

Appendix S2: Additional Results

Circumpolar analysis of the Adélie penguin reveals the importance of environmental variability in phenological mismatch

Casey Youngflesh, Stephanie Jenouvrier, Yun Li, Rubao Ji, David G. Ainley, Grant Ballard, Christophe Barbraud, Karine Delord, Katie M. Dugger, Louise M. Emmerson, William R. Fraser, Jefferson T. Hinke, Phil O’B. Lyver, Silvia Olmastroni, Colin J. Southwell, Susan G. Trivelpiece, Wayne Z. Trivelpiece, Heather J. Lynch

Covariates do not predict mean breeding success

Table S1: Breeding success (BS) as a function of penguin breeding phenology (CID), Bloom Mismatch Index (BMI), and Sea-ice Mismatch Index (SMI). Model is a quadratic regression fit in a frequentist framework (so as to produce an interpretable r^2 value). Low r^2 values indicate that the predictor values do not predict the response variable with any reliability.

Model	r^2
BS ~ CID	0.078
BS ~ BMI	0.042
BS ~ SMI	0.035

Parameter estimates for hierarchical regressions

Parameter estimates derived from Bayesian analyses (posterior mean values) can be interpreted in a similar manner to point estimates derived from frequentist analyses. Bayesian posteriors represent the uncertainty around the estimate of a particular parameter. Larger ‘credible intervals’ (the range of values in which there is an X percent certainty that the X% interval contains the true parameter value) result from wider posterior distributions and denote ‘less confidence’ in the estimated value for the parameter.

Table S2: Parameter estimates (posterior mean and 95% credible intervals) for penguin breeding phenology as a function of time, modeled in a hierarchical Bayesian framework (see Methods, equation 3). \hat{R} represents the Gelman-Rubin convergence diagnostic. Values near 1 signify convergence for that particular parameter. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Site	Parameter	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	α	0.068	-0.674	0.813	1.001
AB	β	-0.005	-0.052	0.041	1.001
HI	α	0.274	-1.097	2.123	1.001
HI	β	-0.008	-0.058	0.03	1.001
PG	α	-0.115	-1.733	1.157	1.001
PG	β	0.002	-0.018	0.027	1.001
CC	α	-0.076	-2.648	1.843	1.001
CC	β	9.209×10^{-4}	-0.021	0.03	1.001
CR	α	-0.199	-3.351	1.649	1.001

Site	Parameter	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
CR	β	0.002	-0.016	0.032	1.001
CB	α	-0.026	-2.507	2.048	1.001
CB	β	2.245×10^{-4}	-0.017	0.021	1.001
BE	β	0.069	-0.016	0.032	1.001
BE	β	-5.569×10^{-4}	-0.018	0.017	1.001

Table S3: Parameter estimates (posterior mean and 95% credible intervals) for Bloom Mismatch Index as a function of time, modeled in a hierarchical Bayesian framework (see Methods, equation 3). \hat{R} represents the Gelman-Rubin convergence diagnostic. Values near 1 signify convergence for that particular parameter. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Site	Parameter	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	α	-0.261	-1.039	0.517	1.001
AB	β	0.009	-5.477	6.281	1.001
HI	α	-3.068	-5.373	-0.105	1.001
HI	β	0.018	-0.03	0.067	1.001
PG	α	1.481	-0.738	3.716	1.001
PG	β	0.083	0.005	0.144	1.001
CC	α	-0.309	-5.178	4.718	1.001
CC	β	-0.023	-0.057	0.011	1.001
CR	α	-0.691	-6.191	4.592	1.001
CR	β	0.003	-0.053	0.057	1.001
CB	α	-0.217	-5.522	5.519	1.001
CB	β	0.007	-0.044	0.059	1.001
BE	β	0.009	-0.044	0.059	1.001
BE	β	-1.092×10^{-4}	-0.047	0.041	1.001

Table S4: Parameter estimates (posterior mean and 95% credible intervals) for Sea-ice Mismatch Index as a function of time, modeled in a hierarchical Bayesian framework (see Methods, equation 3). \hat{R} represents the Gelman-Rubin convergence diagnostic. Values near 1 signify convergence for that particular parameter. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Site	Parameter	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	α	-0.398	-1.162	0.365	1.001
AB	β	-0.484	-6.452	5.135	1.001
HI	α	-2.264	-4.833	0.318	1.001
HI	β	0.028	-0.018	0.076	1.001
PG	α	1.977	-0.436	4.182	1.001
PG	β	0.062	-0.007	0.129	1.001
CC	α	-1.108	-6.613	3.413	1.001
CC	β	-0.031	-0.064	0.006	1.001
CR	α	-1.64	-8.307	3.132	1.001
CR	β	0.012	-0.038	0.074	1.001
CB	α	-0.867	-6.846	4.267	1.001

Site	Parameter	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
CB	β	0.016	-0.03	0.079	1.001
BE	β	-0.484	-0.03	0.079	1.001
BE	β	0.004	-0.038	0.048	1.001

Table S5: Parameter estimates (posterior mean and 95% credible intervals) for differences in the β (slope) parameter for penguin breeding phenology. This metric was used to determine if a parameter was changing at any one site more rapidly than another. \hat{R} represents the Gelman-Rubin convergence diagnostic. Values near 1 signify convergence for that particular parameter. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Site 1	Site 2	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	HI	0.002	-0.043	0.039	1.001
AB	PG	0.011	-0.017	0.046	1.001
AB	CC	0.011	-0.021	0.046	1.001
AB	CR	0.011	-0.02	0.047	1.001
AB	CB	0.013	-0.014	0.048	1.001
AB	BE	0.013	-0.012	0.049	1.001
HI	PG	0.009	-0.015	0.049	1.001
HI	CC	0.009	-0.016	0.046	1.001
HI	CR	0.009	-0.016	0.047	1.001
HI	CB	0.011	-0.01	0.048	1.001
HI	BE	0.011	-0.009	0.049	1.001
PG	CC	6.619×10^{-5}	-0.023	0.018	1.001
PG	CR	6.999×10^{-4}	-0.022	0.018	1.001
PG	CB	0.002	-0.016	0.019	1.001
PG	BE	0.003	-0.014	0.02	1.001
CC	CR	6.337×10^{-4}	-0.019	0.02	1.001
CC	CB	0.002	-0.014	0.022	1.001
CC	BE	0.003	-0.012	0.023	1.001
CR	CB	0.001	-0.014	0.022	1.001
CR	BE	0.002	-0.012	0.022	1.001
CB	BE	6.094×10^{-4}	-0.013	0.016	1.001

Table S6: Parameter estimates (posterior mean and 95% credible intervals) for differences in the β (slope) parameter for Bloom Mismatch Index. This metric was used to determine if a parameter was changing at any one site more rapidly than another. \hat{R} represents the Gelman-Rubin convergence diagnostic. Values near 1 signify convergence for that particular parameter. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Site 1	Site 2	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	HI	-0.059	-0.127	0.019	1.001
AB	PG	7.841×10^{-5}	-0.044	0.05	1.001
AB	CC	0.004	-0.049	0.053	1.001
AB	CR	0.006	-0.046	0.054	1.001
AB	CB	0.008	-0.039	0.055	1.001

Site 1	Site 2	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	BE	0.009	-0.037	0.056	1.001
HI	PG	0.059	-0.008	0.123	1.001
HI	CC	0.063	-0.003	0.127	1.001
HI	CR	0.064	-0.001	0.127	1.001
HI	CB	0.067	3.914×10^{-4}	0.129	1.001
HI	BE	0.068	0.001	0.129	1.001
PG	CC	0.004	-0.044	0.044	1.001
PG	CR	0.005	-0.041	0.044	1.001
PG	CB	0.008	-0.033	0.045	1.001
PG	BE	0.009	-0.031	0.045	1.001
CC	CR	0.001	-0.044	0.047	1.001
CC	CB	0.004	-0.038	0.049	1.001
CC	BE	0.005	-0.035	0.05	1.001
CR	CB	0.003	-0.038	0.047	1.001
CR	BE	0.004	-0.036	0.047	1.001
CB	BE	0.001	-0.037	0.039	1.001

Table S7: Parameter estimates (posterior mean and 95% credible intervals) for differences in the β (slope) parameter for Sea-ice Mismatch Index. This metric was used to determine if a parameter was changing at any one site more rapidly than another. \hat{R} represents the Gelman-Rubin convergence diagnostic. Values near 1 signify convergence for that particular parameter. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Site 1	Site 2	Mean	Lower 95% CI	Upper 95% CI	\hat{R}
AB	HI	-0.031	-0.106	0.038	1.001
AB	PG	-3.386×10^{-4}	-0.048	0.053	1.001
AB	CC	0.009	-0.051	0.06	1.001
AB	CR	0.009	-0.054	0.061	1.001
AB	CB	0.014	-0.037	0.063	1.001
AB	BE	0.016	-0.032	0.064	1.001
HI	PG	0.031	-0.031	0.099	1.001
HI	CC	0.04	-0.02	0.108	1.001
HI	CR	0.04	-0.021	0.107	1.001
HI	CB	0.045	-0.011	0.112	1.001
HI	BE	0.047	-0.009	0.114	1.001
PG	CC	0.009	-0.043	0.05	1.001
PG	CR	0.009	-0.046	0.05	1.001
PG	CB	0.014	-0.029	0.052	1.001
PG	BE	0.016	-0.024	0.053	1.001
CC	CR	-3.113×10^{-4}	-0.053	0.049	1.001
CC	CB	0.005	-0.038	0.055	1.001
CC	BE	0.007	-0.033	0.057	1.001
CR	CB	0.005	-0.036	0.058	1.001
CR	BE	0.007	-0.031	0.06	1.001
CB	BE	0.002	-0.036	0.042	1.001

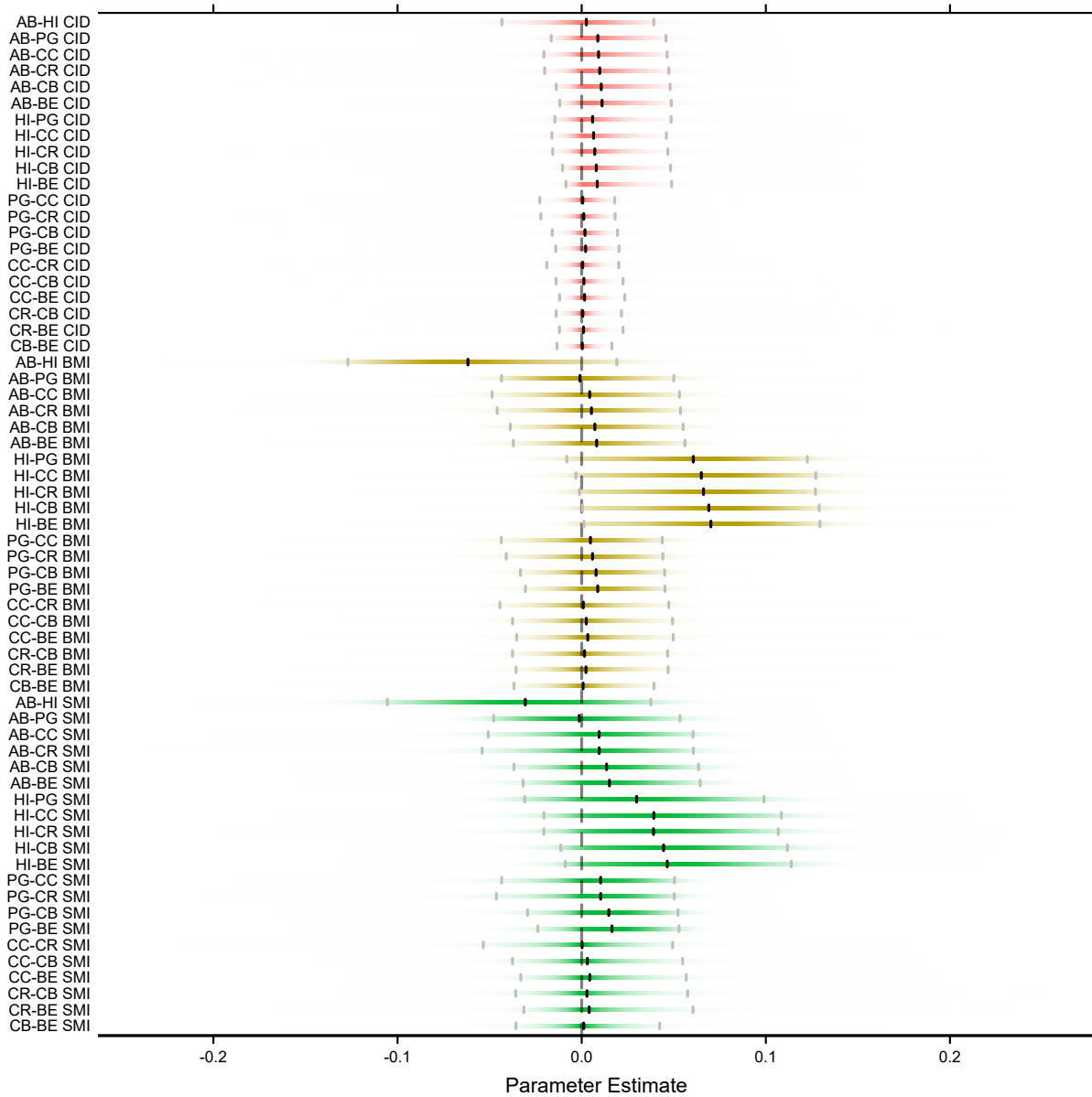


Figure S1: Posterior distributions for differences in the β (slope) parameter between any given site and all others for penguin breeding phenology (CID - red), Bloom Mismatch Index (BMI - yellow), and Sea-ice Mismatch Index (SMI - green). Posterior means are indicated by the black tick. 95% credible intervals are indicated by the gray ticks. Letter codes represent breeding sites: AB = Admiralty Bay, HI = Humble Island, PG = Point Géologie, CC = Cape Crozier, CR = Cape Royds, CB = Cape Bird, BE = Béchervaise Island.

Parameter estimates for quantile regression

Table S8: Parameter estimates (posterior mean and 95% credible intervals) for model of breeding success (BS) as a function of penguin breeding phenology (CID), Bloom Mismatch Index (BMI), and Sea-ice Mismatch Index (SMI) obtained from a quadratic 85th quantile regression implemented in a Bayesian framework (see Methods, equation 2).

Model	Coefficient term	Estimate	Lower 95% CI	Upper 95% CI
BS ~ CID	α	0.884	0.738	1.04
BS ~ CID	β_1 (linear)	-0.321	-0.462	-0.214
BS ~ CID	β_2 (quadratic)	0.002	-0.076	0.088
BS ~ BMI	α	1.156	1.004	1.292
BS ~ BMI	β_1	0.088	-0.059	0.236
BS ~ BMI	β_2	-0.173	-0.266	-0.076
BS ~ SMI	α	1.171	1.001	1.308
BS ~ SMI	β_1	-0.079	-0.221	0.082
BS ~ SMI	β_2	-0.225	-0.32	-0.123