The following supplement accompanies the article

The decline of Norwegian kittiwake populations: modelling the role of ocean warming

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Supplement. Density-dependent models

All models in Tables 1 and 2 were re-run under the assumption of density dependence. These logistic population models had the form:

$$\ln N_{t+1} = \ln N_t + r_0\left(1 - N_t/K\right) - \tfrac{1}{2}\sigma_{\mathrm{d}}^2 N_t^{-1} + \sum \beta_i X_{i,t} + \varepsilon_t \,, \qquad \text{(S1)}$$

with K as the carrying capacity; r_0 is the intrinsic population growth rate at infinitesimal population size (see Eqn. 1 in the main article for explanations of the remaining variables). Maximum likelihood estimation of the parameters (cf. Eqn. 2, main article) was constrained to positive values because non-positive estimates of K, r_0 and σ_{e}^2 are not biologically meaningful.

In the case of common models for all 5 colonies (cf. Table 1, main article), all density-dependent models obtained poorer support than the corresponding density-independent models (all ΔAICc > 3.5; cf. Table S1). When analysing colonies separately (cf. Table 2), Sklinna was the only colony where density-dependent and density-independent models obtained a comparable fit (i.e. within 2 AICc units; Table S2). This was true only when the Sklinna population time series was truncated in 2001 (see main text, Section 2.1). In this case, growth rate r_0 and carrying capacity K were estimated as 0.143 [95% confidence intervals: 0.371; 0.907] and 56 [34; 76], respectively. In all other colonies (and in Sklinna, when all years were included), density-dependent models estimated r_0 to be close to 0 (all $r_0 \ll 10^{-9}$).

Based on these results, PVAs were run assuming density-independent population dynamics. (The only exception might have been Sklinna. However, because this colony went extinct, it was neither possible nor necessary to run PVAs for it.)

Table S1. Population models for 5 Norwegian black-legged kittiwake populations, fitted to all populations simultaneously. The table includes all models from Table 1 in the main article, and adds the corresponding logistic models. Model structure depends on the covariate and its time lag, whether the covariate had been detrended (detr.), whether 1 common or 5 separate values were estimated for growth rates ($\bar{r}$) and environmental variances (σ_e^2) for the 5 colonies, and on whether the model was density-dependent (DD, i.e. logistic) or density-independent (i.e. Brownian). See Table 1 (main article) for an explanation of the remaining columns. **Bold**: best-supported models

	Model structure					Estimate		Model performance		
Covariate	lag	detr.	$\bar{r}$	σ_e^2	DD	mean	CI	K	ΔAIC_C	ML
Grand Banks	**3**		**1**	**5**		$\boldsymbol{b} = \mathbf{-0.079}$	**–0.132, –0.027**	**7**	**0.00**	**1.000**
Svalbard	**1**		**1**	**5**		$\boldsymbol{b} = \mathbf{-0.244}$	**–0.404, –0.081**	**7**	**0.12**	**0.942**
Grand Banks	3		1	5	DD	$b = -0.078$	–0.136, –0.020	12	3.52	0.172
Svalbard	1	detr.	1	5		$b = -0.240$	–0.450, –0.035	7	3.60	0.165
Grand Banks	1		1	5		$b = -0.059$	–0.113, –0.004	7	4.07	0.131
Grand Banks	3	detr.	1	5		$b = -0.088$	–0.174, –0.004	7	4.40	0.111
Colonies	1		1	5		$b = -0.065$	–0.133, +0.003	7	5.12	0.077
Svalbard	1		1	5	DD	$b = -0.254$	–0.425, –0.082	12	5.51	0.064
None			1	5		$\bar{r} = -0.055$	–0.081, –0.030	6	6.42	0.040
Grand Banks	1	detr.	1	5		$b = -0.031$	–0.116, +0.052	7	8.09	0.018
Colonies	1	detr.	1	5		$b = -0.027$	–0.142, +0.085	7	8.44	0.015
Grand Banks	1		1	5	DD	$b = -0.069$	–0.130, –0.011	12	9.72	0.008
Colonies	1		1	5	DD	$b = -0.073$	–0.150, +0.001	12	11.43	0.003
None			5	5				10	12.21	0.002
Svalbard	1	detr.	1	5	DD	$b = -0.239$	–0.459, –0.009	12	14.31	0.001
Grand Banks	3	detr.	1	5	DD	$b = -0.081$	–0.172, +0.011	12	15.74	0.000
None			1	5	DD	$r_0 = 2.4 \times 10^{-10}$	9.5×10^{-11}, 2.1×10^{-8}	11	17.67	0.000
Grand Banks	1	detr.	1	5	DD	$b = -0.044$	–0.136, +0.047	12	19.50	0.000
Colonies	1	detr.	1	5	DD	$b = -0.032$	–0.158, +0.091	12	19.94	0.000
None			5	5	DD			15	27.43	0.000
None			1	1		$\bar{r} = -0.070$	–0.106, –0.035	2	45.64	0.000
None			5	1		$\sigma_e^2 = 0.038$	0.027, 0.046	6	51.89	0.000
None			1	1	DD	$r_0 = 2.3 \times 10^{-10}$	2.0×10^{-11}, 1.5×10^{-8}	7	66.70	0.000
None			5	1	DD	$\sigma_e^2 = 0.042$	0.031, 0.052	11	75.37	0.000

Table S2. Separate population models for 5 Norwegian black-legged kittiwake populations. The table includes all models from Table 2 and adds the corresponding density-dependent (DD, i.e. logistic) models plus models with detrended (detr.) covariates. (Because Table 2 in the main article is used as the reference, negative ΔAICc values can occur)

Colony	Model: covariate (time lag)	Detr.	DD	Estimate	CI	*K*	ΔAIC_C	R^2
Runde	Grand Banks (3)	detr.		–0.226	–0.447, –0.008	3	–0.26	0.134
	Grand Banks (3)			–0.127	–0.259, +0.005	3	0.00	0.125
	null					2	0.79	
	null		DD			3	9.28	
	Grand Banks (3)		DD	–0.113	–0.265, +0.038	4	10.04	0.125
Sklinna	Grand Banks (1)		DD	–0.549	–1.031, –0.242	4	–1.35	0.334
	null					2	0.00	
	Grand Banks (1)	detr.		–0.476	–1.097, +0.146	3	0.67	0.112
	Grand Banks (1)			–0.284	–0.661, +0.088	3	0.70	0.110
	null		DD			3	1.94	
Vedøy	null					2	0.00	
	Grand Banks (3)			–0.059	–0.145, +0.025	3	0.65	0.063
	Grand Banks (3)	detr.		–0.052	–0.178, +0.074	3	1.84	0.023
	null		DD			3	9.09	
	Grand Banks (3)		DD	–0.065	–0.163, +0.033	4	10.05	0.063
Hjelmsøya	Svalbard (1) + colony (1)	detr.		–1.122 +0.971	–1.789, –0.446 +0.223, +1.722	4	–1.46	0.416
	Svalbard (1) + colony (1)			–1.186 +0.589	–1.865, –0.490 +0.102, +1.068	4	0.00	0.372
	Svalbard (1)	detr.		–0.948	–1.710, –0.178	3	0.92	0.233
	Svalbard (1)			–0.733	–1.391, –0.090	3	1.95	0.192
	null					2	3.47	
	Svalbard (1) + colony (1)		DD	–1.151 +0.596	–1.952, –0.349 +0.025, +1.176	5	10.01	0.372
	null		DD			3	10.28	
	Svalbard (1)		DD	–0.692	–1.435, +0.068	4	10.35	0.192
Hornøya	Svalbard (1)			–0.310	–0.526, –0.084	3	0.00	0.210
	Svalbard (1)	detr.		–0.344	–0.646, –0.041	3	1.97	0.152
	Grand Banks (3)			–0.077	–0.151, –0.002	3	2.78	0.127
	colony (4)			–0.140	–0.285, +0.005	3	3.33	0.110
	null					2	4.11	
	Svalbard (1)		DD	–0.318	–0.555, –0.082	4	5.58	0.210
	colony (4)		DD	–0.143	–0.295, +0.011	4	8.80	0.110
	Grand Banks (3)		DD	–0.073	–0.153, +0.007	4	8.81	0.127
	null		DD			3	9.21	