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).

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†: Number of surveys ≤ 10
*: Number of surveys 11 – 25
Table S2. Pearson’s correlation coefficients between kernel smoothed (gaussian, \(\sigma = 7\) 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.

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<th>Northerly wind component ((v))</th>
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### 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.

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<th>Beaches</th>
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<td>V. pres.</td>
<td>Tot.</td>
<td>Rate (%)</td>
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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.

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<td>26/Mar - 9/Apr</td>
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<td>18/Apr</td>
<td>9/Apr - 23/Apr</td>
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<td>21/Apr</td>
<td>23/Apr - 7/May</td>
</tr>
<tr>
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<td>25/Mar</td>
<td>23/Apr - 7 May</td>
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<td>23/Apr - 7/May</td>
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*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**

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<tr>
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<td>0.84 - 0.99</td>
<td>0.91 - 0.98</td>
<td>0.96 - 0.99</td>
</tr>
<tr>
<td>2</td>
<td>0.81 - 0.98</td>
<td>0.88 - 0.97</td>
<td>0.91 - 0.98</td>
</tr>
<tr>
<td>3</td>
<td>0.78 - 0.93</td>
<td>0.80 - 0.98</td>
<td>0.93 - 0.98</td>
</tr>
<tr>
<td>4</td>
<td>0.85 - 0.95</td>
<td>0.83 - 0.93</td>
<td>0.89 - 0.97</td>
</tr>
<tr>
<td>12-1</td>
<td>0.90 - 0.97</td>
<td>0.95 - 0.97</td>
<td>0.96 - 0.99</td>
</tr>
<tr>
<td>1-2</td>
<td>0.90 - 0.99</td>
<td>0.94 - 0.99</td>
<td>0.98 - 0.99</td>
</tr>
<tr>
<td>2-3</td>
<td>0.81 - 0.97</td>
<td>0.78 - 0.97</td>
<td>0.90 - 0.98</td>
</tr>
<tr>
<td>3-4</td>
<td>0.70 - 0.96</td>
<td>0.66 - 0.94</td>
<td>0.88 - 0.97</td>
</tr>
<tr>
<td>12-2</td>
<td>0.90 - 0.99</td>
<td>0.95 - 0.98</td>
<td>0.97 - 0.99</td>
</tr>
<tr>
<td>1-3</td>
<td>0.90 - 0.99</td>
<td>0.88 - 0.98</td>
<td>0.97 - 0.99</td>
</tr>
<tr>
<td>2-4</td>
<td>0.81 - 0.97</td>
<td>0.74 - 0.96</td>
<td>0.88 - 0.97</td>
</tr>
</tbody>
</table>

**Average [min - max] correlation coefficient by location**

<table>
<thead>
<tr>
<th>Location</th>
<th>Average easterly</th>
<th>Proportion onshore</th>
<th>Cumulative onshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>0.97 [0.95 - 0.99]</td>
<td>0.96 [0.87 - 0.99]</td>
<td>0.97 [0.95 - 0.99]</td>
</tr>
<tr>
<td>47°</td>
<td>0.95 [0.93 - 0.97]</td>
<td>0.94 [0.86 - 0.97]</td>
<td>0.98 [0.97 - 0.99]</td>
</tr>
<tr>
<td>48°</td>
<td>0.84 [0.70 - 0.90]</td>
<td>0.85 [0.66 - 0.95]</td>
<td>0.93 [0.88 - 0.98]</td>
</tr>
</tbody>
</table>
**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.

<table>
<thead>
<tr>
<th>Data</th>
<th>MS Section</th>
<th>Latitudinal extent (°N)</th>
<th>Spatial units</th>
<th>Period</th>
<th>Temporal units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base data</td>
<td>2.1</td>
<td>40.35-48.34</td>
<td>Beach (~1 km)</td>
<td>2000-2019</td>
<td>Day</td>
<td>Presence/absence of Velella reports</td>
</tr>
<tr>
<td>Spatial</td>
<td>2.2</td>
<td>40.35-48.34</td>
<td>Beach (~1 km) &amp; smoothed (~50 km)</td>
<td>2000-2019</td>
<td>All years; 2000-2014; 2014-2019</td>
<td>Beach-specific reporting rate: % of surveys performed on each beach that were accompanied by reports of Velella</td>
</tr>
<tr>
<td>Spatio-temporal</td>
<td>2.2</td>
<td>40.35-48.34</td>
<td>50 km latitudinal bands</td>
<td>2000-2019</td>
<td>Calendar month</td>
<td>Presence/absence of Velella reports from surveys performed each month from 2000-2019 splitting the coastline into 50km latitudinal bands</td>
</tr>
<tr>
<td>Seasonal</td>
<td>2.2</td>
<td>40.35-48.34</td>
<td>&gt; 44°N &amp; &lt; 44°N</td>
<td>2003-2019</td>
<td>14 days</td>
<td>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</td>
</tr>
<tr>
<td>Annual</td>
<td>2.3.2</td>
<td>44.0-48.34</td>
<td></td>
<td>2002-2019</td>
<td>Bi-Annual (Jan-June; July-Dec)</td>
<td>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</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Metric</th>
<th>Months</th>
<th>Multiple predictor models</th>
<th>Single predictor models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>inc. 2015</td>
<td>exc. 2015</td>
</tr>
<tr>
<td>SSTa</td>
<td>Ave.</td>
<td>Dec-Jan</td>
<td>0.007</td>
<td>0.056</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Feb</td>
<td>0.162</td>
<td>0.193</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feb-Mar</td>
<td>0.042</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dec-Feb</td>
<td><strong>0.296</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td><strong>0.264</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Mar</td>
<td>0.21</td>
<td>0.205</td>
</tr>
<tr>
<td></td>
<td>Ave.</td>
<td>Dec-Jan</td>
<td><strong>0.931</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td><strong>0.915</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Feb</td>
<td>0.004</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feb-Mar</td>
<td>0.010</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dec-Feb</td>
<td>0.001</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Mar</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dec-Jan</td>
<td>0.011</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Feb</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feb-Mar</td>
<td><strong>0.018</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.004</td>
</tr>
<tr>
<td>Upwelling</td>
<td>Prev.</td>
<td>Dec-Feb</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Mar</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dec-Jan</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Feb</td>
<td>0.006</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feb-Mar</td>
<td>0.008</td>
<td><strong>0.023</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dec-Feb</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jan-Mar</td>
<td>0.002</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>Cumu.</td>
<td>Feb-Mar</td>
<td>0.006</td>
<td>0.003</td>
</tr>
<tr>
<td>Wind</td>
<td>Ave.</td>
<td>Mar</td>
<td>0.018</td>
<td>0.523&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Apr</td>
<td>0.133</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mar-Apr</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mar</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Prev.</td>
<td>Apr</td>
<td><strong>0.653</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td><strong>0.430</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mar-Apr</td>
<td>0.004</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mar</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Cumu.</td>
<td>Apr</td>
<td>0.013</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mar-Apr</td>
<td>0.011</td>
<td>0.013</td>
</tr>
</tbody>
</table>

<sup>a</sup>: highest akaike weight among metrics within forcing factor group
<sup>b</sup>: 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) $\Delta$AICc is given relative to the best possible model in that set and $W_{\text{AICc}}$ is the akaike weight ($W_{\text{AICc}} = e^{-\frac{\Delta \text{AICc}}{2}}$) as a measure of the evidence in support of that model being the best model given the data and the candidate model set. VIF$_{\text{max}}$ is the maximum VIF statistic calculated among predictors included in that model as a measure of multicollinearity among model predictors.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Predictors</th>
<th>AICc</th>
<th>VIF$_{\text{max}}$</th>
<th>$\Delta$AICc</th>
<th>$W_{\text{AICc}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SSTa [Dec-Feb]</td>
<td>92.67</td>
<td>0</td>
<td>0</td>
<td>0.555</td>
</tr>
<tr>
<td>2</td>
<td>SSTa [Dec-Feb] + Wind-prev [Apr]</td>
<td>93.36</td>
<td>2.17</td>
<td>0.70</td>
<td>0.391</td>
</tr>
<tr>
<td>3</td>
<td>Wind-prev [Apr]</td>
<td>98.35</td>
<td>5.68</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SSTa [Dec-Feb] + Upwell-cumu [Feb-Mar]</td>
<td>99.41</td>
<td>1.70</td>
<td>6.74</td>
<td>0.019</td>
</tr>
<tr>
<td>6</td>
<td>None</td>
<td>105.46</td>
<td>12.80</td>
<td>0.088</td>
<td>0.001</td>
</tr>
<tr>
<td>7</td>
<td>Upwell-cumu [Feb-Mar] + Wind-prev [Apr]</td>
<td>106.94</td>
<td>1.8</td>
<td>14.27</td>
<td>0.000</td>
</tr>
<tr>
<td>8</td>
<td>Upwell-cumu [Feb-Mar]</td>
<td>111.92</td>
<td>19.26</td>
<td>0.040</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rank</th>
<th>Predictor</th>
<th>AICc</th>
<th>VIF$_{\text{max}}$</th>
<th>$\Delta$AICc</th>
<th>$W_{\text{AICc}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SSTa [Dec-Feb]</td>
<td>92.67</td>
<td>0.00</td>
<td>0.872</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Wind-prev [Mar-Apr]</td>
<td>97.25</td>
<td>4.58</td>
<td>0.088</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Upwell-prev [Dec-Jan]</td>
<td>98.85</td>
<td>6.18</td>
<td>0.040</td>
<td></td>
</tr>
</tbody>
</table>

$^a$: 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.