Supplementary material

Materials and methods

(a) Capture

We captured and equipped sixty ringed seals with Satellite-Relay Data Loggers (SRDLS, Sea Mammal Research Unit, University of St Andrews, St Andrews, Scotland) in Svalbard, Norway during two time periods, before and after a major collapse in sea-ice. Twenty-two animals were captured in "normal" sea-ice conditions in 2002-2003 and 38 were captured following the collapse of sea-ice, in 2010-2012 (table 1). We captured the seals using drift nets set from shore and after capture placed the seals in individual restraint nets where they were weighed (Salter spring scales ± 0.5 kg) and sex was determined. The SRDLs were glued to the hair on the back mid-dorsally using quick-setting epoxy. The tags were on average 1.1 % of the seals' body mass (range: 0.4 to 2.0 %); all were below the recommended maximum of 2.0 % [23]. All animal-handling protocols were approved by the Norwegian Animal Research Authority and the Governor of Svalbard.

(b) Probability of taking an offshore trip

Nineteen of the captured seals (9 in 2002-2003, 10 in 2010-2012) embarked on offshore trips. Three seals took two trips each bringing the total number of offshore trips to 22, 11 from each time period (table 1). We conducted a generalised linear model (GLM) to test if the probability of a seal taking an offshore trip was dependent on mass, sex or time period. We used the binomial family with a logistic link in the GLM models. We used BIC for model selection [24] and examined residual plots to verify model assumptions.

(c) Data collection and preparation

The SRDLs collected information on the seals' movements and behaviour patterns. The SRDLs transmitted the collected data via the ARGOS satellite system (System Argos, Toulouse, France; see [25,26]). We conducted all data analyses in R version 3.0.2 [27]. Results are presented as mean (± 95 % CI) unless otherwise indicated.

We pre-filtered the transmitted ARGOS locations using the speed-distance-angle (SDA) filter in the argosfilter package [28]. We subsequently filtered the SDA locations in the CRAWL package with a stopping model to account for time periods spent hauled out [29].

(d) First-passage time analysis

We conducted a first-passage time (FPT) analysis on each seal's track(s). FPT is defined as the time it takes for a seal to cross a circle of a given radius and is used to identify the spatial scale where the animals conduct area restricted search (ARS) behaviour [11]. We removed time periods spent hauled out so the analyses reflect time spent in the water. FPTs were calculated for 5 km intervals along the seal's paths for radii ranging from 5 to 150 km (intervals of 500 m from 5 to 20 km and intervals of 2.5 km from 25 to 150 km). We plotted the variance of the log-transformed FPTs against the radii for each seal to identify the radius of maximum variance [11]. A GLM with the binomial family and logistic link was used to test if the number of trips with clear ARS behaviour varied between the two time periods.

(e) Environmental and dive variables

We retrieved bathymetry data at 500 m resolution from the International Bathymetric Chart of the Arctic Ocean version 3.0 [30]. We obtained ASI Algorithm SSMI-SSMIS sea-ice concentration data, originally computed at and provided by IFREMER, Brest, France, as 5-day median-filtered and gap-filled products for 2002-2003 and 2010-2012 from the Integrated Climate Date Center (ICDC, http://icdc.zmaw.de/, University of Hamburg, Hamburg,

Germany; [31,32]). Data on sea-ice age was originally provided by Mark Tschudi (CCAR, University of Colorado, Boulder, CO), which we obtained in netCDF format from the ICDC for 2002-2003 and 2010-2012 [33].

The dive variables we included in the analyses were dive duration, surface duration between two dives, maximum dive depth and proportion of the water column used (or proportion of the top 100 m in the Arctic Ocean Basin).

(f) Habitat-use

To investigate the habitat used by the ringed seals, we extracted the sea-ice concentration, sea-ice age and distance from the coastline for hourly points along the seals' tracks. We investigated whether this varied between time periods using linear-mixed effect models as described below.

(g) Statistical analyses

We performed linear mixed effects (LME) models for each dive variable, environmental variable and proportion of time hauled out per day, with the response variable transformed as needed to fulfill model assumptions [34]. We used the Gaussian family with the identity link in the LME models. Explanatory variables were time period, area (shelf vs Arctic Ocean Basin), mass and sex. BIC was used for model selection. A unique number assigned to each trip was included as a random effect and as a grouping factor in the corAR1 temporal autocorrelation term [35]. We conducted post-hoc multiple comparison tests using Tukey's pairwise comparison and examined residual plots to verify model assumptions [34].

Because of inter-annual variability in sea-ice conditions, we also investigated models with trip number and year as nested random effects. The BIC selected model was always the model with only trip number as a random effect. Also, the differences in parameter estimates

and statistical significance were minor between the two sets of models and residual plots made from models with only trip number as a random effect showed no patterns with respect to year. Because of this, we decided to use BIC to guide model selection and used models with only trip number as a random effect.

References:

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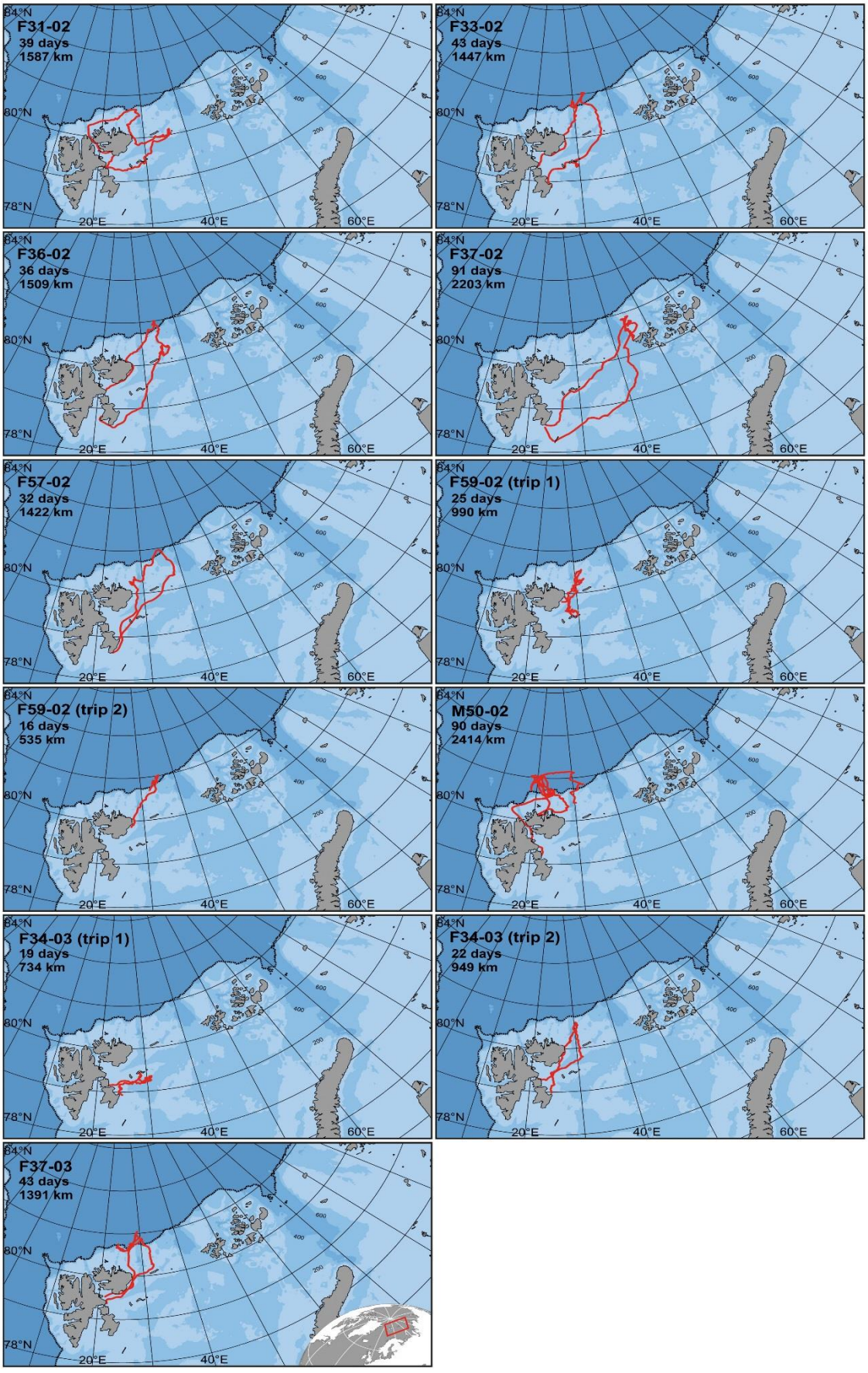
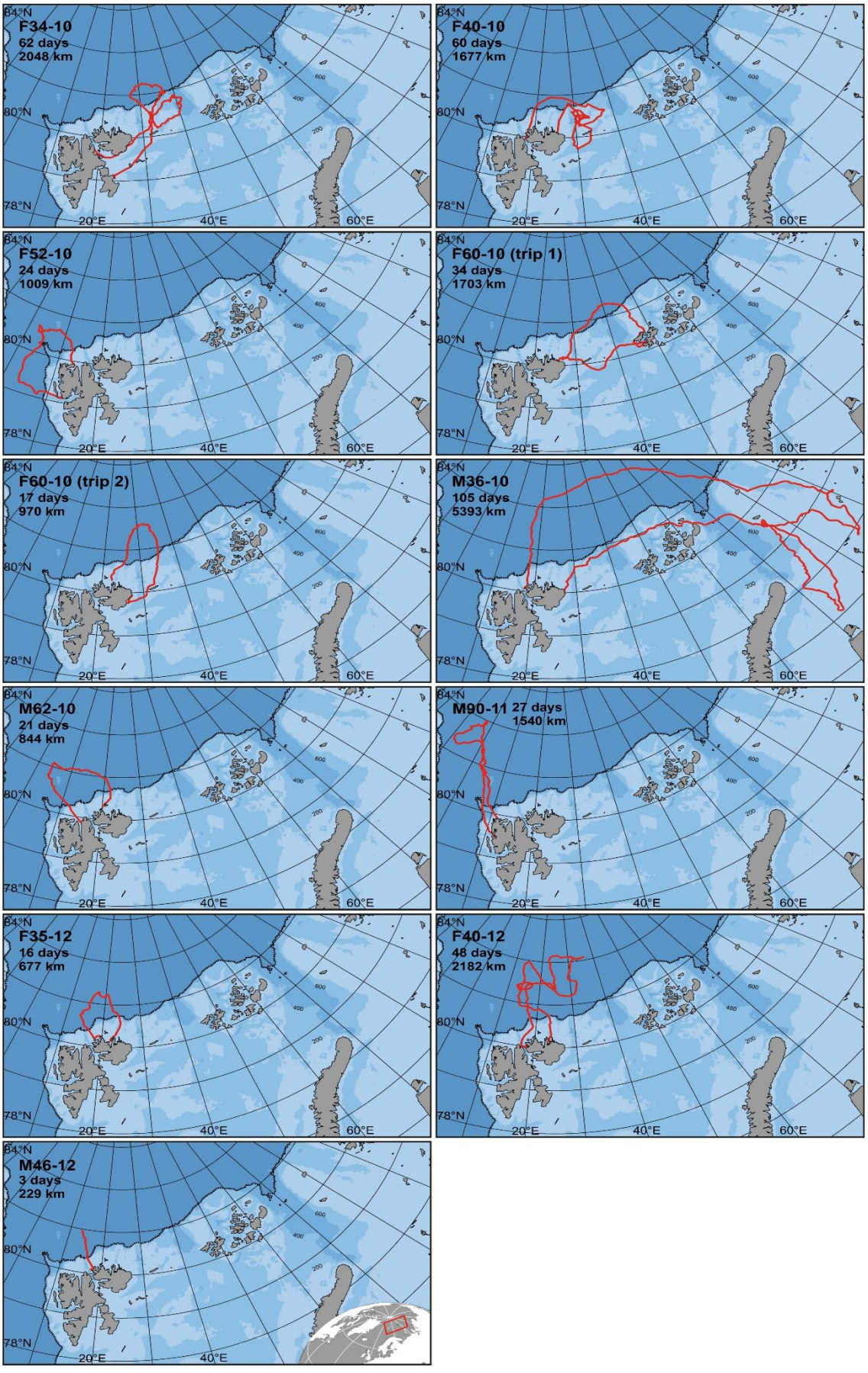

F31-02
39 days
1587 km
F33-02
43 days
1447 km
F36-02
36 days
1509 km
F37-02
91 days
2203 km
F57-02
32 days
1422 km
F59-02 (trip 1)
25 days
990 km
F59-02 (trip 2)
16 days
535 km
M50-02
90 days
2414 km
F34-03 (trip 1)
19 days
734 km
F34-03 (trip 2)
22 days
949 km
F37-03
43 days
1391 km
84°N
80°N
78°N
20°E
40°E
60°E

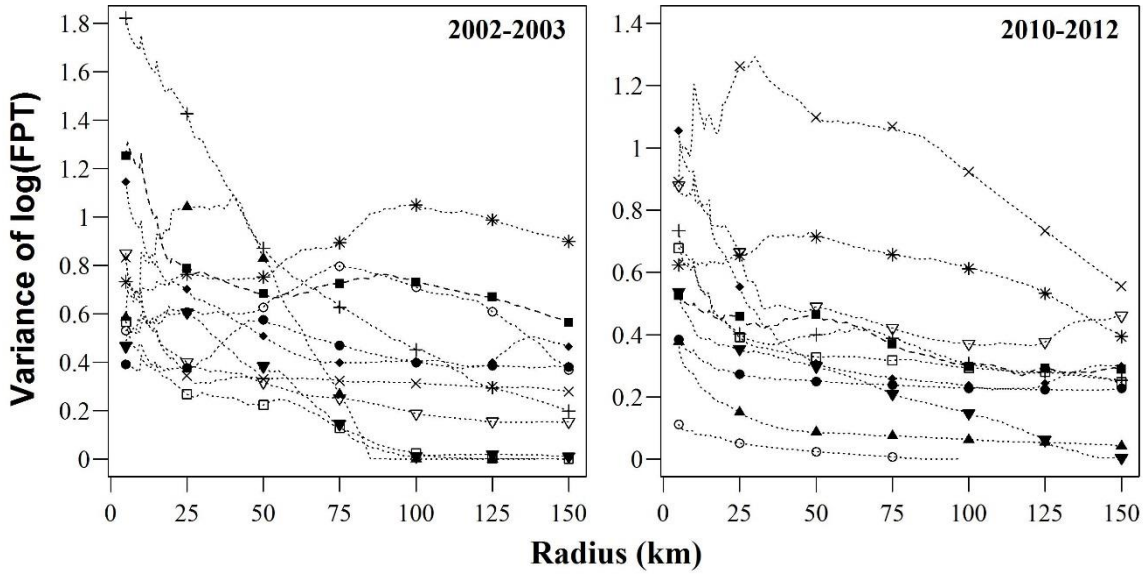
Supplementary Figure 1.

Individual tracks for the eleven offshore foraging trips undertaken by ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2002-2003 in Svalbard, Norway. Trip duration and length for each offshore trip are included. The black stippled line denotes the continental shelf.


F34-10
62 days
2048 km
F40-10
60 days
1677 km
F52-10
24 days
1009 km
F60-10 (trip 1)
34 days
1703 km
F60-10 (trip 2)
17 days
970 km
M36-10
105 days
5393 km
M62-10
21 days
844 km
M90-11 27 days
1540 km
F35-12
16 days
677 km
F40-12
48 days
2182 km
M46-12
3 days
229 km
84°N
80°N
78°N
20°E
40°E
60°E

Supplementary Figure 2.

Individual tracks for the eleven offshore foraging trips undertaken by ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2010-2012 in Svalbard, Norway. Trip duration and length for each offshore trip are included. The black stippled line denotes the continental shelf.



Supplementary Figure 3.

Variance in log first-passage time (FPT) corresponding to different radii for the twenty-two offshore foraging trips undertaken by the ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2002-2003 and 2010-2012 in Svalbard, Norway.

Model	BIC	Δ BIC	BIC_w
Mass	**72.24**	**0.00**	**0.51**
Mass*Sex	73.73	1.48	0.24
Mass+Sex	74.43	2.19	0.17
Mass*Sex+TimePd	77.82	5.58	0.03
Mass+Sex+TimePd	78.59	6.34	0.02
Sex	79.72	7.47	0.01
TimePd	81.76	9.51	0.00

Supplementary Table 1.

The Bayesian information criterion (BIC), change in BIC and weight of BIC for the generalised linear models comparing the probability of embarking on an offshore late-summer foraging trip to mass, sex and time period (i.e. 2002-2003 and 2010-2012) for the 60 ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2002-2003 and 2010-2012 in Svalbard, Norway. The BIC selected model is bolded.

Coefficients	Estimate	Std. error	z-value	p-value
Intercept	2.263	1.053	2.149	0.032
Mass	-0.057	0.020	-2.819	0.005

Supplementary Table 2.

The BIC selected model results for the probability of taking an offshore foraging-migration trip for the 60 ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2002-2003 and 2010-2012 in Svalbard, Norway.

Variable	2002-2003	2010-2012	p-value
Mean latitude where ice is first encountered (°N)	80.0 (79.7 to 80.5)	81.0 (80.5 to 81.7)	0.0038
Mean distance from any coastline (km)	67 (41 to 93)	132 (95 to 168)	0.0026
Proportion of hourly locations over Arctic Ocean Basin (%)	20 (5 to 52)	58 (17 to 90)	0.0719
Mean sea ice concentration along track (%)	45 (33 to 57)	40 (23 to 58)	0.6053
Mean sea ice age along track (yrs)	1.2 (0.9 to 1.6)	1.2 (0.8 to 1.7)	0.9430

Supplementary Table 3.

Results of linear mixed models (mean ± 95 % CI) comparing movement and dive parameters for ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2002-2003 and 2010-2012 in Svalbard, Norway.

Variable	Model	BIC	Δ BIC	BIC_w
Dive duration (min)	**TimePd*Shelf**	**57888.54**	**0.00**	**0.53**
	TimePd*Shelf+Mass	57888.81	0.27	0.47
	TimePd	58331.28	442.74	0.00
	Mass	58335.16	446.62	0.00
	Sex	58336.57	448.03	0.00
Surface duration (min)	**TimePd*Shelf**	**71709.11**	**0.00**	**1.00**
	TimePd*Shelf+Mass	71721.07	11.96	0.00
	TimePd	71797.85	88.74	0.00
	Sex	71809.63	100.52	0.00
	Mass	71813.19	104.08	0.00
Max depth (m)	**TimePd*Shelf**	**271190.90**	**0.00**	**0.66**
	TimePd*Shelf+Mass	271192.20	1.30	0.34
	TimePd	271782.10	591.20	0.00
	Sex	271783.60	592.70	0.00
	Mass	271785.20	594.30	0.00
Haul-out percentage	**TimePd*Shelf**	**-241.19**	**0.00**	**0.63**
	TimePd	-239.22	1.96	0.24
	Sex	-237.75	3.44	0.11
	Mass	-234.29	6.90	0.02
	TimePd*Shelf+Mass	-227.95	13.24	0.00
Time over Arctic Ocean basin (%)	**TimePd**	**28.34**	**0.00**	**0.47**
	TimePd+Mass	28.94	0.60	0.35
	Mass	30.66	2.32	0.15
	Sex	33.59	5.25	0.03
Distance travelled (km/d)	**TimePd**	**35489.85**	**0.00**	**1.00**
	Mass	35508.80	18.95	0.00
	TimePd*Shelf	35509.07	19.22	0.00
	Sex	35512.46	22.61	0.00
	TimePd*Shelf+Mass	35514.21	24.36	0.00

Supplementary Table 4.

Bayesian Information Criterion (BIC) tables showing the BIC value, change in BIC and BIC weight for the models run for each variable for the 22 offshore foraging trips undertaken by ringed seals equipped with Satellite-Relay Data Loggers (SRDLs) in 2002-2003 and 2010-2012 in Svalbard, Norway. The BIC selected model is bolded.