Supplementary Materials

Longterm patterns of mass stranding of the colonial cnidarian Velella velella: Influence of environmental forcing

Table S1. Velella reporting rates in April for alternate participant sets. Reporting rates are the percent of surveys reporting Velella in April of the focal year (columns) limited to surveys performed by participants who were also active in April of a given reference year (rows). Reference years were restricted to five years either side of the focal year to maintain an adequate sample size. Cells highlighted in bold are those where reporting rate deviated by more than 10% from the overall reporting rate (final row) calculated using all available surveys (i.e. not restricted).

	Focal year																		
Ref. year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2001		0*	14†	11†	**44†**	11†													
2002	0*		**33***	6*	**44***	14*	0*												
2003	0*	0*		9*	23	14*	0*	0*											
2004	0*	0*	10*		32	21*	0*	0	0										
2005	0†	0*	**23***	0*		17	0	0	0	0*									
2006	0*	0*	14*	6*	22		3	0	0	0*	0*								
2007		0†	14*	0*	27	15		0	0	0	0	0*							
2008			14*	5*	30*	18	2		0	0	0	0	0						
2009				5*	29	11	2	0		0	0	0	0	0					
2010					**40***	13*	0	0	0		0	0	0	0	46				
2011						13*	3	0	0	0		0	0	0	45	11			
2012							3	0	0	0	0		0	0	40	11	7		
2013								0	0	0	0	0		0	45	11	9	19	
2014									0	0	0	0	0		42	13	10	16	5
2015										0	0	0	0	0		15	15	19	5
2016											0	0	0	0	42		14	18	6
2017												0	0	0	44	16		18	5
2018													0	0	43	14	14		6
2019														0	46	19	11	18	
ALL	0	0	12.5	5	24.4	12	1.5	0	0	0	0	0	0	0	39.2	14.2	15.2	19.4	4.4

†: Number of surveys ≤ 10
*: Number of surveys 11 – 25

Table S2. Pearson's correlation coefficients between kernel smoothed (gaussian, σ = 7 days) wind speed components reported at three different locations (45°N: 45.00°N, 124.65°W; 47°N: 47.06°N, 124.94°W; 48°N: 47.91°N, 125.25°W) relative to a reference location used throughout the study (46°N: 46.21°N, 124.64°W). For each alternate location, values represent the correlation between time-aligned wind speed components (easterly – *u*, northerly – *v*) reported at that location and the values reported at 46°N, broken up into individual years by wind-speed component. The final row gives the median correlation coefficient across all reported years for each alternate location. Values less than 0.7 are highlighted in bold.

	Easterly wind component (*u*)			Northerly wind component (*v*)		
Year	45°N	47°N	48°N	45°N	47°N	48°N
2002	0.961	0.946	0.803	0.988	0.991	0.985
2003	0.955	0.888	0.709	0.990	0.988	0.986
2004	0.960	0.934	0.871	0.982	0.976	0.942
2005	0.951	0.894	0.714	0.986	0.986	0.977
2006	0.950	0.828	**0.662**	0.993	0.991	0.985
2007	0.945	0.866	0.717	0.991	0.985	0.974
2008	0.943	0.864	0.739	0.992	0.987	0.982
2009	0.964	0.908	0.770	0.986	0.979	0.977
2010	0.956	0.911	0.827	0.990	0.992	0.988
2011	0.943	0.822	**0.665**	0.990	0.987	0.981
2012	0.957	0.819	**0.633**	0.990	0.989	0.981
2013	0.959	0.887	0.743	0.983	0.971	0.960
2014	0.964	0.907	0.732	0.993	0.982	0.983
2015	0.946	0.876	0.758	0.991	0.984	0.977
2016	0.951	0.911	0.792	0.994	0.993	0.991
2017	0.961	0.886	0.726	0.991	0.986	0.980
2018	0.957	0.871	**0.673**	0.989	0.989	0.986
2019	0.950	0.918	0.795	0.988	0.972	0.963
MED	0.956	0.888	0.736	0.990	0.987	0.981

Table S3. Annual report and survey frequency as well as reporting rate for spring (Jan – Jun) and Autumn (Aug – Dec) periods. Shown are survey and beach-based reporting frequencies and rates constrained to surveys performed north of 44°N. V. pres. - number of surveys or beaches reporting Velella, respectively; Tot. - total surveys, or beaches, respectively.

	Spring						Autumn					
	Surveys			Beaches			Surveys			Beaches		
Year	V. pres.	Tot.	Rate (%)	V. pres.	Tot.	Rate (%)	V. pres.	Tot.	Rate (%)	V. pres.	Total	Rate (%)
2002	0	199	0.00	0	33	0.00	0	251	0.00	0	42	0.00
2003	13	233	5.58	7	34	20.59	1	245	0.41	1	35	2.86
2004	12	252	4.76	9	35	25.71	0	311	0.00	0	40	0.00
2005	28	258	10.85	18	42	42.86	10	342	2.92	10	53	18.87
2006	6	305	1.97	6	50	12.00	0	285	0.00	0	59	0.00
2007	2	364	0.55	2	68	2.94	0	518	0.00	0	70	0.00
2008	0	532	0.00	0	69	0.00	0	477	0.00	0	73	0.00
2009	0	544	0.00	0	77	0.00	0	617	0.00	0	96	0.00
2010	1	425	0.24	1	83	1.20	0	413	0.00	0	76	0.00
2011	0	398	0.00	0	84	0.00	0	446	0.00	0	90	0.00
2012	0	488	0.00	0	99	0.00	0	561	0.00	0	108	0.00
2013	0	551	0.00	0	126	0.00	0	674	0.00	0	135	0.00
2014	0	679	0.00	0	133	0.00	37	662	5.59	31	141	21.99
2015	134	685	19.56	80	134	59.70	6	595	1.01	6	124	4.84
2016	40	587	6.81	33	119	27.73	0	569	0.00	0	122	0.00
2017	32	594	5.39	29	117	24.79	0	611	0.00	0	116	0.00
2018	68	594	11.45	45	108	41.67	1	615	0.16	1	108	0.93
2019	6	584	1.03	6	105	5.71	0	552	0.00	0	103	0.00

Table S4. Spring (Jan – June) period reporting phenology, including the date of first report, and the 14-day period in which reporting rate peaked each year. Values are drawn from surveys north of 44°N so that coverage and effort was approximately equivalent among years.

Year	First report	Peak 14d period
2002		
2003	23/Mar	26/Mar - 9/Apr
2004	27/Mar	26/Mar - 9/Apr
2005	18/Apr	9/Apr - 23/Apr[a]
2006	21/Apr	23/Apr - 7/May
2007	25/Mar	23/Apr - 7 May
2008		
2009		
2010		
2011		
2012		
2013		
2014		
2015	18/Mar	23/Apr - 7/May
2016	16/Mar	26/Mar - 9/Apr
2017	31/Mar	23/Apr - 7/May
2018	9/Feb	9/Apr - 23/Apr
2019	20/Apr	23/Apr - 7/May

[a]:In spring 2005 there were two peaks, one in the 14-day period from 9-Apr to 23-Apr (reporting rate = 33%) and one from 4-Jun to 18-Jun (reporting rate = 36%)

Table S5. Pearson's correlation coefficients among location-specific metrics of easterly wind speeds. Each row gives the range of correlation coefficients for comparisons of the wind-speed metric for the stated month(s) period across calculations performed at 45°N (45.00°N, 124.65°W), 47°N (47.06°N, 124.94°W) and 48°N (47.91°N, 125.25°W) relative to a reference location at 46°N (46.21°N, 124.64°W). The lower section of the table gives the mean and range in correlation coefficients across alternate metrics specific to each location.

	Pearson's Correlation Coefficients		
Month	Average easterly	Onshore prevalence	Cumulative onshore
12	0.85 - 0.96	0.87 - 0.97	0.95 - 0.99
1	0.84 - 0.99	0.91 - 0.98	0.96 - 0.99
2	0.81 - 0.98	0.88 - 0.97	0.91 - 0.98
3	0.78 - 0.93	0.80 - 0.98	0.93 - 0.98
4	0.85 - 0.95	0.83 - 0.93	0.89 - 0.97
12-1	0.90 - 0.97	0.95 - 0.97	0.96 - 0.99
1-2	0.90 - 0.99	0.94 - 0.99	0.98 - 0.99
2-3	0.81 - 0.97	0.78 - 0.97	0.90 - 0.98
3-4	0.70 - 0.96	0.66 - 0.94	0.88 - 0.97
12-2	0.90 - 0.99	0.95 - 0.98	0.97 - 0.99
1-3	0.90 - 0.99	0.88 - 0.98	0.97 - 0.99
2-4	0.81 - 0.97	0.74 - 0.96	0.88 - 0.97
	Average [min - max] correlation coefficient by location		
Location	Average easterly	Proportion onshore	Cumulative onshore
45°	0.97 [0.95 - 0.99]	0.96 [0.87 - 0.99]	0.97 [0.95 - 0.99]
47°	0.95 [0.93 - 0.97]	0.94 [0.86 - 0.97]	0.98 [0.97 - 0.99]
48°	0.84 [0.70 - 0.90]	0.85 [0.66 - 0.95]	0.93 [0.88 - 0.98]

Table S6. Summaries of spatial and temporal units and extents/periods of processed data used in the analysis of spatio-temporal patterns, and environmental analyses of interannual patterns.

		Spatial		Temporal		
Data	**MS Section**	**Latitudinal extent (°N)**	**Spatial units**	**Period**	**Temporal units**	**Description**
Base data	2.1	40.35-48.34	Beach (~ 1 km)	2000-2019	Day	Presence/absence of Velella reports
Spatial	2.2	40.35-48.34	Beach (~ 1 km) & smoothed (~ 50 km)	2000-2019	All years; 2000-2014; 2014-2019	Beach-specific reporting rate: % of surveys performed on each beach that were accompanied by reports of Velella
Spatio-temporal	2.2	40.35-48.34	50 km latitudinal bands	2000-2019	Calendar month	Presence/absence of Velella reports from surveys performed each month from 2000-2019 splitting the coastline into 50km latitudinal bands
Seasonal	2.2	40.35-48.34	> 44°N & < 44°N	2003-2019	14 days	Reporting rate (% of surveys reporting Velella) within 14-day windows each year calculated separately for beaches north of 44°N and south of 44°N
Annual	2.3.2	44.0-48.34		2002-2019	Bi-Annual (Jan-June; July-Dec)	Bi-annual reporting rate (Year split into spring=Jan-June, autumn=July-Dec) calculated as the % of beaches surveyed north of 44°N reporting Velella in each half year

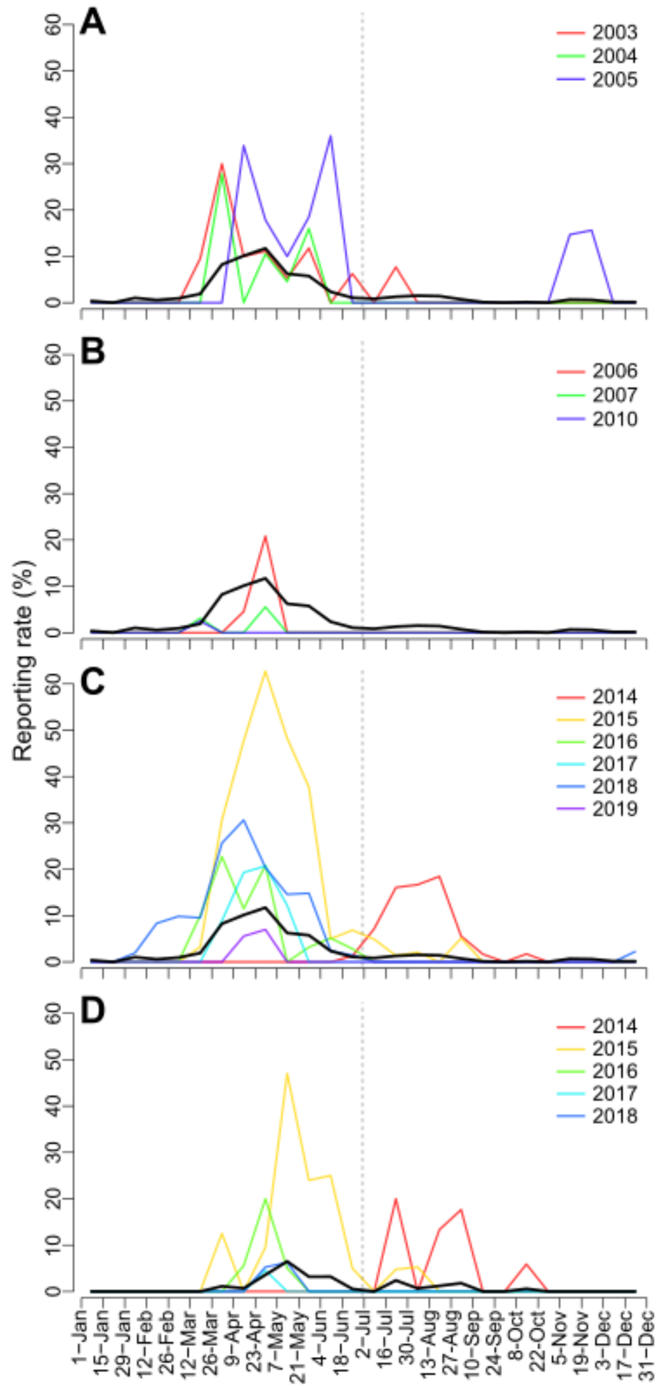

Fig. S1. Interannual seasonal occurrence of Velella stranding events. Reporting rates (surveys reporting Velella expressed as a % of all surveys per 14-day window) are plotted in 14 day intervals throughout the year for surveys north of 44°N (**A**-**C**) from 2003-2005 (**A**), 2006-2010 (**B**) and 2014-2019 (**C**); and south of 44°N (**D**). Years with no reports are not plotted. Plots for 2000-2001 are not shown due to insufficient sample size (< 5 surveys per 14 day window).

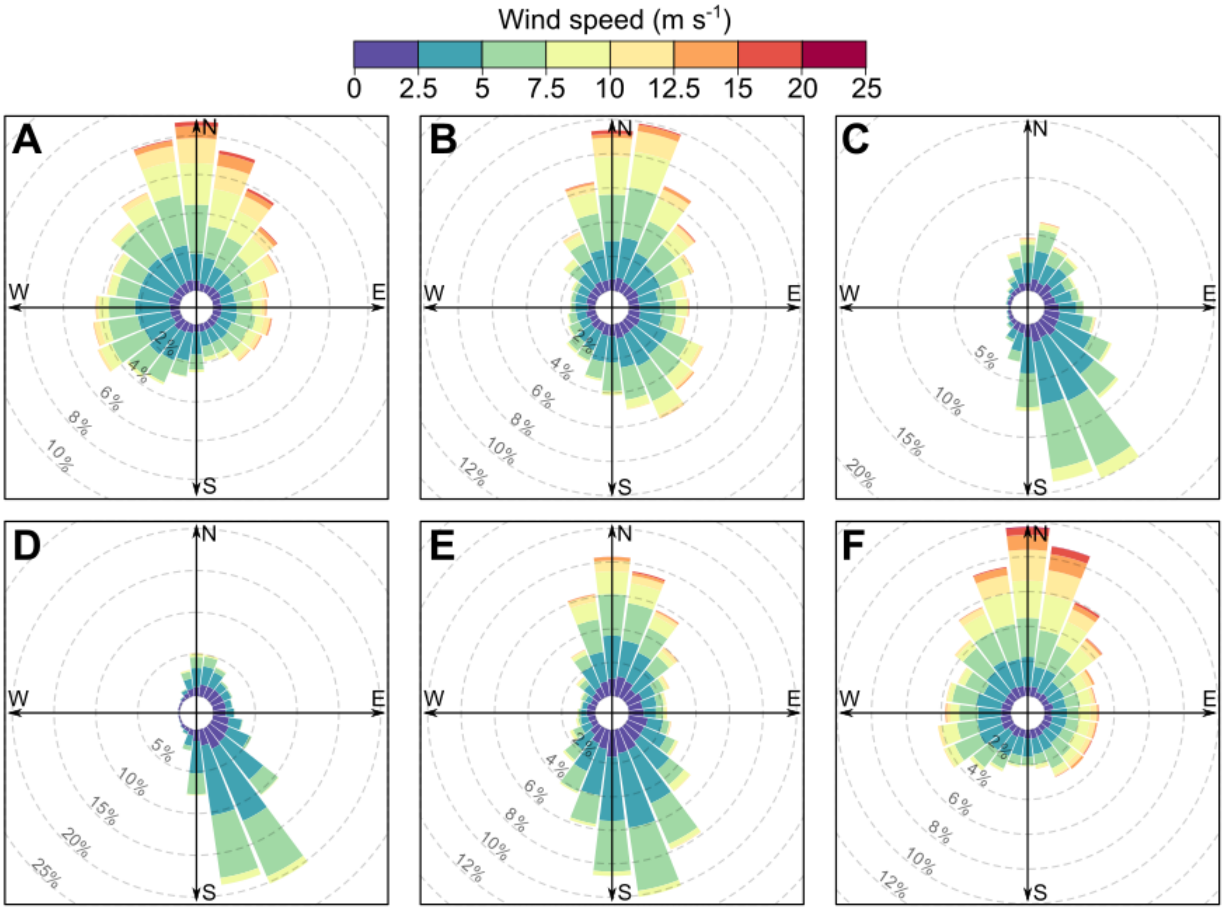

Fig. S2. Prevailing wind speed and direction derived from NARR data at 46.20°N, 124.64°W in Jan-Feb (**A**), Mar-Apr (**B**), May-Jun (**C**), Jul-Aug (**D**), Sep-Oct (**E**), Nov-Dec (**F**). Wind roses show the prevalence of wind speed by direction of transport.

Table S7. Summed Akaike weights across alternate metrics of SSTa, upwelling and onshore winds for multiple predictor models and single predictor models, with and without 2015. Summed weights are standardized (i.e. sum to one) across all models with VIF < 2.5 (multiple predictors). Single predictor models only consider model weights for models that contained a representation of that environmental forcing factor, such that weights are representative of the best metric for that forcing factor.

			Multiple predictor models		Single predictor models	
Factor	Metric	Months	inc. 2015	exc. 2015	inc. 2015	exc. 2015
SSTa	None		0.007	0.056	0.000	0.001
	Ave.	Dec-Jan	0.283	0.231	0.236	0.208
		Jan-Feb	0.162	0.193	0.201	0.194
		Feb-Mar	0.042	0.052	0.033	0.031
		Dec-Feb	**0.296**[a]	**0.264**[a]	**0.409**[a]	**0.457**[a]
		Jan-Mar	0.21	0.205	0.121	0.110
Upwelling	None		**0.931**[a]	**0.915**[a]	0.027	0.031
	Ave.	Dec-Jan	0.001	0.002	0.008	0.013
		Jan-Feb	0.004	0.003	0.004	0.007
		Feb-Mar	0.010	0.008	0.001	0.001
		Dec-Feb	0.001	0.004	0.005	0.007
		Jan-Mar	0.000	0.002	0.002	0.004
	Prev.	Dec-Jan	0.011	0.018	**0.826**[a]	**0.834**[a]
		Jan-Feb	0.003	0.002	0.003	0.003
		Feb-Mar	**0.018**[b]	0.004	0.001	0.001
		Dec-Feb	0.003	0.001	0.019	0.018
		Jan-Mar	0.001	0.001	0.005	0.005
	Cumu.	Dec-Jan	0.001	0.001	0.084	0.061
		Jan-Feb	0.006	0.003	0.002	0.002
		Feb-Mar	0.008	**0.023**[b]	0.001	0.001
		Dec-Feb	0.001	0.002	0.010	0.009
		Jan-Mar	0.002	0.012	0.003	0.002
Wind	None		0.185	**0.523**[a]	0.009	0.009
	Ave.	Mar	0.000	0.000	0.002	0.001
		Apr	0.133	0.007	0.007	0.022
		Mar-Apr	0.002	0.004	0.061	0.047
	Prev.	Mar	0.000	0.000	0.002	0.001
		Apr	**0.653**[a]	**0.430**[b]	0.029	0.315
		Mar-Apr	0.004	0.022	**0.790**[a]	**0.545**[a]
	Cumu.	Mar	0.000	0.000	0.003	0.002
		Apr	0.013	0.001	0.006	0.009
		Mar-Apr	0.011	0.013	0.091	0.049

[a]:highest akaike weight among metrics within forcing factor group
[b]:these metrics had the highest akaike weights when this forcing factor was included, but models without this forcing factor constituted the overall highest akaike weight

Table S8. Model selection table for generalised additive models of spring Velella reporting rate excluding 2015. Multiple predictor models are compared among all permutations of models constructed including average December to February SSTa, onshore wind speed prevalence in April, and positive upwelling prevalence in February to March, which were identified as the best representations of each environmental forcing factor based on summed akaike weight. Best possible models consisting of only a single predictor of SSTa, wind, or upwelling are given in the latter half of the table. For each part of the table (multiple, single) ΔAICc is given relative to the best possible model in that set and W_{AICc} is the akaike weight ($WAICc = e^{-\Delta AICc/2}$) as a measure of the evidence in support of that model being the best model given the data and the candidate model set. VIF_{max} is the maximum VIF statistic calculated among predictors included in that model as a measure of multicollinearity among model predictors.

Multiple predictor model selection table					
Rank	Predictors	AICc	VIF_{max}	ΔAICc	W_{AICc}
1	SSTa [Dec-Feb]	92.67		0	0.555
2	SSTa [Dec-Feb] + Wind-prev [Apr]	93.36	2.17	0.70	0.391
3	Wind-prev [Apr]	98.35		5.68	0.032
4	SSTa [Dec-Feb] + Upwell-cumu [Feb-Mar]	99.41	1.70	6.74	0.019
5	SSTa [Dec-Feb] + Upwell-cumu [Feb-Mar] + Wind-prev [Apr]	100.91	4.15[a]	8.25	
6	None	105.46		12.80	0.001
7	Upwell-cumu [Feb-Mar] + Wind-prev [Apr]	106.94	1.8	14.27	0.000
8	Upwell-cumu [Feb-Mar]	111.92		19.26	0.000
Best single predictor					
Rank	Predictor	AICc	VIF_{max}	ΔAICc	W_{AICc}
1	SSTa [Dec-Feb]	92.67		0.00	0.872
2	Wind-prev [Mar-Apr]	97.25		4.58	0.088
3	Upwell-prev [Dec-Jan]	98.85		6.18	0.040

[a]:This model had a maximum VIF value exceeding the 2.5 cut-off and is excluded from the calculation of akaike weight due to multicollinearity among included predictors

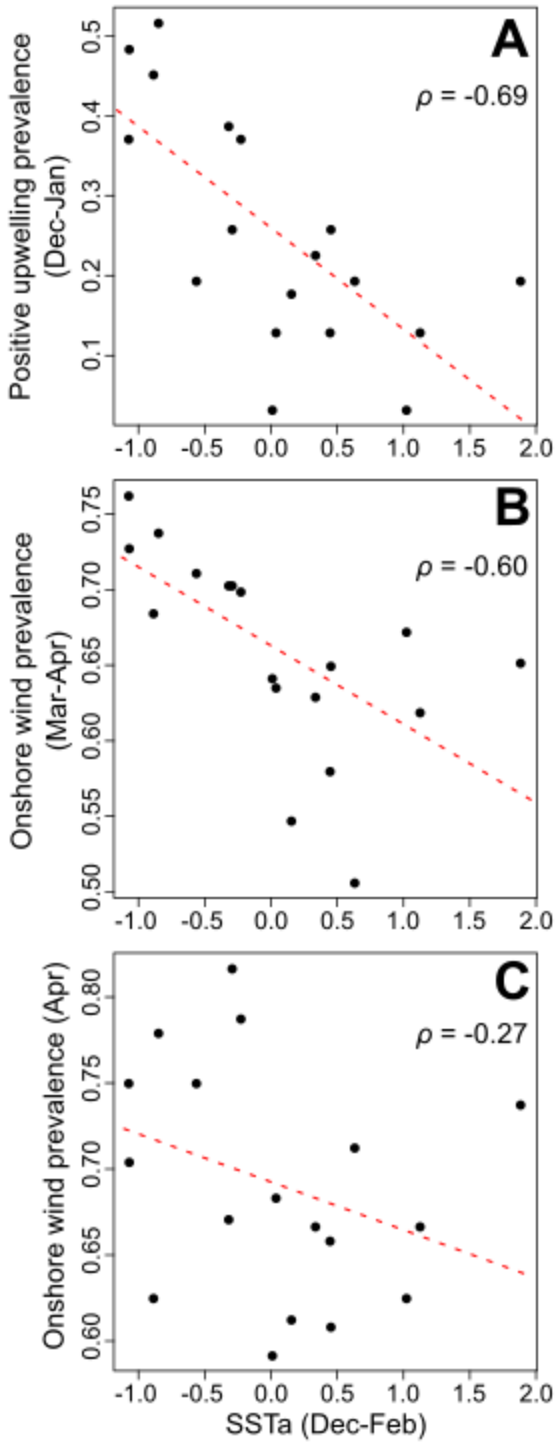

Fig. S3. Correlation between annual measures of proportional upwelling in winter (**A**), and onshore winds in spring (**B & C**) and winter SSTa.