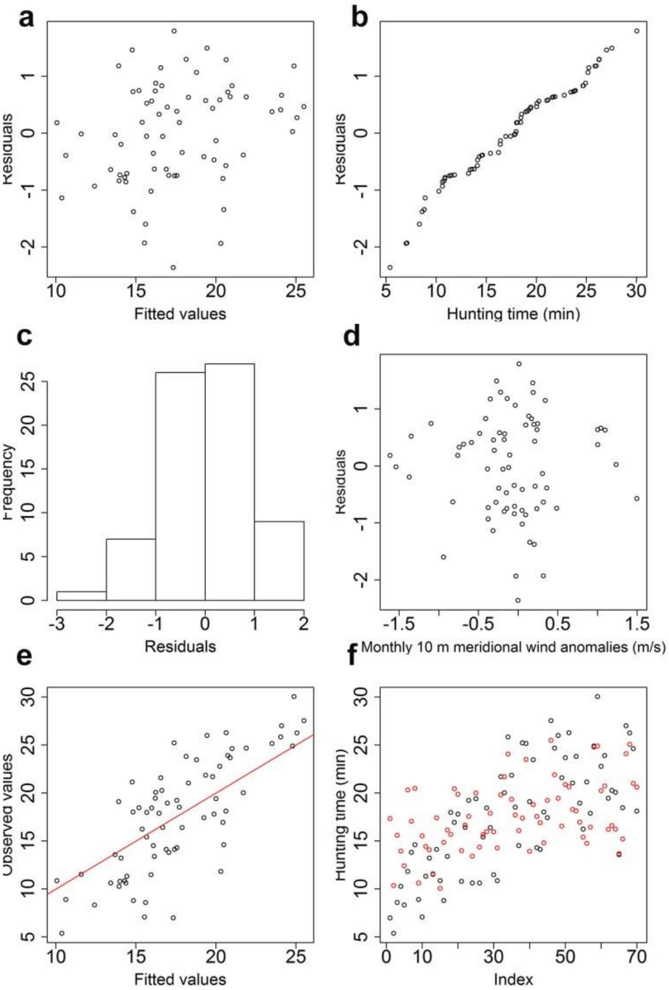

Figure S4 | Diagnostic of the model examining the relationships between foraging activity and meridional near-surface wind anomalies for females at the monthly scale. To verify the homogeneity and normality of residuals Pearson residuals were plotted against fitted values (**a**), against the explanatory variable (**d**), their distribution was drawn on a histogram (**c**) and on a normal QQ plot (**b**). Finally to examine the quality of the prediction, observed values were plotted against fitted values (**e**) and their distribution were superimposed (**f**) with black dots observed values and red dots fitted values.

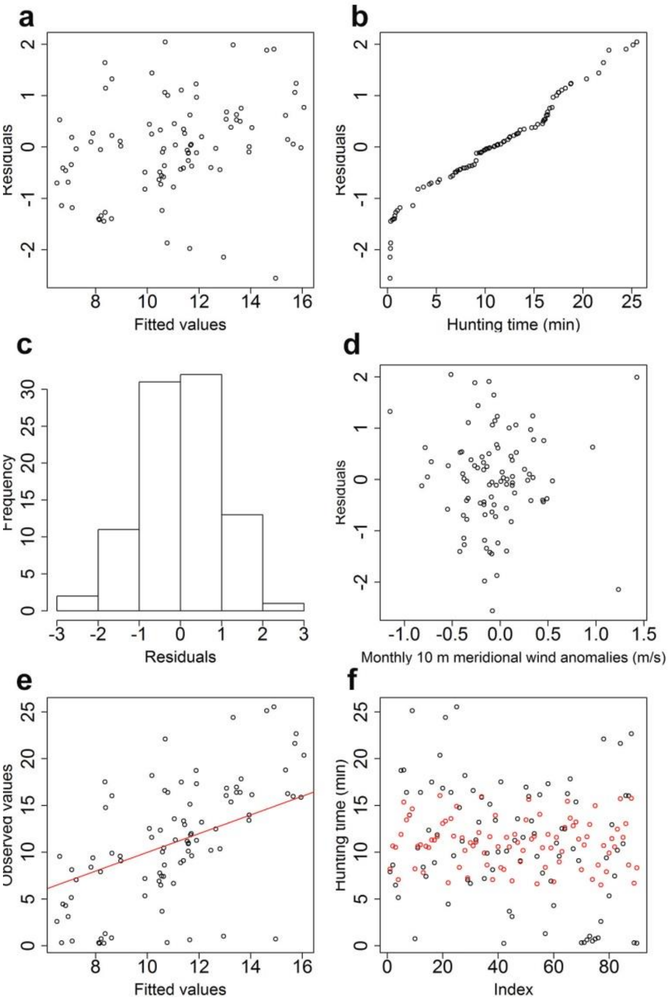

Figure S5 | Diagnostic of the model examining the relationships between foraging activity and meridional near-surface wind anomalies for males at the monthly scale. To verify the homogeneity and normality of residuals Pearson residuals were plotted against fitted values (**a**), against the explanatory variable (**d**), their distribution was drawn on a histogram (**c**) and on a normal QQ plot (**b**). Finally to examine the quality of the prediction, observed values were plotted against fitted values (**e**) and their distribution were superimposed (**f**) with black dots observed values and red dots fitted values.