

B. Supplementary tables

Foraging movements during two years of extreme and contrasted sea ice conditions

Table B1: Movement parameters for the Southern fulmars from a telemetric study in 2000 and 2001. Posterior medians and 95% credible limits for movement parameters estimated from the state-space model are shown, specifically the DCRWS (first difference correlated random walk switching) model. Subscripts 1 and 2 refer to the travelling and foraging behavioral modes, respectively. Turning angle Θ is measured in radians and traveling speed Υ is measured in km.h^{-1} . The degree of correlation in both movement speed and direction is Γ ; and κ_1 is the probability of being in behavioral mode 1 at time t , given the same behavioral mode at time $t - 1$; while κ_2 is the probability of being in behavioral mode 1 at time t , given behavioral mode 2 at time $t - 1$.

years	2000			2001		
Percentiles	0.025	0.5	0.975	0.025	0.5	0.975
Υ_1	12.4	29	66.6	2.4	24.7	63.2
Υ_2	1.1	11.2	53	0.9	7.1	34.6
Θ_1	-0.91	-0.09	0.71	-0.72	-0.09	0.39
Θ_2	2.57	3.28	3.89	2.33	3.14	3.63
κ_1	0.02	0.4	0.94	0.08	0.62	0.93
κ_2	0	0.06	0.49	0	0.05	0.34
Γ_1	0.2	0.61	0.93	0.26	0.61	0.92
Γ_2	0.08	0.45	0.67	0.14	0.41	0.64

Model selection for the estimation of the vital rates

We started our model selection with an umbrella model based on the results of a previous analysis on the adult life cycle ($s = 2, \dots, 4$), which included birds marked as chicks and adults (Guery, 2011). This analysis tested for time variation (constant, free, or additive time variation¹), and differences among adult breeding stages. The best model selected from this analysis included:

- additive time variation among stages for detection probabilities p_s , $s = 2, \dots, 4$, with equal detection probabilities of previously successful and failed breeders $p_2 = p_3$;
- additive time variation among stages for breeding success probabilities γ_s , $s = 2, \dots, 4$, with equal breeding success between previously failed breeders and non-breeders $\gamma_3 = \gamma_4$;
- additive time variation among stages for breeding probabilities β_s , $s = 2, \dots, 4$;
- constant annual adult survival probabilities σ_s , $s = 2, \dots, 4$, with or without differences among stages; both are well supported. We thus start our model selection procedure with the model with the least number of parameters, i.e. with annual adult survival probabilities equal among adult stages $\sigma_2 = \sigma_3 = \sigma_4$.

For parametrizing our life cycle, we added the pre-breeders stage in this multi-stage model.

For pre-breeders ($s = 1$) our umbrella model includes annual time variation in the survival probability, σ_1 . To avoid identifiability issues (Giménez et al., 2004) detection (p_1),

¹“Free time-variation” means that parameters vary according to time and breeding stages differently. Additive time-variation” constraints parameters to vary in parallel among breeding stages on the logit scale (Hunter and Caswell, 2009). In other words, the temporal variations in a given parameter will be synchronous among breeding stages.

breeding (β_1), and chick raising success (γ_1) vary with additive time-variation among adults stages. Therefore, our umbrella model includes:

1. detection probabilities p_s , $s = 1, \dots, 4$, varied with additive time variations among stages, and detection probabilities of successful and failed breeders were equal $p_2 = p_3$;
2. breeding success probabilities γ_s , $s = 1, \dots, 4$, varied with additive time variations among stages and breeding success of previously failed breeders and non- breeders were equal $\gamma_3 = \gamma_4$;
3. breeding probabilities β_s , $s = 1, \dots, 4$, varied with additive time variations among stages;
4. annual adult survival probabilities σ_s , $s = 2, \dots, 4$ do not vary with time and are equal among adults stages but annual pre-breeder survival probabilities σ_1 vary freely with time.

From this umbrella model, we selected a first model for detection probabilities with additive time variations among stages (Table B2 model highlighted in bold in section 1: Detection probabilities). From this first model, we selected a second model for success probabilities with additive time variations among stages and equal breeding success of pre-breeders, failed breeders and non- breeders $\gamma_1 = \gamma_3 = \gamma_4$ (Table B2 model highlighted in bold in section 2: Success probabilities). From this second model we selected a third model for breeding probabilities with additive time variations among stages (Table B2 model highlighted in bold in section 3: Return probabilities). From this third model we selected a final model for survival probabilities with no time neither variations among stages (Table B2 model highlighted in bold in section 4: Survival probabilities).

Using model averaging of this complete set of models, we found that:

- detection probabilities vary with additive time variations among stages, and detection probabilities of pre-breeders are lower than non-breeders and breeders.
- breeding success probabilities vary with additive time variations among stages with equal breeding success between previously pre-breeders, failed breeders and non-breeders $\gamma_1 = \gamma_3 = \gamma_4$; the breeding success of previously successful breeders is higher than other stages;
- breeding probabilities vary with additive time variations among stages; breeding probabilities are the smallest for previously pre-breeders, while they are the highest for previously breeders, especially successful breeders (Fig. A3).
- annual adult survival probabilities do not vary with time, and differences among stages are small.

Table B2: Multi- state capture recapture model selection for the Southern fulmar. We tested various time variations hypothesis (column one) and differences among states (column two) for each vital rate. Free time-variation means that parameter temporal variations are different among states. Additive time-variation means that parameters temporal variations are parallel on the logit scale among states. AIC_c refers to Akaike Information Criterion (AIC) corrected for small sample size (Burnham and Anderson, 2002) and is calculated from the number of parameters K and the deviance of the model. The model with the lowest AIC_c is selected for each demographic parameter and is highlighted in bold.

time	states	K	Deviance	AIC_c
1. Detection probabilities				
additive	$1 \neq 2 = 3 \neq 4$	182	7086.64	7481.11
freely	$1 \neq 2 = 3 \neq 4$	221	7013.68	7501.38
constant	$1 \neq 2 = 3 \neq 4$	182	7196.64	7591.11
additive	$1 = 4 \neq 2 = 3$	181	7126.08	7518.21
2. Success probabilities				
additive	$1 \neq 2 \neq 3 = 4$	181	7126.08	7518.21
freely	$1 \neq 2 \neq 3 = 4$	222	7055.30	7545.44
constant	$1 \neq 2 \neq 3 = 4$	182	7093.75	7488.22
additive	$2 \neq 1 = 3 = 4$	181	7086.99	7479.12

Table B2 continued.

time	states	K	Deviance	AIC_c
3. Return probabilities				
additive	$1 \neq 2 \neq 3 \neq 4$	181	7086.99	7479.12
freely	$1 \neq 2 \neq 3 \neq 4$	223	7045.47	7538.04
constant	$1 \neq 2 \neq 3 \neq 4$	181	7159.11	7551.24
additive	$1 = 4 \neq 2 \neq 3$	180	7199.62	7589.40
additive	$1 = 3 \neq 2 \neq 4$	180	7687.16	8076.94
additive	$1 = 2 \neq 3 \neq 4$	180	8338.97	8728.75
4. Survival probabilities				
σ_1 freely; other constant	$1 \neq 2 = 3 = 4$	181	7086.99	7479.12
constant	$1 = 2 = 3 = 4$	137	7142.06	7433.01
constant	$1 \neq 2 \neq 3 \neq 4$	140	7138.60	7436.32
constant	$1 \neq 2 = 3 = 4$	138	7141.96	7435.16
constant	$1 \neq 2 \neq 3 = 4$	139	7139.50	7434.96
constant	$1 \neq 2 = 3 \neq 4$	139	7139.50	7434.96

Model selection for the study of effect of extreme sea ice condition on vital rates

We tested if extreme covariates have a:

1. *direct effect*: $ECE_t \rightarrow \theta_{t-1/t}$;
2. *indirect and lagged effect* on breeders vital rates: $ECE_t \rightarrow \theta_{t/t+1}^{2,3}$
3. *indirect and lagged effect* on breeders vital rates in *extremely poor years*:

$$ECE_t^{far} \rightarrow \theta_{t/t+1}^{2,3}.$$

We tested if the difference among stages as found in Table B2 occurs on the intercept only or both on the intercept and slope of the relationship between ECE and a vital rate. The covariates are tested for the time period from 1979 to 2010, for which sea ice conditions are available from satellite measurements. Therefore, we also tested if the time variation of vital rates were different before 1979 than the entire study period as found in Supplementary Table B2.

We started our model selection with the previously selected model in Table B2. From this model, we first selected a model for success probabilities with a direct impact of extreme sea ice conditions on the intercept only (Table B3 in bold). From this first model, we performed the model selection for breeding probabilities. Extreme sea ice conditions do not coincide with extreme breeding probabilities (AIC are higher than the best model (in bold) without effect of extreme sea ice conditions). From the first model, we performed the model selection for survival probabilities. The support for indirect and lagged effect of extreme sea ice conditions on survival probabilities is weak (smaller AIC_c weights).

To summary, among all models (1. Success probabilities to 3. Survival probabilities) our two most likely models account for 60% of AIC_c weights and include an impact of ESIC on success probabilities but not on breeding probabilities nor adult survival probabilities (Table B3, Fig. A3). The models accounting for the remaining 40% of AIC_c weights include an impact of ESIC and differences between stages in both the slope and intercept of the relationship between ECE and survival in addition to the effect of ECE on success probabilities. Supplementary Tables B4 and Table B5 show the estimate obtained from a model averaging procedure using model weights from the model selection on the impact of extreme sea ice conditions described in Supplementary Table B3.

Table B3: Effect of extreme climatic events (ECE) on vital rates (θ) of Southern fulmars: results of model selection of capture- recapture statistical models. Models are described according to the covariate tested as well as the difference between states on the slope and intercept of the relationship between vital rates and ECE covariate. The first column describes the time variation before 1979: T_{1979} . Same legend as Table B2. In addition, AIC_c weights were calculated on the complete model selection on the impact of extreme sea ice conditions on vital rates shown here.

T_{1979}	SLOPE	Intercept	K	Deviance	AIC_c	Weights
1.	Success	probabilities				
	$ECE_t \rightarrow \gamma_t$					
additive	1 = 2 = 3 = 4	2 \neq 1 = 3 = 4	109	7214.07	7442.69	0.00
constant	1 = 2 = 3 = 4	2 \neq 1 = 3 = 4	97	7222.72	7425.09	0.45
constant	2 \neq 1 = 3 = 4	2 \neq 1 = 3 = 4	98	7222.60	7427.15	0.16

Table B3 continued.

T_{1979}	SLOPE	Intercept	K	Deviance	AIC_c	Weights
2.	Return	probabilities				
	$ECE_t \rightarrow \beta_t$					
additive	$1 = 2 = 3 = 4$	$1 \neq 2 \neq 3 \neq 4$	71	7322.57	7469.02	0.00
constant	$1 = 2 = 3 = 4$	$1 \neq 2 \neq 3 \neq 4$	59	7337.68	7458.75	0.00
constant	$1 \neq 2 \neq 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	62	7332.81	7460.19	0.00
	$ECE_t \rightarrow \beta_{t+1}^{2,3}$					
additive	$1 = 2 = 3 = 4$	$1 \neq 2 \neq 3 \neq 4$	113	7253.50	7490.93	0.00
constant	$1 = 2 = 3 = 4$	$1 \neq 2 \neq 3 \neq 4$	100	7258.65	7467.56	0.00
constant	$1 \neq 2 \neq 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	101	7258.57	7469.66	0.00
	$ECE_t^{far} \rightarrow \beta_{t+1}^{2,3}$					
additive	$1 = 2 = 3 = 4$	$1 \neq 2 \neq 3 \neq 4$	113	7255.15	7492.58	0.00
constant	$1 = 2 = 3 = 4$	$1 \neq 2 \neq 3 \neq 4$	100	7260.15	7469.06	0.00
constant	$1 \neq 2 \neq 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	101	7260.05	7471.14	0.00
3.	Survival	probabilities				
	$ECE_t \rightarrow \sigma_{t+1}^{2,3}$					
constant	$1 \neq 2 = 3 \neq 4$	$1 \neq 2 = 3 \neq 4$	101	7220.14	7431.23	0.02
constant	$1 \neq 2 = 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	103	7215.75	7431.21	0.02
constant	$1 \neq 2 \neq 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	104	7211.23	7428.87	0.07
	$ECE_t^{far} \rightarrow \sigma_{t+1}^{2,3}$					
constant	$1 \neq 2 = 3 \neq 4$	$1 \neq 2 = 3 \neq 4$	101	7220.10	7431.19	0.02
constant	$1 \neq 2 = 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	103	7211.88	7427.34	0.14
constant	$1 \neq 2 \neq 3 \neq 4$	$1 \neq 2 \neq 3 \neq 4$	104	7210.22	7427.87	0.11

Table B4: Breeding success probabilities at year $t + 1$ and 95% confidence intervals of the model averaged estimates. The four stages are defined at the end of the breeding season of year t and are: (PB) pre-breeders, (SB) successful breeders, (FB) failed breeders and (NB) non-breeders.

	PB, FB and NB	SB
close	0.73 [0.68 0.78]	0.82 [0.78 0.85]
ordinary	0.64 [0.61 0.67]	0.78 [0.76 0.80]
far	0.55 [0.49 0.60]	0.72 [0.67 0.77]

Table B5: Survival probabilities from year t to $t + 1$ and 95% confidence intervals of the model averaged estimates. The four stages are defined at the end of the breeding season of year t and are: (PB) pre-breeders, (SB) successful breeders, (FB) failed breeders and (NB) non-breeders.

	PB	SB	FB	NB
close	0.917 [0.911 0.922]	0.924 [0.911 0.938]	0.911 [0.880 0.933]	0.904 [0.89 0.916]
ordinary	0.917 [0.911 0.922]	0.924 [0.913 0.934]	0.921 [0.905 0.933]	0.904 [0.89 0.916]
far	0.917 [0.911 0.922]	0.930 [0.903 0.950]	0.926 [0.893 0.949]	0.904 [0.89 0.916]

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